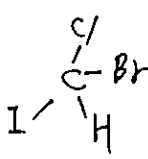


fluoride: 4.0 ppm: causes bone brittleness
 2.0 ppm: mottling of teeth
 <1.0 ppm: good for preventing cavities
Arsenic - build up in flesh, heart
 - 2 million epidemic study this year by AWWARF



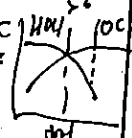
stage 2: 80 ppb THMs
 at the end of Dist. Syst
 short term memory
 high temp, many forms

Oral Review 2/10
 Th: 1:30-5:00

sulfate - diarrhea
 Cincinnati 300 spills/year
benzene found in gasoline - soil from gas stations; single-lined galvanized steel tanks; corrosion; w/ dropstick, pop hole through tank bottom
trichloroethylene, other volatiles;
 - as solvents - potential cancer risk

atrazine - pesticide, might cause birth defects, although not proven
cadmium, lead, mercury, other heavy metals - build up; not washed at high doses, lead cause brain damage (lead paint)
coliform - indicator organism; come back to

N. triate - blue baby disease
 methemoglobinemia



PCBs - used in transformers before 1976
 - found to cause liver toxicity & leukemia at high conc's in rats
 - adsorbs very strongly to act. carb. & soils (so won't migrate very far)

lead-copper rule - related to corrosion
 - distribution system: higher the H, the lower the corrosion
 - Pb in old copper pipe solder
 - is impurity in ornamental bronze fixtures
 Benito Martinez: just leach it out
 radon - a gas that is generated

by the decay of uranium in bedrock - groundwater
 highest in Maine, NH
 - high in N.E. PA, northeast, mountains around Colo
 - mod. in Calif. central valley
 - remove w/ air stripping or GAC
 - Jerry Lowrey. study home: 300,000 pCi/L

Maximum contaminant levels (MCLs) for some regulated contaminants

Contaminant	MCL mg/L	Contaminant	MCL mg/L
✓ Fluoride	4.0	✓ Sulfate (proposed)	400/500
✓ Arsenic (interim)	0.05		
	0.01 10 µg/L		
Phase I (Eight Volatile Organics)			
1,1,1-trichloroethane	0.2	carbon tetrachloride	0.005
1,1-dichloroethylene	0.007	p-dichlorobenzene	0.075
1,2-dichloroethane	0.005	✓ trichloroethylene	0.005
✓ benzene	0.005	vinyl chloride	0.002
Phase II			
1,2-dichloropropane	0.005	epichlorohydrin	TT*
2,4 D	0.07	ethylbenzene	0.7
2,4,5 TP (silvex)	0.05	heptachlor	0.0004
acrylamide	TT*	heptachlor epoxide	0.0002
alachlor	0.002	lindane	0.0002
aldicarb	delayed	✓ mercury (inorganic)	0.002
aldicarb sulfoxide	delayed	methoxychlor	0.04
aldicarb sulfone	delayed	✓ nitrate (as nitrogen)	10
✓ asbestos	7 MFL†	✓ nitrite (no nitrogen)	1
✓ atrazine	0.003	o-dichlorobenzene	0.6
✓ barium	2	✓ PCBs	0.0005
✓ cadmium	0.005	pentachlorophenol	0.001 ³
carbolfuran	0.04	selenium	0.05
chlordane	0.002	styrene	0.1
chlorobenzene	0.1	✓ tetrachloroethylene	0.005
✓ chromium (total)	0.1	toluene	1
cis-1,2 dichloroethylene	0.07	toxaphene	0.003
✓ coliform	TT*	trans-1,2 dichloroethylene	0.1
DBCP	0.0002	xylene (total)	10
EDB	0.00005		
Lead and Copper			
✓ copper	TT*	✓ lead	TT*
✓ copper (action level)	1.3	✓ lead action level	0.015
perchlorate	0.015 mg/L	CDHS: 0.004	Notification level
action levels	0.004	Phase V	
1,1,2-trichloroethane	0.005	di (z-ethylhexyl) phthalate	0.006
1,2,4 trichlorobenzene	0.07	endothall	0.1
antimony	0.006	endrin	0.002
benzo (a) pyrene	0.0002	glyphosate	0.7
beryllium	0.004	hexachlorobenzene	0.001
✓ cyanide	0.2	hexachlorocyclopentadiene	0.05
dalapon	0.2	✓ nickel	0.1
dichloromethane	0.005	oxamyl (wydate)	0.2
dinooseb	0.007	picloram	0.5
dioxin	0.0000003	simazine	0.004
diquat	0.02	thallium	0.002
di (z-ethylhexyl) adipate	0.5		
Radionuclides (proposed)			
beta particle/protom radioactivity	4 mrem/yr	radium 228	20 pCi/L
gross alpha particle activity	15 pCi/L	radon	300 pCi/L
radium 226	20 pCi/L	(franklin)	0.02 mg/L
Disinfection By-products (interim)			
✓ total trihalomethane (THM)	0.10		TTM 80
			THAS 60

TT* = treatment technique requirement.
 MFL = million fibers per liter.

THM: C-Cl
 F-Br - potential cancer

higher pH, above the line

STAGE 2,
 END OF DISTRIBUTION SYSTEM

Coliform

Indicator Organism:

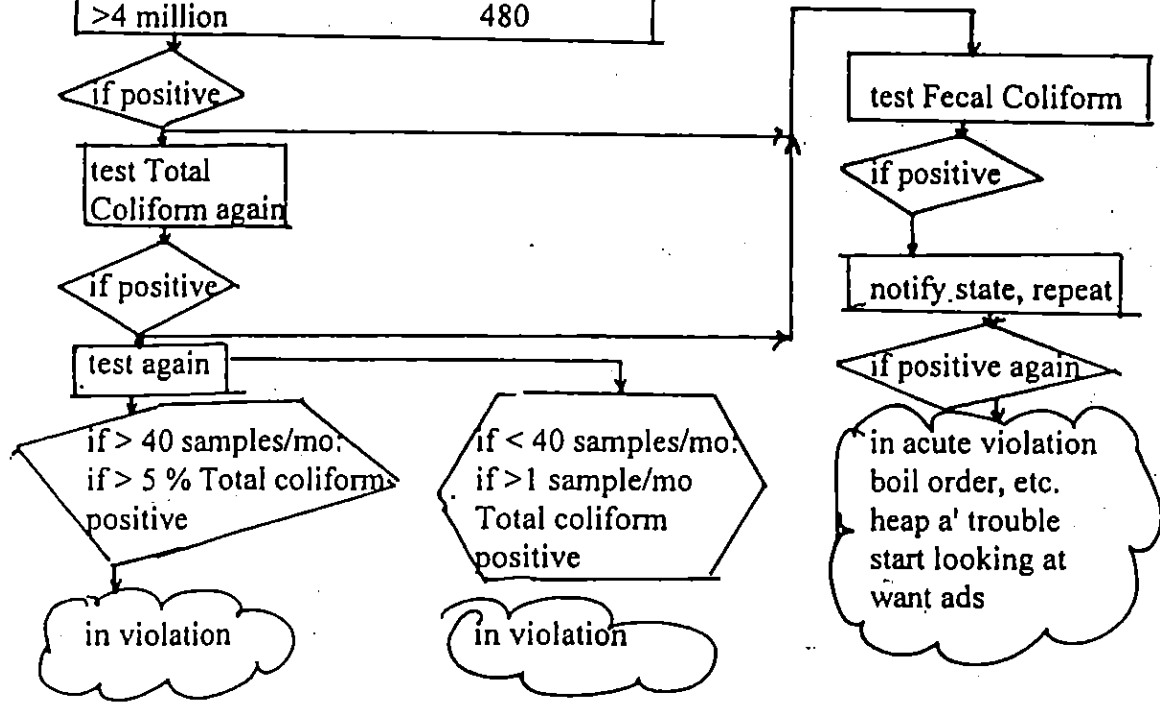
1. Indicator not pathogenic to humans (who are monitoring it).
2. Indicator present when pathogenic organism of concern is present, and absent in clean, uncontaminated water.
3. Indicator present in fecal material in large numbers.
4. Indicator respond to natural environmental conditions and treatment in a manner similar to the pathogens of interest.
5. Indicator should be easy to isolate, identify, enumerate.
6. Ratio of indicator/pathogen high.
7. Indicator and pathogen come from same source (gastro-intestinal tract).

Total Coliform: Either from animals or not from animals.

Fecal Coliform (Escherichia coli): From humans and other warm-blooded animals only.

Coliform Regulation (Promulgated June 29, 1989)

Population	Routine tests/month
<1000	1
<40,000	40
<1 million	300
>4 million	480

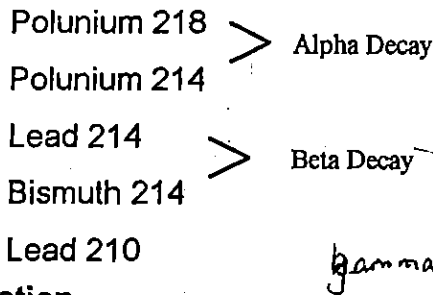


Radon - 300 pCi/L primary standard

uranium 230 (MW) - half life = 4.5×10^9 years

Radon 222 (MW) - half life = 3.8 days

Progeny - cause problems



Organic Contamination

- TOC - Total Organic Carbon (all carbon except CO₂) + chlorine → THM & HAA
- DOC - Dissolved Organic Carbon (all passed through 0.45 μ filter)
- DOX - Dissolved Organic Halogens (Cl, F, Br, I)
- TOX - Total Organic Halogens
- COD - Chemical Oxygen Demand
- BOD - Biochemical Oxygen Demand
- AOC - Assimiable Organic Carbon
- THM - Tri-Halo Methanes
- HAA - Halo Acetic Acids

Surface Water Treatment Rule - SWTR

- Low risk level drinking water
- Giardia - 3 log removal
- Viruses - 4 log removal

3 giardia cysts/L in raw water
 4 log removal = 0.0003 cysts/L = 3 cysts / 10,000L
 = 3 cysts in a room (10x6x6 ft³)

- 1 log - 90%
- 2 log - 99%
- 3 log - 99.9%
- 4 log - 99.99%

Ct Values
 (Ct = conc (log) x time (min))
 so Ct = 1 mg/L x 60 min
 = 2 mg/L x 15 min

4
152

or 10 months after the State determines that a system is using a ground water source under the direct influence of, at the time of the State determination must meet the treatment technique requirements specified in § 141.73 (filtration criteria) and § 141.72(b) (disinfection criteria) and the monitoring and reporting requirements specified in §§ 141.74(c) and 141.75(b), respectively, beginning 40 months after promulgation or 10 months after the State determination, whichever is later.

4. Strategies for Implementation

To comply with this final rule, it is necessary to reduce risk to public health by maintaining more stringent disinfection conditions until filtration is installed. Some systems already have filtration and disinfection in place. While many such systems are already in compliance with all the requirements of the rule, other systems will require significant upgrades in treatment to meet all the performance criteria. As discussed earlier, filtration without disinfection,

with proper pretreatment where appropriate, can be expected to achieve disinfection needed for such systems to meet the overall minimum performance requirements. CT values for achieving 1-log inactivation of *Giardia* cysts are indicated in Table IV-3. CT values to achieve 0.5-log inactivation are one-half those indicated in Table IV-3. Recommended CT values for achieving different levels of virus inactivation are indicated in Table IV-4.

TABLE IV-2. RECOMMENDED MINIMUM LEVEL OF DISINFECTION AND ASSUMED LOG REMOVALS BY FILTRATION METHOD

Treatment	Assumed log removals		Recommended minimum level of disinfection	
	<i>Giardia</i>	Viruses	<i>Giardia</i>	Viruses
Conventional.....	2.5	2.0	0.5	2
Direct filtration.....	2.0	1.0	1.0	3
Slow sand filtration.....	2.0	2.0	1.0	2
Diatomaceous earth filtration.....	2.0	1.0	1.0	3

TABLE IV-3.—CT VALUES FOR ACHIEVING 1-LOG INACTIVATION OF GIARDIA LAMBLIA¹

	pH	Temperature			
		0.5 °C	5 °C	10 °C	15 °C
Free Chlorine ¹	6	49	35	26	19
	7	70	50	37	28
	8	101	72	54	38
	9	146	100	78	59
Ozone.....		0.97	0.63	0.48	0.32
Chlorine Dioxide.....		21	8.4	7.4	6.3
Chloramines (preformed).....		1,270	730	620	500

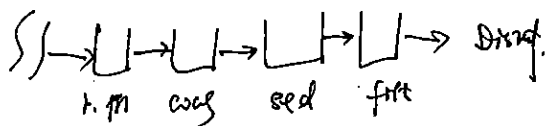
¹ From 3/31/89 draft Guidance Manual. Values to achieve 0.5-log inactivation are one-half those shown in the table.
² CT values will vary depending on the concentration of free chlorine. Indicated CT values are for 2.0 mg/l free chlorine. (For other free chlorine concentrations, see the final Guidance Manual.)

TABLE IV-4.—CT VALUES FOR ACHIEVING INACTIVATION OF VIRUSES AT PHs 6 THROUGH 9¹

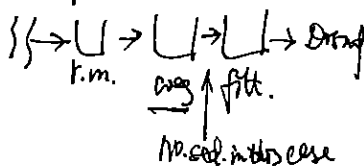
	Log inactivation	Temperature			
		0.5 °C	5 °C	10 °C	15 °C
Free chlorine.....	2	6	4	3	2
	3	9	6	4	3
Ozone.....	2	0.9	0.6	0.5	0.4
	3	1.4	0.9	0.8	0.6
Chlorine Dioxide ¹	2	0.4	5.6	4.2	2.8
	3	25.8	17.1	12.8	8
Chloramines ²	2	1,243	857	643	428
	3	2,063	1,423	1,067	712

¹ CT values for free chlorine, ozone, and chlorine dioxide include safety factors. CT values for chloramines are based on laboratory data using preformed chloramine to inactivate *Poliovirus A* and do not include a safety factor (Sobsey, 1988).
² CT values for chlorine dioxide were based on laboratory studies at pH 6 (Sobsey, 1988). Based on limited data, chlorine dioxide appears much more effective at higher pHs. Procedures for demonstrating if lower CT values may be appropriate will be included in the final Guidance Manual.
³ CT values for chloramines are only applicable if chlorine is added prior to ammonia. Procedures for demonstrating that lower CT values are appropriate will be included in the final Guidance Manual.

Conventional

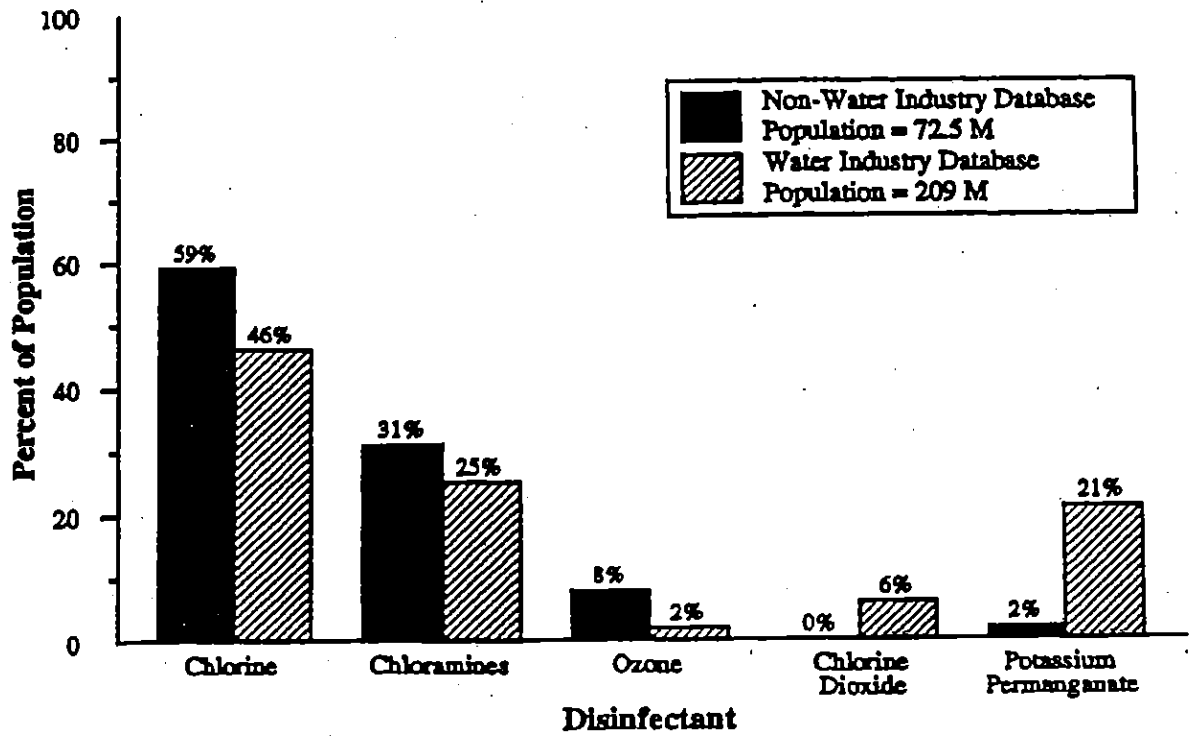
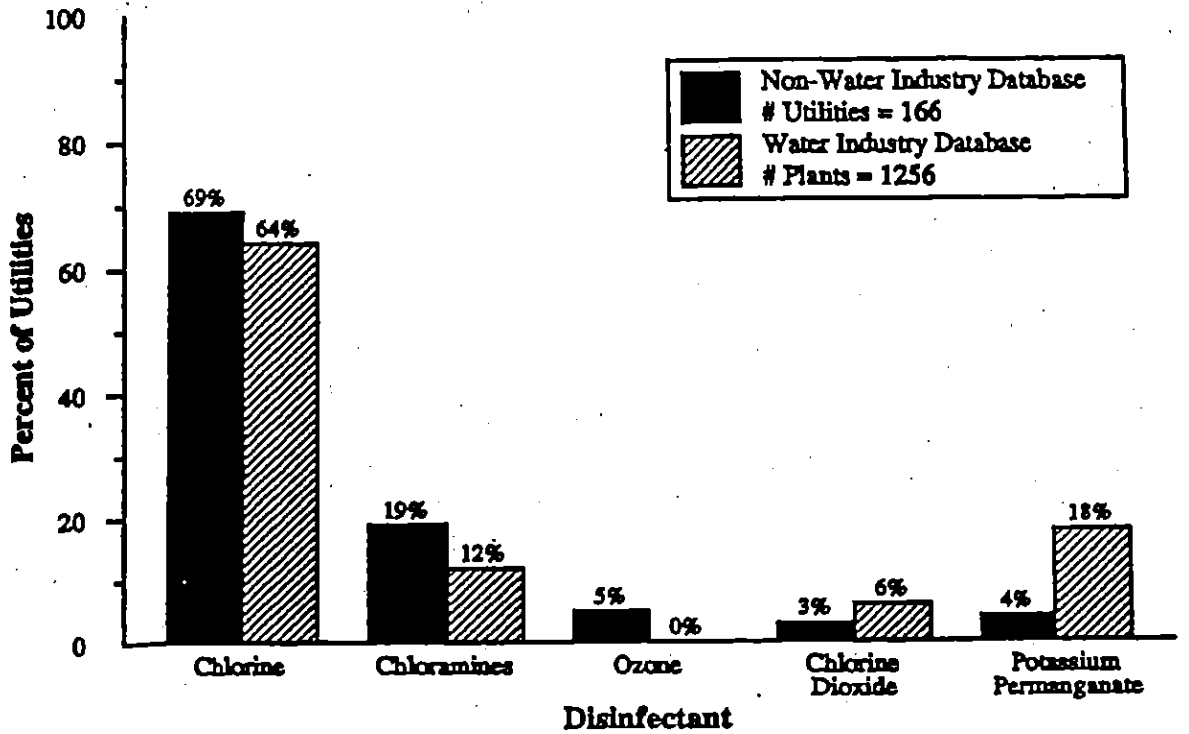


Direct filtration



3B
12A

Figure VI-1
Comparison of Disinfectant Use Among Two Different Databases



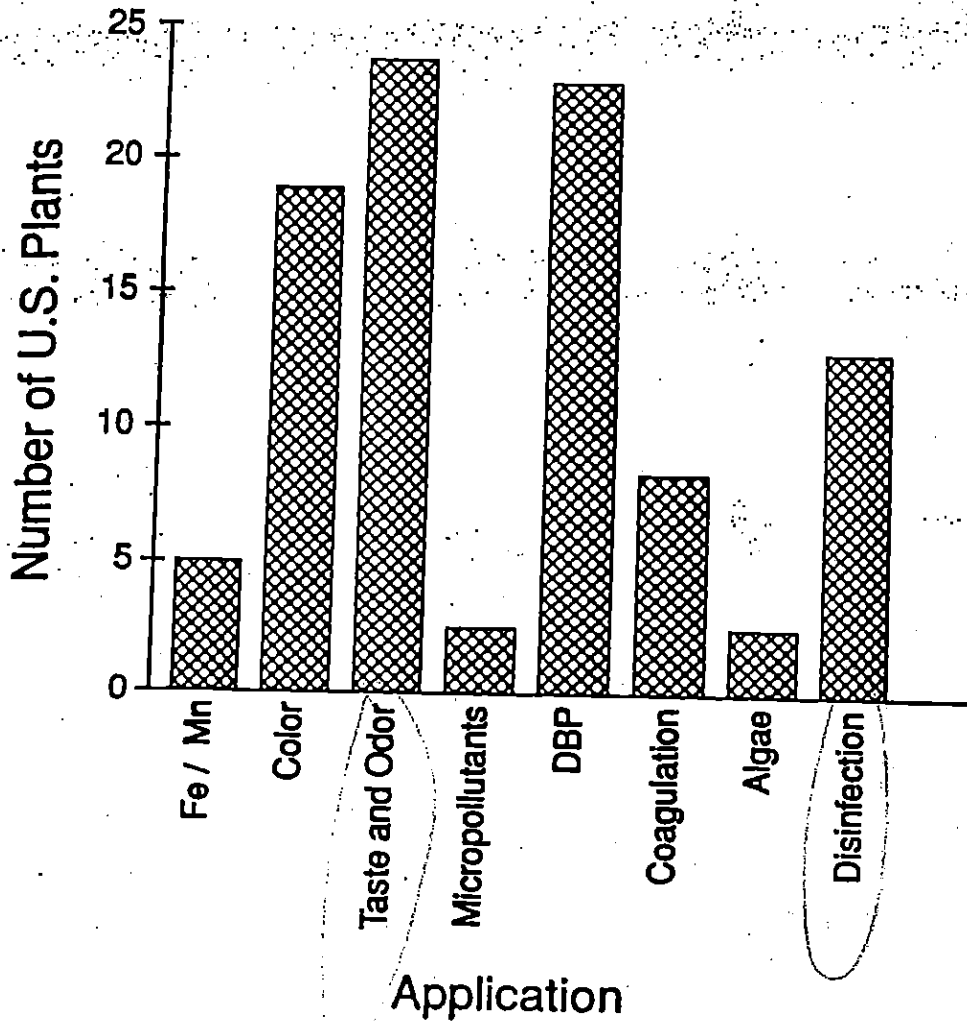


Figure III-1 Applications of Ozone in U.S. Drinking Water Treatment Plants

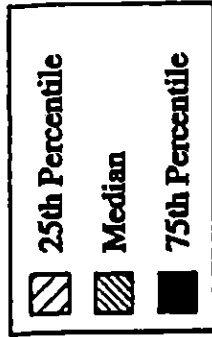
Table III-1 Summary of Ozone Applications

Control of:	Point of Application	Ozone Dose	Best Pathway*	Notes
Fe/Mn	Pre, Inter	Med	Molec.	Inter may be best with high-DOC waters.
Color	Inter	Med-High	Molec.	Two-step stoichiometry.
Taste and odor	Inter	High	Rad.	T&O may be produced by low ozone doses.
SOCs	Inter	Med-High	Rad.	Molec. may be best for some compounds.
Particulates	Pre	Low	Unknown	May require high calcium concentration.
Algae	Pre, Inter	Low-Med	Unknown	Can be used with flotation.
Pathogens	Pre, Post	Med-High	Molec.	Pre in U.S.; post in Europe.
Cl ₂ by-products	Inter, Pre	Low-High	Molec.	High levels of removal require Rad.
Biodegradables	Inter	Med	Unknown	Design of downstream filtration process is important.

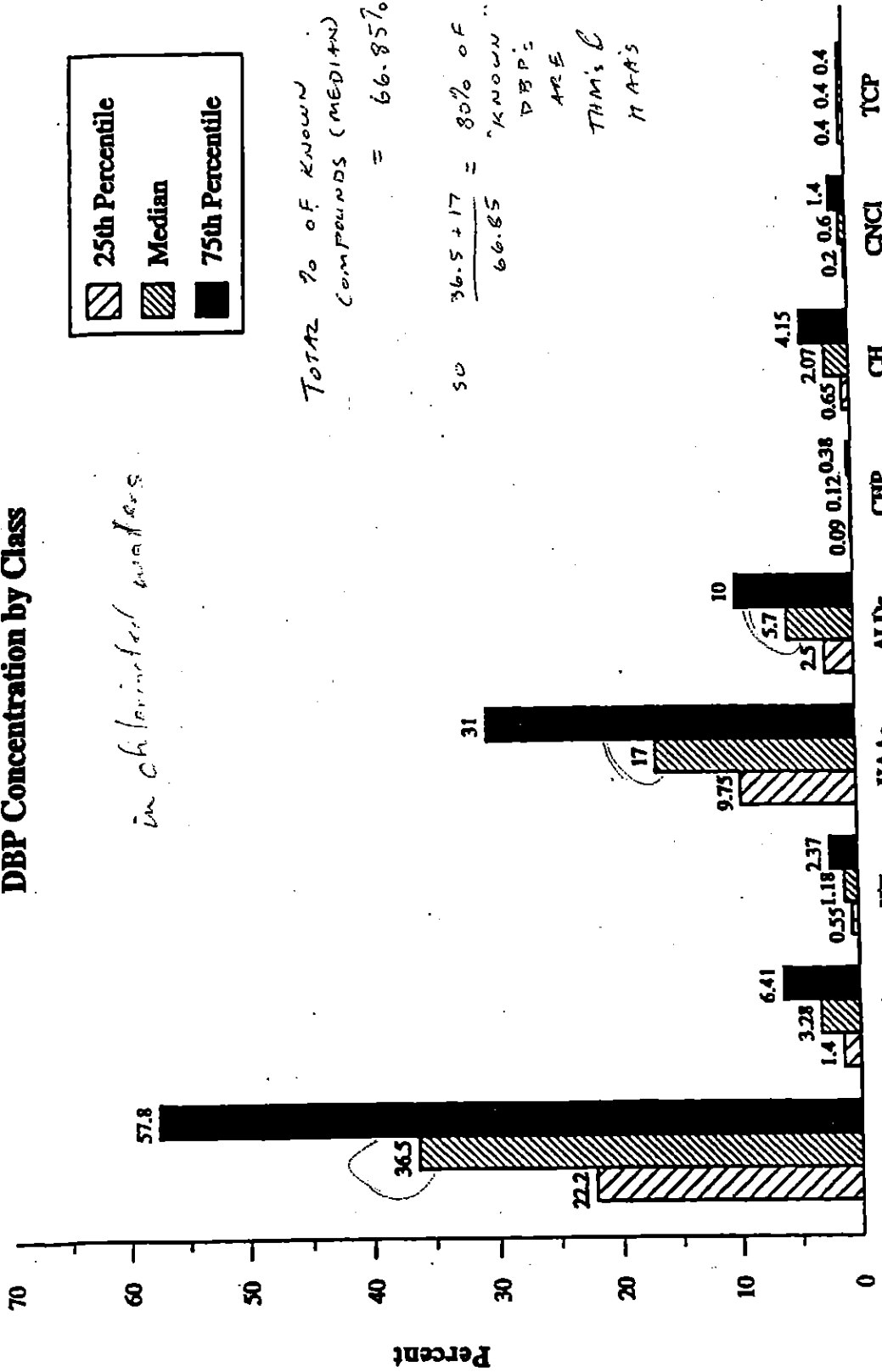
*Choice of molecular (Molec.) or radical (Rad.) pathway.

3. Oxidation of organic micropollutants
 - a. Taste and odor compounds
 - b. Phenolic pollutants
 - c. Pesticides

Figure VI-12
DBP Concentration by Class



in chlorinated waters

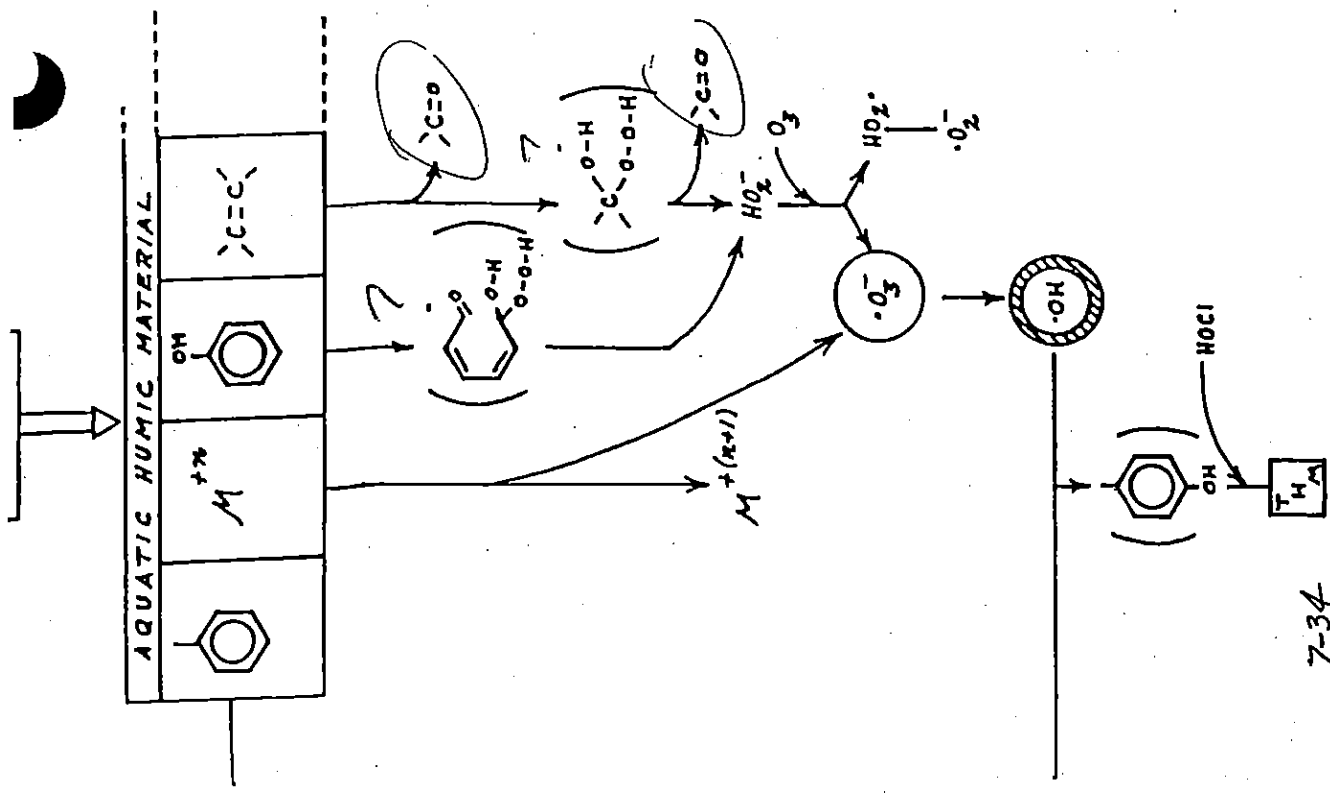


TOTAL % OF KNOWN COMPOUNDS (MEDIAN) = 66.85%

SO $\frac{36.5 + 17}{66.85} = 80\%$ OF DBP'S ARE THM'S & HAAS

DBP Class

THM's
Halo- acetylene
nitro-ics
Halo- nitro-ics
Aldehydes
Acids
Aldehydes



7-34

Figure 2. Conceptualized representation of some possible reactions of ozone with chemical group constituents of aquatic humic material.

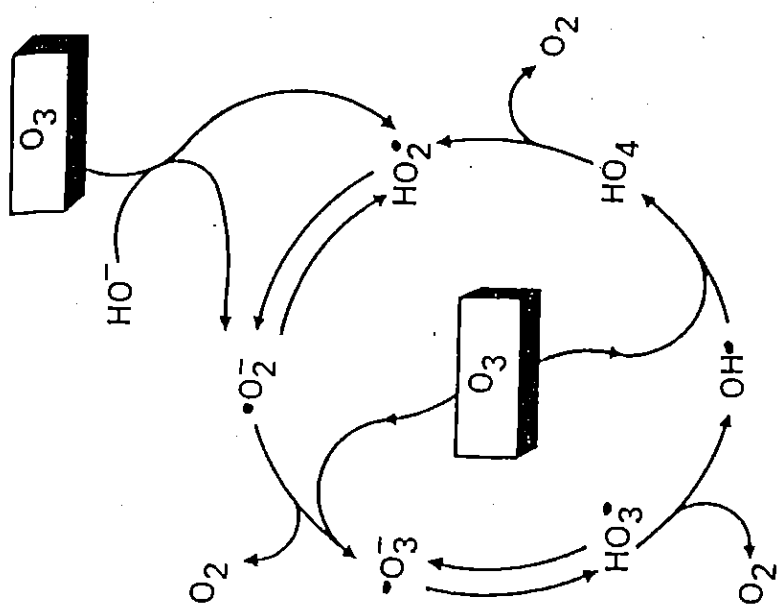
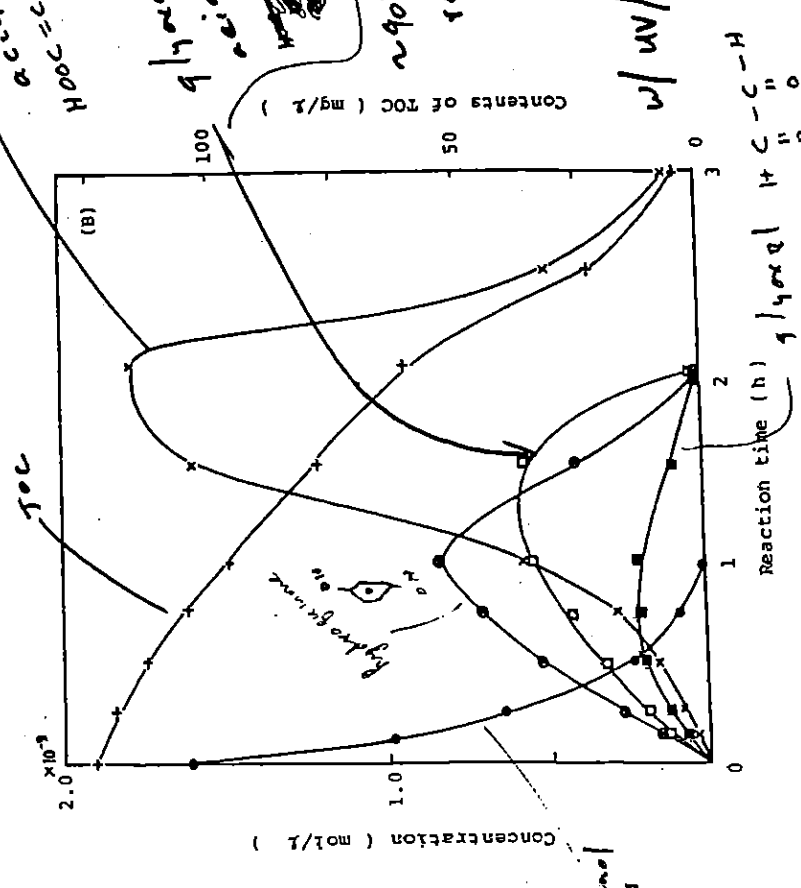
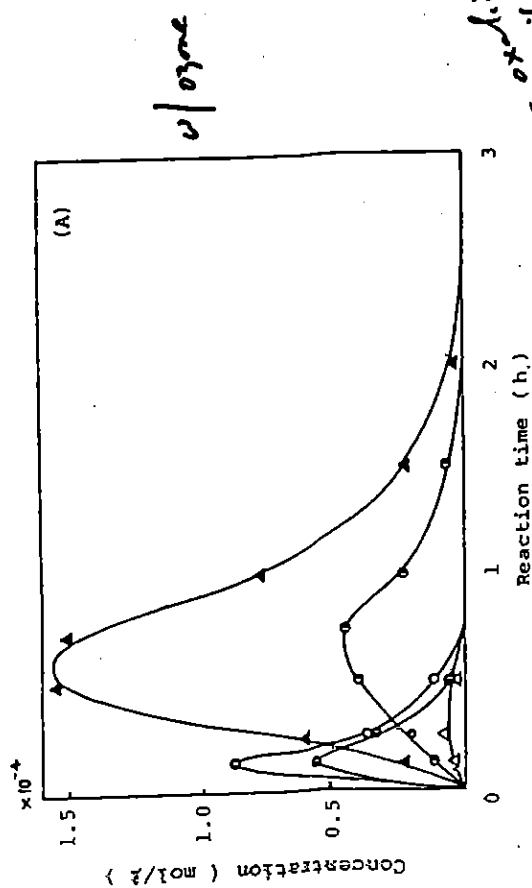
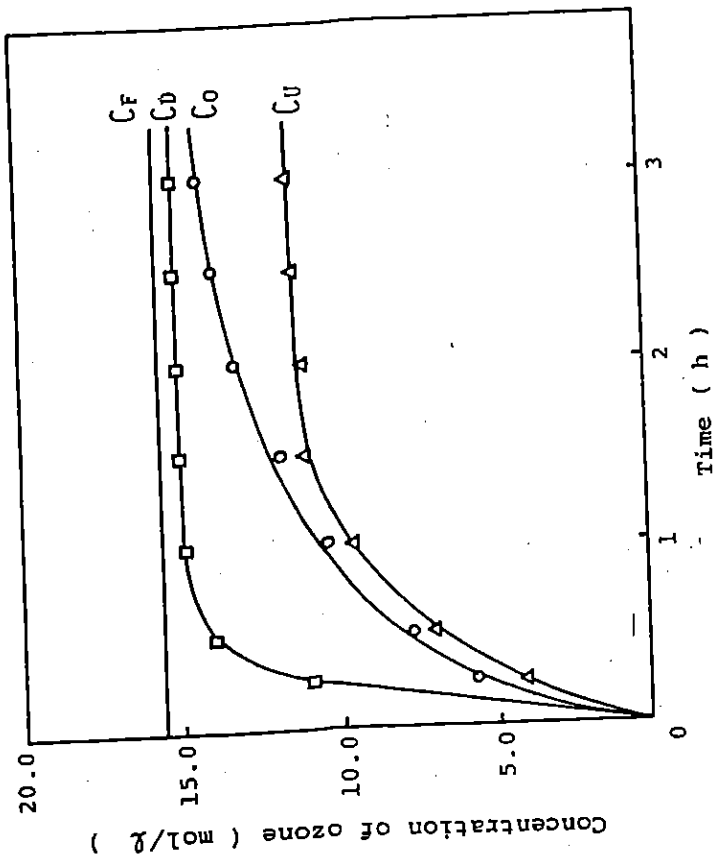


Figure 1. Chain decomposition mechanism for decomposition of ozone initiated by hydroxyl ions (after Hoigne).

176A



Figures 2A and 2B. Ozonation of phenol (2A); UV/ozonation of phenol (2B). Legends identical with Figure 2.



CF : Concentration of ozone in the feed gas
 CD : Concentration of ozone in the exhaust gas passed through distilled and deionized water
 CO : Concentration of ozone in the exhaust gas passed through phenol solution treated by the ozone oxidation method
 CU : Concentration of ozone in the exhaust gas passed through phenol solution treated by the UV/ozonation method

Figure 3. Change of concentration of ozone with time at discharge potential 100 V, low pressure mercury lamp 120 W, and initial concentration of phenol = 1.6×10^{-3} mol/L.

As shown in Figure 2, in spite of the similarity of the reaction products, there was a great difference in the changes between them with reaction time between the O₃ and O₃/UV methods. In the O₃ method, catechol, hydroquinone, and fumaric acid were identified at the initial stage of the reaction, and concentrations of both catechol and hydroquinone reached maxima in 7.5 minutes of treatment. Maleic acid and muconic acid were identified for a fairly long period during the reaction, and they reached maximum concentrations in about 30 to 45 minutes. However, the amounts of these five compounds were small in comparison with those of glyoxal, glyoxylic acid, oxalic acid, and formic acid, and they disappeared after 1.5 to 2.0 hours of treatment.

45

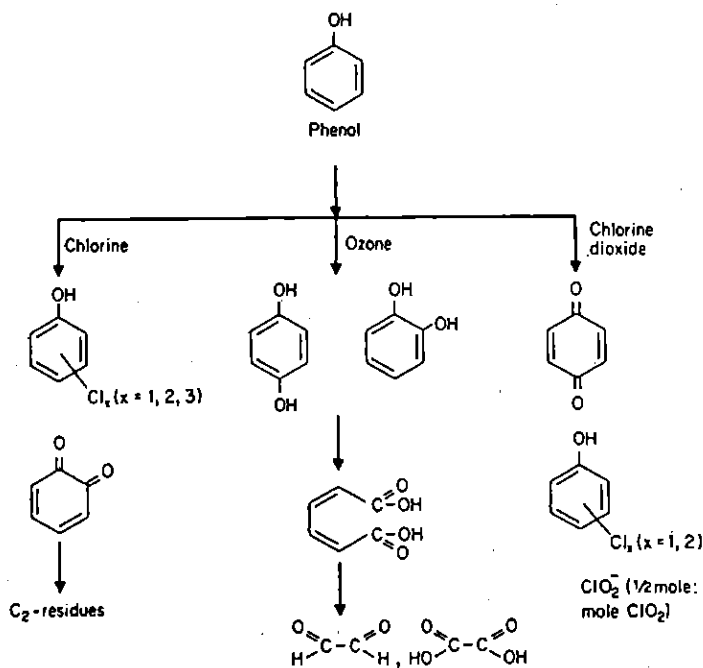


Figure 12.6 Scheme showing principal by-products from the oxidation of phenol by chlorine,⁴³ ozone,⁴⁴ and chlorine dioxide.⁴⁵

can occur because of the formation of chlorinated phenols. With ozone complete oxidation will yield small polar molecules such as glyoxalic acid, but at lower doses partially oxidized species such as hydroquinones and muconic acid are formed, as shown in Fig. 12.6. In the case of each oxidant, the yields of by-products will depend on the oxidant dose. Lower doses will favor the formation of partial oxidation products.

Ozone and the other common oxidants are theoretically capable of reacting with other synthetic organics, but they are highly selective; i.e., the rates of the processes are often too inefficient to be of practical value. This is especially true when pollutants present at micrograms per liter are competing with natural contaminants at milligrams per liter. For example, the common oxidants are usually not cost-effective for the removal of trichloroethylene and other chlorinated solvents and pesticides in polluted surface water or groundwater. New oxidation processes that show promise for these purposes are described in the next section.

General effectiveness of water treatment oxidants

Tables 12.3 and 12.4 summarize the general effectiveness of the common oxidants used in water treatment. The reader must appreciate

118 14.2 EFFECT OF OZONATION ON THE REMOVAL OF TRICHLOROETHYLENE FROM WATER. 2.5 mg/L during first 6 weeks and 2.5 mg/L thereafter. (Source: W. H. Glaze et al., L. Wallace, "Control of Trihalomethane Precursors in Drinking Water: Granular Activated Carbon With and Without Preozonation," J. AWWA, vol. 76, no. 2, Feb. 1984, p. 68.)

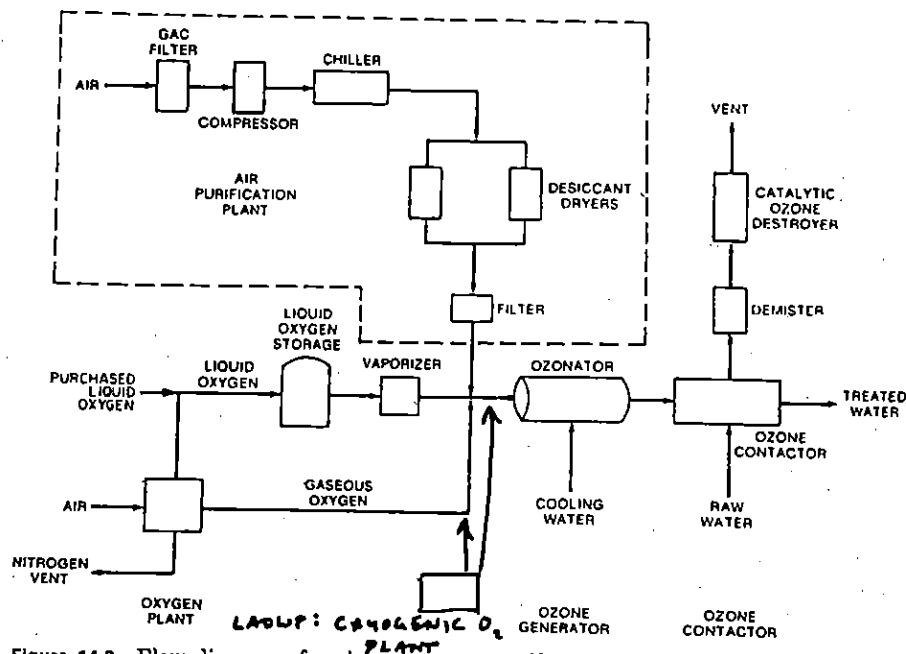


Figure 14.8 Flow diagrams for air and oxygen purification for ozone production from oxygen-enriched air. The air purification unit may be omitted when pure oxygen is used or it may be used without oxygen enrichment.

Ozone contactors. After generation, ozone is piped to a contactor where the ozone is transferred into the water. The most common type of contactor is the countercurrent sparged tank with diffuser (Fig. 14.9). In this reactor ozone-containing gas forms small bubbles as it is passed through a porous stone at the bottom of the tank. As the bubbles rise through the tank, ozone is transferred from the gas phase into water according to the rate equation

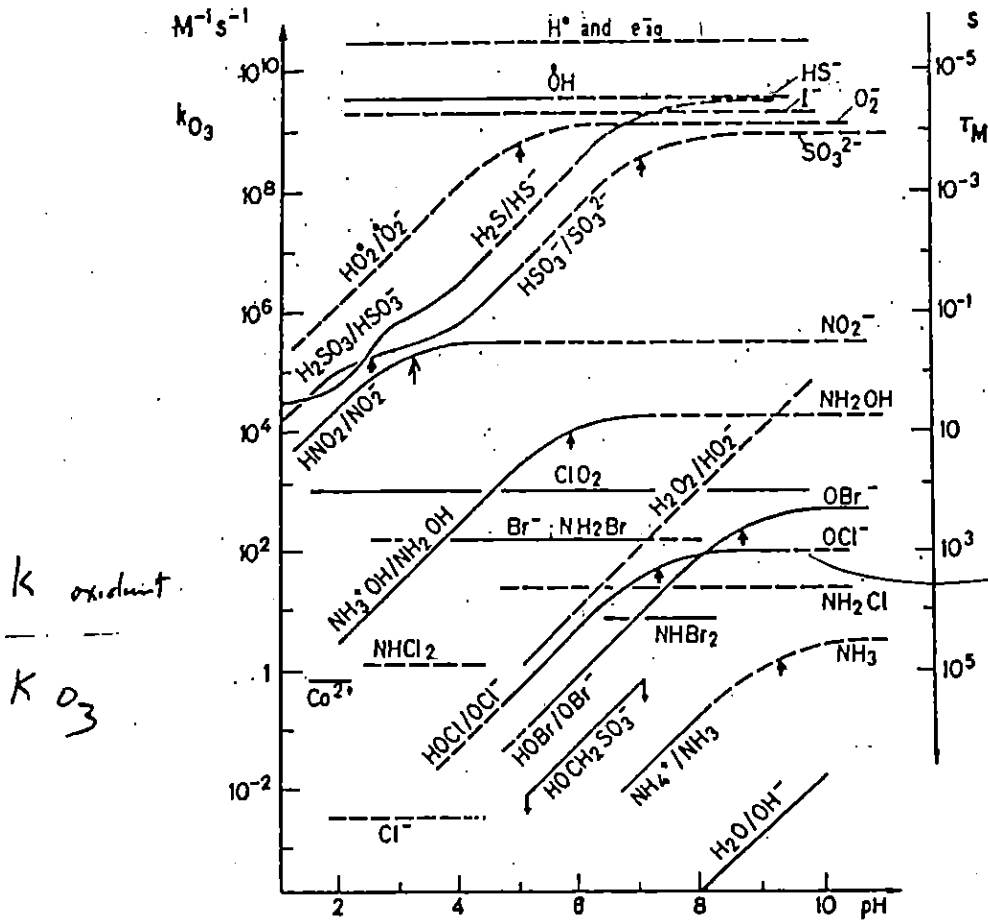
$$\text{Rate of transfer [mol/(m}^3\text{)(s)]} = K_1a(C^* - C) \quad (14.35)$$

Here C (mol/m³) is the prevailing concentration of ozone in the liquid, C^* is the concentration at saturation, and K_1a is an overall transfer coefficient (s⁻¹). The value of C^* depends on the percentage of ozone in the gas and may be calculated from the equation

$$C^* = \frac{P_{\text{gas}}}{H} \quad (14.36)$$

OZONA
EFFLUI

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47

but isn't HOCl (at low pH) better than OCl-?

Don type

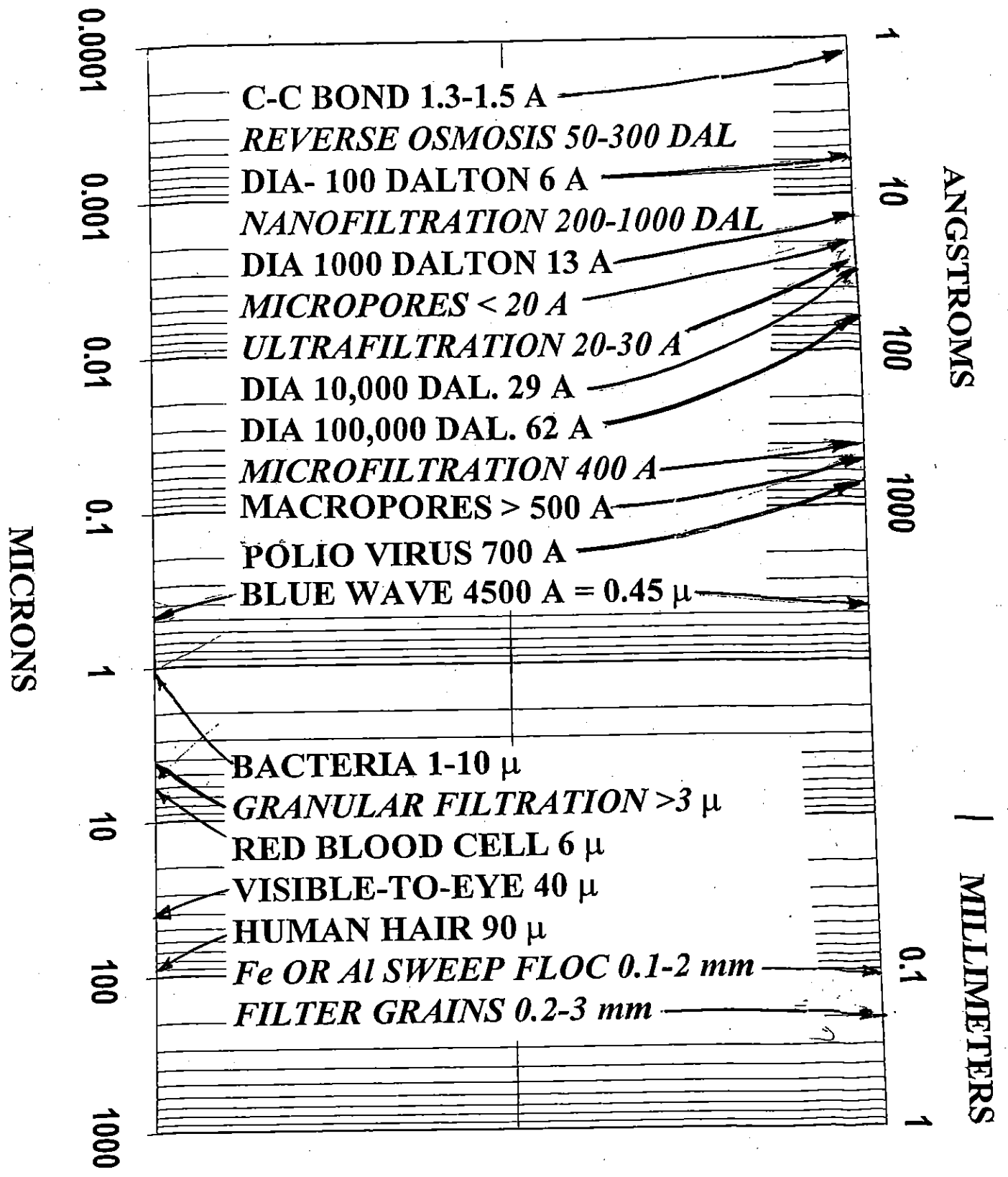
Figure 7-33

Bild 3: Scheinbare Reaktionsgeschwindigkeitskonstanten anorganischer Ionen und Radikale in Abhängigkeit des pH-Wertes.

—: Messbereich; - - - - -: extrapoliert, unter Annahme, dass Konstanten ^{corresponding} dem Dissoziationsgrad ^{derer} der Spezies ansteigen.

↑: Markierung der pK_a-Werte;

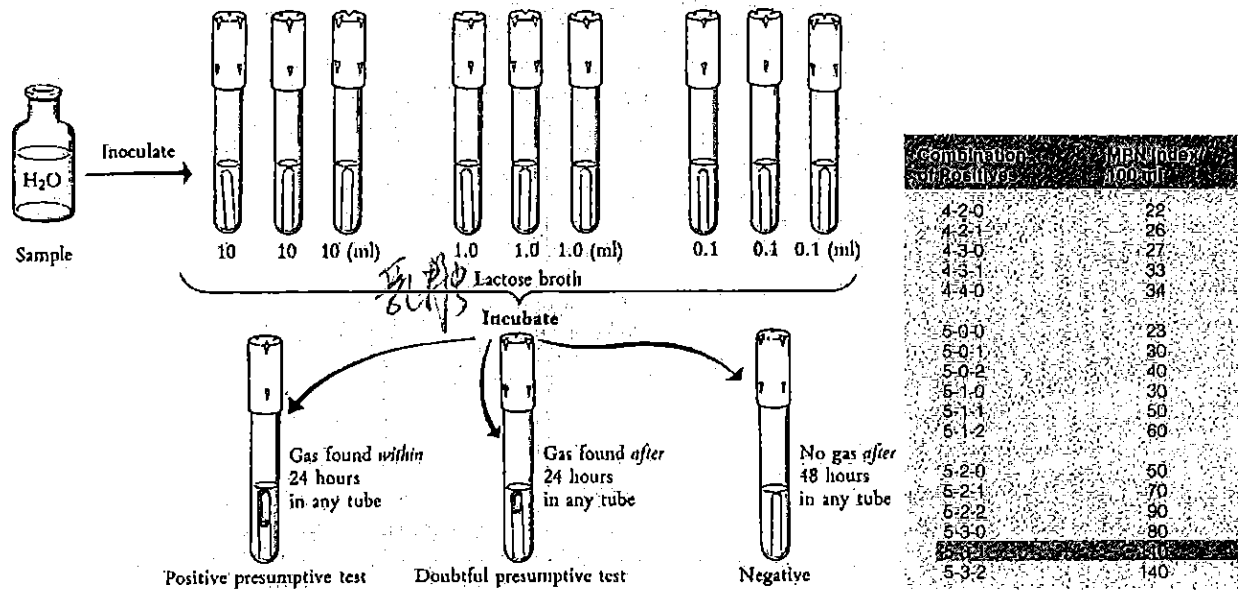
Rechte Skala: Berechnete Reaktionszeit, innerhalb welcher in einem Chargenreaktor (Propfströmungsreaktor) die Restkonzentration auf 37% der Anfangskonzentration fällt, falls der Reaktand auf 10⁻⁵M (entsprechend 0,5 mg/L Ozon) konstant gehalten wird (Figur aus Ref. [4]).



Spread plate method

Membrane filtration method

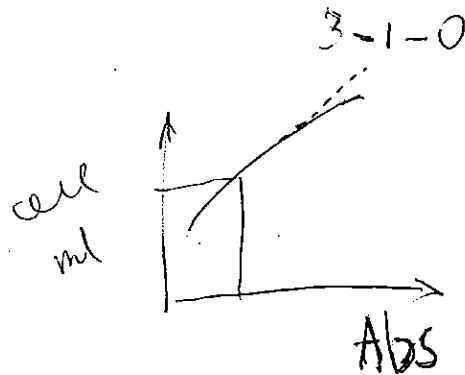
Most-Probable Number (MPN) Technique



Total Cell Counts

Chemical Analysis

Turbidimetric Method



in the intestine, is also classified as a coliform because of its fermentative properties.

In general, we assume that the presence of coliform organisms in a water sample indicates fecal contamination and makes the water unsafe for human consumption. When excreted into water, the coliforms eventually die, but they do not die as quickly as some pathogens. The coliforms and the pathogens behave similarly during water purification.

The Coliform Test

Two procedures are commonly used to test for coliforms in water samples. These are the *most-probable-number* (MPN) procedure and the *membrane filter* (MF) procedure. The MPN procedure employs liquid culture medium in test tubes, in which samples of drinking water added to the media. Growth in the culture vessels indicates microbial contamination of the water supply. For the more common MF procedure, at least 100 ml of the water sample is passed through a sterile membrane filter, which removes the bacteria (∞ Section 20.3). The filter is placed on the surface of a plate of eosin-methylene blue (EMB) culture medium, which is highly selective for coliform organisms (Figure 28.1; ∞ Section 24.2). The coliform colonies are counted, and from this value the number of coliform *Bacteria* in the original water sample can be determined. In well-regulated water supply systems, coliform tests should be negative. If coliform tests are positive, a breakdown in the system has occurred in purification procedures or distribution systems.

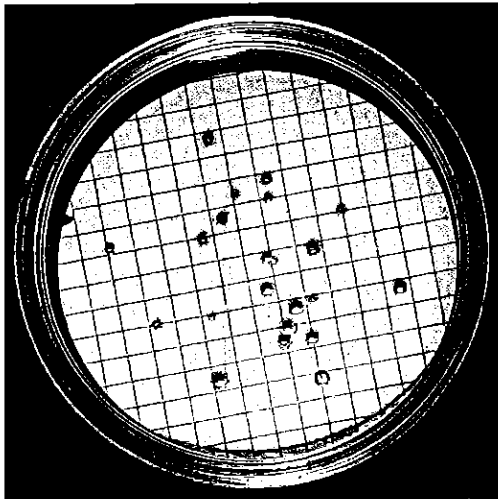


Figure 28.1 Coliform colonies growing on a membrane filter. A drinking water sample has been passed through the filter. The filter was placed on eosin-methylene blue (EMB) media that is both selective and differential for lactose-fermenting bacteria (coliforms) (∞ Section 24.2). The dark color of the colonies is characteristic of coliforms. Each colony represents one viable coliform isolated from the original sample.

Drinking water standards in the United States are specified under the Safe Drinking Water Act, which provides a framework for the development of drinking water standards. For the membrane filter (MF) technique, 100-ml samples are filtered. To be considered safe, the number of coliform bacteria in drinking water samples cannot exceed any of the following levels: (1) 1/100 ml as the arithmetic mean of all samples examined per month; (2) 4/100 ml in more than one sample when fewer than 20 are examined per month; or (3) 4/100 ml in more than 5% of the samples when 20 or more samples are examined per month. Water utilities report their results to the United States Environmental Protection Agency, and if they do not meet the prescribed standards, the utilities must notify the public and take steps to correct the problem. Many smaller communities and even large cities sometimes fail to meet these standards.

Public Health and Drinking Water Purification

Today the incidence of waterborne disease in developed countries is so low that it is difficult to directly measure the effectiveness of treatment practices and maintenance of drinking water standards. Most intestinal infections in developed countries are no longer due to transmission by water but via food (∞ Chapter 29). Effective water treatment practices were not in place until the twentieth century. Microbial culture methods for evaluating the health significance of polluted drinking water were not practiced until coliform counting procedures were developed and adapted in about 1905. Until then, water purification was limited to filtration to reduce turbidity (∞ Chapter 25, box, Snow on Cholera). Although filtration significantly decreases the microbial load of water, many microorganisms still passed through the filters. In about 1910, chlorine was discovered to be an extremely efficient disinfectant for large water supplies. Chlorine was so effective and so inexpensive that its use spread widely and was of major significance in reducing the incidence of waterborne disease. Figure 28.2 illustrates the dramatic drop in incidence of typhoid fever (infection with *Salmonella typhi*) in a major American city after filtration and chlorination purification procedures were introduced. Similar results were obtained in other major cities. The dramatic improvement in the health of the American people in the early decades of the twentieth century was largely due to the establishment of water purification procedures, and the effectiveness of chlorination could not have been assessed if standard methods for determining the coliform content of drinking water had not been developed. Thus, public works engineering, microbiology, and public health moved forward together.

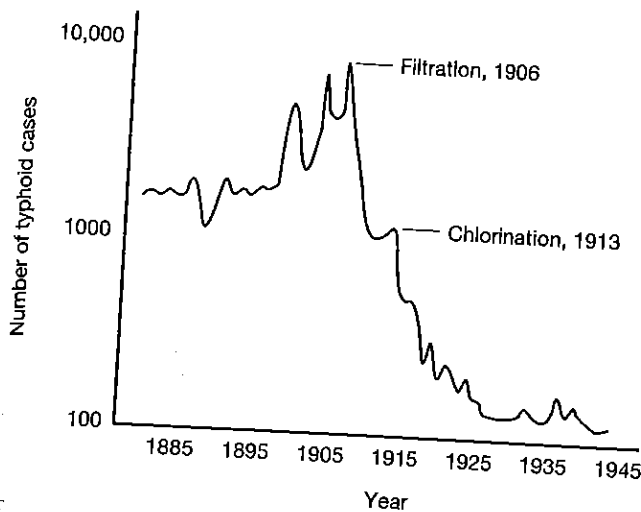


Figure 28.2 The effect of water purification on the incidence of waterborne disease. The graph shows the incidence of typhoid fever in Philadelphia (Pennsylvania, USA) before and after the introduction of filtration and chlorination processes for drinking water supplies. Note the dramatic reduction in the incidence of typhoid fever after the introduction of both filtration and chlorination. This result parallels the results obtained for reduction of other waterborne diseases.

28.1 Concept Check

Drinking water quality is determined by counting coliform bacteria. Strict adherence to uniform microbiologic standards make this method a reliable and reproducible indicator of fecal contamination in all public water supplies in the United States. Filtration and chlorination of water supplies significantly decreases microbial load. Application of water purification methods to drinking water is the most important public health measure ever devised.

Why do the bacterial colonies recovered from drinking water and grown on EMB media indicate fecal contamination of the water supply?

What procedures are used to reduce microbial load in water supplies?

28.2 Wastewater and Sewage Treatment

Wastewater and sewage treatment involves a large-scale use of microorganisms and can be considered a type of industrial-scale bioconversion. Wastewater enters a treatment plant and, following treatment, the effluent water is suitable for release into rivers and streams or to drinking water purification facilities.

Wastewater

Wastewater is liquid effluent derived from domestic sewage or industrial sources that cannot be discarded in its treated form into lakes or streams due to public health,

economic, and aesthetic considerations. Sewage is liquid effluent contaminated with human or animal fecal materials. Wastewater commonly contains potentially harmful inorganic and organic compounds as well as pathogenic microorganisms. As we shall see, complete wastewater treatment involves chemical and biological (microbiological) treatments to remove or neutralize contaminants.

About 15,000 wastewater treatment facilities exist in the United States. The vast majority of them are fairly small, treating 1 million gallons (3.8 million liters) or less of wastewater per day. Collectively, however, these plants treat nearly 40 billion gallons of wastewater every day. Wastewater plants are usually constructed to handle both domestic and industrial wastes. Domestic wastewater is made up of sewage, "gray water" (the water resulting from washing, bathing, and cooking), and wastewater from food processing. Industrial wastewater includes effluent from the petrochemical, pesticide, food and dairy, plastics, pharmaceutical, and metallurgical industries.

Industrial wastes may contain toxic substances that must be pretreated before they can be released for wastewater treatment. Pretreatment is generally a mechanical process in which debris that could clog equipment in the wastewater treatment plant is removed. However, certain wastewaters are pretreated biologically to remove highly poisonous substances such as cyanide and heavy metals. These substances can be converted to less toxic forms through the action of specific microorganisms capable of neutralizing, oxidizing, precipitating, or volatilizing toxic or infectious wastes. We now discuss the processes involved in a typical wastewater treatment facility.

Wastewater Treatment and Biochemical Oxygen Demand

The goal of a wastewater treatment facility is to reduce organic and inorganic materials in wastewater to a level that no longer supports microbial growth and to eliminate other potentially toxic materials. The efficiency of treatment is expressed in terms of a reduction in the biochemical oxygen demand (BOD), the relative amount of dissolved oxygen consumed by microorganisms to completely oxidize all organic and inorganic matter in a water sample (see Section 19.5). Higher levels of oxidizable organic and inorganic materials in the wastewater result in a higher BOD. Typical values for domestic wastewater, including sewage, are approximately 200 BOD units. For industrial wastewater, for example from sources such as dairy plants, the values can be as high as 1500 BOD units. An efficient wastewater treatment facility reduces levels to less than 5 BOD units in the water released from the treatment plant.



Figure 28.7 A floc formed by the bacterium *Zoogloea ramigera*, a characteristic organism found in the activated sludge process. The floc consists of a large number of small, rod-shaped cells of *Z. ramigera* surrounded by a polysaccharide slime layer, arranged in characteristic fingerlike projections. Negative stain using India ink.

added. Sand, gravel, and other large particles settle out. This pretreated water is then pumped to a clarifier or coagulation basin, a large holding tank where coagulation takes place: The alum and anionic polymers form larger suspended particles from the much smaller suspended colloidal particles. After mixing, the particles continue to interact, forming large, aggregated masses, a process known as flocculation. The large, aggregated particles, called floc, settle out by gravity, trapping any remaining microorganisms and absorbing organic matter and sediment. After coagulation and flocculation, the clarified water undergoes filtration. The water is passed through a series of filters designed to remove the remaining suspended particles and microorganisms. The filters usually consist of thick layers of sand and ionic filtration media. When combined with previous purification steps, the filtered water is free of all particulate matter, most organic and inorganic chemicals, and all microorganisms.

Disinfection

Clarified, filtered water must then be disinfected before it is released to the supply system as pure, potable finished water. Chlorination is the most common method of disinfection. In sufficient doses, chlorine kills microorganisms within 30 minutes (certain pathogenic protozoa such as *Cryptosporidium* are not easily killed by chlorine treatment and thus can be important waterborne pathogens; see Section 28.6). In addition to killing microorganisms, chlorine reacts with organic compounds, oxidizing and effectively neutralizing them. Therefore, since most taste- and odor-producing compounds are organic in nature, chlorine treatment also improves water taste and smell. Chlorine is added to water either from a concentrated

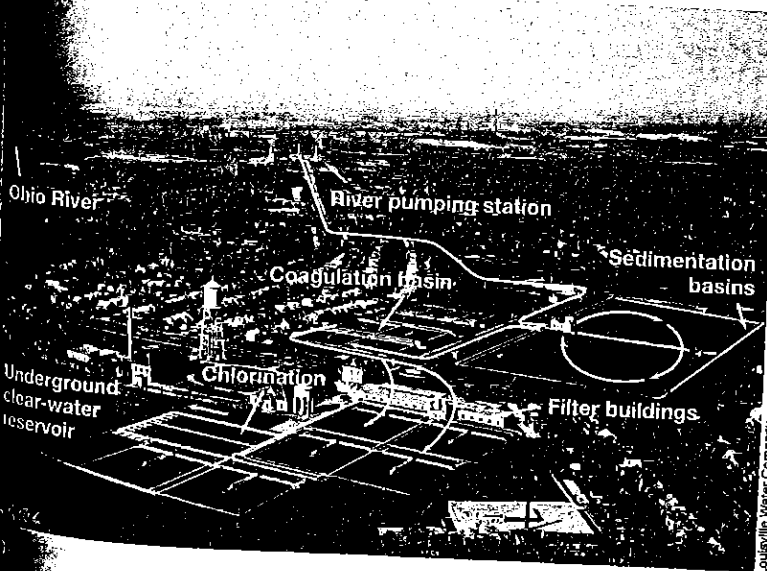
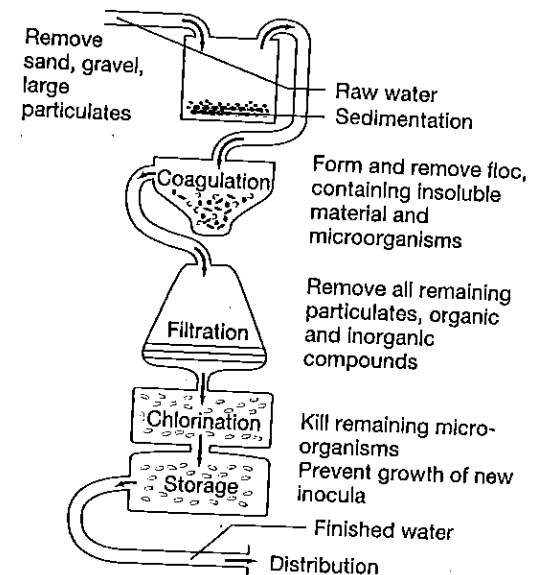


Figure 28.8 Water purification plant. (a) Aerial view of a water treatment plant in Louisville, Kentucky, USA. The arrows indicate direction of flow of water through the plant. (b) Schematic overview of a typical community water purification system.



(b)

TABLE 28.1 Waterborne infectious disease outbreaks associated with drinking water in the United States^a

Disease	Agent	Outbreaks	Cases
Shigellosis	<i>Shigella sonnei</i>	1	183
Giardiasis	<i>Giardia lamblia</i>	4	159
Cryptosporidiosis	<i>Cryptosporidium parvum</i>	2	1432
Gastroenteritis	<i>Escherichia coli</i> O157:H7	3	164
Acute gastro-intestinal illness	Unknown	5	163

^aCompiled from data provided by the Centers for Disease Control and Prevention for 1997–1998. There were a total of 15 outbreaks and 2001 cases of infectious disease due to drinking water contamination.

✓ 28.4 Concept Check

Drinking water and recreational water may both be sources of waterborne pathogens. In the United States, the number of disease outbreaks due to either of these sources is relatively small in relation to the large number of exposures to water. Worldwide, lack of adequate water treatment facilities and access to clean water contributes significantly to the spread of infectious diseases.

- ✓ Identify the microorganism most commonly responsible for disease outbreaks due to drinking water contamination.
- ✓ Identify the disease most commonly caused by exposure to contaminated recreational water.

28.5 Cholera

Cholera is a severe diarrheal disease that is now largely restricted to the developing parts of the world. Cholera is an example of a major waterborne disease that can be controlled by application of appropriate water treatment measures.

Biology and Epidemiology

The disease cholera is caused by *Vibrio cholerae*, a gram-negative, curved rod (∞ Section 12.12) transmitted almost exclusively via contaminated water. However, as with many waterborne diseases, cholera is also associated with food consumption. In the Americas, consumption of raw shellfish and raw vegetables has also been associated with cholera. Presumably, the vegetables were washed in contaminated water and the shellfish beds were contaminated by untreated sewage.

Since 1817, cholera has swept the world in seven major pandemics. The seventh began in 1961 and continues to the present. Two biotypes of *Vibrio cholerae* have been recognized, the classic and the El Tor types. The classic strain of *V. cholerae* was first isolated by Robert Koch in 1883 and was the prevalent biotype causing cholera pandemics before 1961. The El Tor biotype is responsible for the seventh pandemic that started in 1961. At least 5 million cases of cholera have been reported since 1961, with over 250,000 deaths. In 1999, there were over 400,000 cases and 9000 deaths worldwide.

Cholera is endemic in Africa, Southeast Asia, the Indian subcontinent, and Central and South America, especially in areas where sewage treatment is either inadequate or absent. Travelers to endemic areas should consider being immunized for cholera. Even in developed countries the disease is a threat. Sporadic outbreaks of cholera (fewer than 250 total cases) have been reported in the United States, mostly along the Gulf Coast, in the last 10 years. Raw shellfish may be the vehicle; *Vibrio*

tion Agency has established guidelines for fresh recreational water (monthly geometric mean of $\leq 33/100$ ml for enterococci or $\leq 126/100$ ml for *E. coli*), although local and state authorities can set standards above or below the guidelines. Private and therefore unregulated swimming pools, spas, and hot tubs are also occasional sources of outbreaks of waterborne diseases.

Over the last decade, about 15 waterborne disease outbreaks have occurred annually from regulated recreational waters in the United States. Table 28.2 categorizes these outbreaks according to the diseases produced.

Waterborne Infections in Developing Countries

Worldwide, waterborne infections are a much larger problem than in the United States and other developed countries. Developing countries often have poorly developed water and sewage treatment facilities, and access to safe potable water is limited. As a result, diseases such as cholera (Section 28.5), typhoid fever, and amebiasis (Section 28.8) are important public health problems worldwide.

TABLE 28.2 Recreational waterborne disease outbreaks in the United States, 1989–1998

Disease	Number of outbreaks	Percent
Gastroenteritis ^a	74	49.0
Dermatitis	50	33.1
Meningoencephalitis	18	11.9
Other	9	6.0
Total	151	100.0

^aMost cases of gastroenteritis were due to *Cryptosporidium parvum* (Section 28.7), *Escherichia coli* O157:H7 (∞ Section 29.7), or a Norwalk-like virus (Section 28.8). Most cases of dermatitis were caused by *Pseudomonas aeruginosa* (Section 28.8). Meningoencephalitis was caused by the amoeba *Naegleria fowleri* (Section 28.8). Other diseases caused by microorganisms include leptospirosis and Pontiac fever due to infection by *Legionella* (Section 28.7).

Solution:

Step 1. Calculate yearly 3% sludge volume, v

$$\begin{aligned} v &= 1500 \text{ lb/Mgal} \times 1 \text{ mgd} / 0.03 \\ &= 50,000 \text{ lb/d} \\ &= 50,000 \text{ lb/d} \times 365 \text{ d} / (62.4 \text{ lb/ft}^3) \\ &= 292,500 \text{ ft}^3 \end{aligned}$$

Step 2. Calculate area A ($D = \text{depth}$, $n = \text{number of applications/year}$)

$$\begin{aligned} v &= A D n \\ \text{or } A &= v / D n = 292,500 \text{ ft}^3 / (1.5 \text{ ft} \times 24 \text{ ft}) \\ &= 8125 \text{ ft}^2 \\ &= 755 \text{ m}^2 \end{aligned}$$

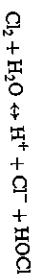
18 DISINFECTION

Disinfection is a process to destroy disease-causing organisms, or pathogens. Disinfection can be done by boiling the water, ultraviolet radiation, and chemical inactivation. In the water treatment processes, pathogens and other organisms can be physically eliminated through coagulation, flocculation, sedimentation, and filtration to the natural die-off. After filtration, to insure pathogen-free water, the chemical addition of chlorine (so called chlorination), rightly or wrongly, is most widely used for disinfecting drinking water. The use of ozone and ultraviolet for disinfection of water and wastewater is increasing in the U.S.

Chlorination serves not only for disinfection, but as an oxidant for other substances. Chlorination serves not only for disinfection, but as an oxidant for other substances, taste and odor control in water and wastewater. Other chemical disinfectants include dioxide, ozone, bromine, and iodine. The last two chemicals are generally used for application, not for the public water supply.

18.1 Chemistry of Chlorination

Free available chlorine. Effective chlorine disinfection depends upon its chemical form in water. The influencing factors are temperature, pH, and organic content in the water. The chlorine gas is dissolved in water, it rapidly hydrolyzes to hydrochloric acid and chlorous acid (HOCl)



The equilibrium constant is

$$\begin{aligned} K_H &= \frac{[\text{H}^+][\text{Cl}^-][\text{HOCl}]}{[\text{Cl}_2]_{\text{gas}}} \\ &= 4.48 \times 10^4 \text{ at } 25^\circ\text{C} \text{ (White 1972)} \end{aligned}$$

The dissolution of gaseous chlorine, $\text{Cl}_{2(\text{g})}$, to form dissolved molecular chlorine, $\text{Cl}_{2(\text{aq})}$ follows Henry's law and can be expressed as (Downs and Adams, 1973)

$$\text{Cl}_{2(\text{g})} = \frac{C_{\text{Cl}_{2(\text{aq})}}}{H \text{ (mole/L atm)}} = \frac{C_{\text{Cl}_{2(\text{aq})}}}{P_{\text{Cl}_2}} \quad (6.154)$$

where $C_{\text{Cl}_{2(\text{aq})}}$ = molar concentration of Cl_2
 P_{Cl_2} = partial pressure of chlorine in atmosphere

The distribution of free chlorine between HOCl and OCl^- is presented in Fig. 6.10. The disinfection capabilities of HOCl is generally higher than that of OCl^- (Water, 1978).

$$\begin{aligned} H &= \text{Henry's law constant, mole/L atm} \\ &= 4.805 \times 10^{-6} \exp\left(\frac{2818.48}{T}\right) \end{aligned} \quad (6.155)$$

Hypochlorous acid is a weak acid and subject to further dissociation to hypochlorite ions (OCl^-) and hydrogen ions:



and its acid dissociation constant K_a is

$$\begin{aligned} K_a &= \frac{[\text{OCl}^-][\text{H}^+]}{[\text{HOCl}]} \\ &= 3.7 \times 10^{-8} \text{ at } 25^\circ\text{C} \\ &= 2.61 \times 10^{-8} \text{ at } 20^\circ\text{C} \end{aligned} \quad (6.157)$$

The values of K_a for hypochlorous acid is a function of temperature in kelvins as follows (Morris 1966):

$$\ln K_a = 23.184 - 0.0587T - 6908/T \quad (6.158)$$

EXAMPLE 1: The dissolved chlorine in the gas chlorinator is 3900 mg/L at pH 4.0. Determine the equilibrium vapor pressure of chlorine solution at 20°C (use $K_H = 4.5 \times 10^4$).

Solution: Since pH = 4.0 < 5, from Fig. 6.10, the dissociation of HOCl to OCl^- is not occurring. The available chlorine is $[\text{Cl}_2] + [\text{HOCl}]$.

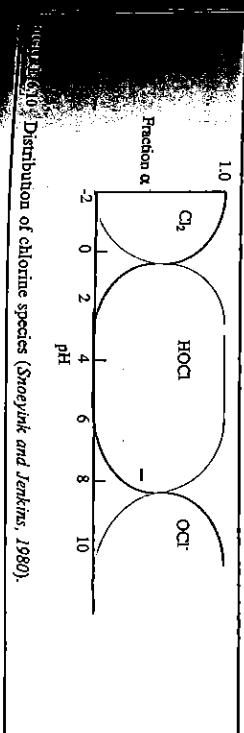


FIGURE 6.10 Distribution of chlorine species (Snoeyink and Jenkins, 1980).

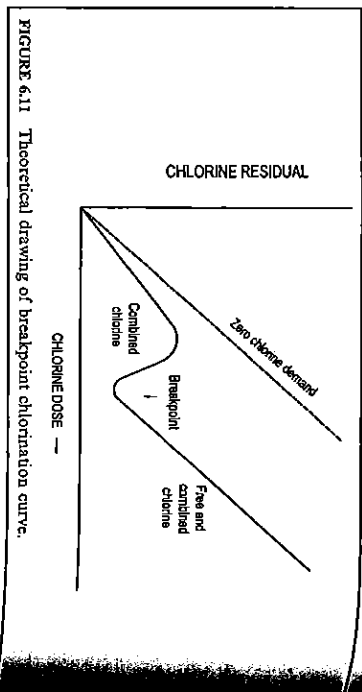


FIGURE 6.11 Theoretical drawing of breakpoint chlorination curve.

$$A = \frac{BM}{1 - [1 - BM(2 - M)]^{1/2}} - 1$$

where

A = ratio of available chlorine in di- to monochloramine

M = molar ratio of chlorine (as Cl_2) added to ammonia-N present

$$B = 1 - 4K_{eq}[H^+]$$

where the equilibrium constant K_{eq} is from



$$K_{eq} = \frac{[NH_4^+][NHCl_2]}{[H^+][NH_2Cl]^2}$$

$$= 6.7 \times 10^5 \text{ L/mole at } 25^\circ\text{C}$$

The relationship (Eq. (6.168)) is pH dependent. When pH decreases and the Cl_2 dose increases, the relative amount of dichloramine also increases.

EXAMPLE: The treated water has pH of 7.4, a temperature of 25°C, and a free chlorine residual of 1.2 mg/L.

Chloramine is planned to be used in the distribution system. How much ammonia-N is required to keep the ratio of dichloramine to monochloramine of 0.15, assuming that ammonia-N are not dissipated yet.

Solution:

Step 1. Determine factor B by Eq. (6.171)

$$K_{eq} = 6.7 \times 10^5 \text{ L/mole at } 25^\circ\text{C}$$

$$\text{pH} = 7.4, [H^+] = 10^{-7.4}$$

$$B = 1 - 4K_{eq}[H^+] = 1 - 4(6.7 \times 10^5)(10^{-7.4}) = 0.893$$

Step 2. Compute molar ratio M

$$A = 0.15$$

Using Eq. (6.168)

$$A = \frac{BM}{1 - [1 - BM(2 - M)]^{1/2}} - 1$$

$$0.15 = \frac{0.893M}{1 - [1 - 0.893M(2 - M)]^{1/2}} - 1$$

$$1 - [1 - 0.893M(2 - M)]^{1/2} = 0.777M$$

$$(1 - 0.777M)^2 = 1 - 0.893M(2 - M)$$

$$0.29M^2 - 0.232M = 0$$

$$M = 0.80$$

Step 3. Determine the amount of ammonia nitrogen (N) to be added

$$\text{Mol. wt. of } Cl_2 = 70.9 \text{ g}$$

$$1.2 \text{ mg/L of } Cl_2 = \frac{1.2 \text{ mg/L}}{70.9 \text{ g/mol}} \times 1000 \text{ mg/g}$$

$$= 1.7 \times 10^{-5} \text{ mol/L}$$

$$M = \frac{1.7 \times 10^{-5} \text{ mol/L}}{NH_3}$$

$$NH_3 = 1.7 \times 10^{-5} \text{ (mol/L)} / 0.80$$

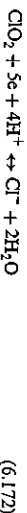
$$= 2.12 \times 10^{-5} \text{ mol/L}$$

$$= 2.12 \times 10^{-5} \text{ mol/L} \times 14 \text{ g of N/mol}$$

$$= 0.30 \text{ mg/L as N}$$

Chlorine dioxide. Chlorine dioxide (ClO_2) is an effective disinfectant (1.4 times that of the oxidation power of chlorine). It is an alternative disinfectant of potable water, since it does not produce significant amounts of trihalomethanes (THMs) which chlorine does. Chlorine dioxide has not been widely used for water and wastewater disinfection in the United States. In western Europe, the use of chlorine dioxide is increasing.

Chlorine dioxide is a neutral compound of chlorine in the + IV oxidation state, and each mole of chlorine dioxide yields five redox equivalents (electrons) on being reduced to chloride ions. The chemistry of chlorine dioxide in water is relatively complex. Under acid conditions, it is reduced to chlorite:



Under relatively neutral pH found in most natural water it is reduced to chlorite:



In alkaline solution, chlorine dioxide is disproportioned into chlorite, ClO_2^- , and chlorate,



TABLE 6.4 Baffling Classification and T_{10}/T Values

Baffling condition	Baffling description	T_{10}/T
Unbaffled (mixed flow)	No baffles, agitated basin, very low length to width ratio, high inlet and outlet flow velocities	0.1
Poor	Single or multiple unbaffled inlets and outlet, no intra-basin baffles	0.3
Average	Only baffled inlet or outlet with some intra-basin baffles	0.5
Superior	Perforated inlet baffles, serpentine or perforated intra-basin baffles, outlet weir or perforated launders	0.7
Perfect (plug flow)	Very high length to width ratio (pipelike flow), perforated inlet, outlet, and intra-basin baffles	1.0

Source: Table C-5 of Guidance Manual (U.S. EPA, 1989a)

The procedure to determine the inactivation capability of a water plant is summarized as follows:

1. Determine hydraulic detention time $HRT = T = V/Q$
2. Find correction factor, T_{10}/T , from Appendix C of the Manual (U.S. EPA, 1989a) (Table 1 of the Manual = Table 6.4)
3. Compute effective retention time $ERT = HRT(T_{10}/T)$
4. Calculate CT value for the tank or basin (using ERT for T) based on actual disinfectant concentration, pH, residual chlorine concentration, and log₁₀ removal
5. Find CT_{99} value from Appendix E of the Manual (Tables 2-4 of U.S. EPA, 1989a) on water temperature, pH, residual chlorine concentration, and log₁₀ removal
6. Compute the inactivation ratio, CT_{actual}/CT_{99} and CT_{actual}/CT_{99} for *Giardia*, respectively
7. Multiply the ratio of step 6 by 3 for *Giardia* log inactivation and by 4 for log inactivation
8. Sum up log inactivation values of each segment (such as rapid mixing tanks, clarifiers, filters, clearwell, and pipelines)
9. Determine whether the inactivations achieved are adequate. If the sum of the ratios is greater than or equal to one, the required 3-log inactivation of *Giardia* has been achieved.
10. The total percent of inactivation can be determined as:

$$y = 100 - 100/10^x$$

where y = % inactivation
 x = log inactivation

Tables 6.5 and 6.6 present the CT values for achieving 99.9 percent and 99.999 percent inactivation of *Giardia lamblia*. Table 6.7 presents CT values for achieving inactivation of pH 6 through 9 (U.S. EPA, 1989b). The SWTR Guidance Manual did not provide CT values at pH above 9 due to the limited research results available at the time of publication. In November 1997, a new set of proposed rules were developed for the higher pH of 11.5 (Federal Register, 1997).

TABLE 6.5 CT Values for Achieving 99.9 Percent (3-log) Inactivation of *Giardia lamblia*

Disinfectant mg/L	pH	0.5 or < 1	Temperature, °C					
			5	10	15	20	25	
Free chlorine ≤ 0.4	6	137	97	73	49	36	24	
	7	195	139	104	70	52	35	
	8	277	198	149	99	74	50	
	9	390	279	209	140	105	70	
	1.0	548	405	309	215	155	100	
	7	210	149	112	75	56	37	
	8	306	216	162	108	81	56	
	9	437	312	236	156	117	78	
	1.6	157	109	83	56	42	28	
	7	226	155	119	79	59	40	
2.0	8	321	227	170	116	87	58	
	9	466	329	236	169	126	82	
	6	165	116	87	58	44	29	
	7	236	165	126	83	62	41	
	8	346	263	182	122	91	61	
	9	500	353	265	177	132	88	
	1.0	718	518	395	275	200	138	
	6	181	126	95	63	47	32	
	7	261	182	137	91	68	46	
	8	382	268	201	136	101	67	
CO ₂	9	552	389	292	195	146	97	
	6-9	63	26	23	19	15	11	
	Ozone	6-9	2.9	1.9	1.43	0.95	0.72	0.58
		6-9	3800	2200	1850	1500	1100	750

Abstracted from Table E-1 - E-6, E-8, E-10, and E-12 of Guidance Manual (U.S. EPA, 1989a).

EXAMPLE 1: What are the percentages of inactivation for 2- and 3.4-log removal of *Giardia lamblia*?

Solution:

$$\text{Inactivation} = 100 - 100/10^x$$

$$\text{Inactivation} = 100 - 100/10^{2.0} = 100 - 10 = 90\%$$

$$\text{Inactivation} = 100 - 100/10^{3.4} = 100 - 0.04 = 99.96\%$$

EXAMPLE 2: A water system of 100,000 gpd (0.044 m³/s) slow sand filtration system serves a population of 100,000 persons. The filter effluent turbidity values are 0.4-0.6 mg/L and pH is 7.8. Chlorine is dosed after filtration and prior to the clearwell. The 4-in (10-cm) distribution main to the first customer is 1640 ft (500 m) in distance. The residual chlorine in the clearwell and the distribution main are 1.6 and 1.0 mg/L, respectively.

TABLE 6.6 CT Values (mg/L min) for Achieving 90 Percent (1 log) Inactivation of *Giardia lamblia*

Disinfectant mg/L	pH	Temperature, °C				
		0.5 or < 1	5	10	15	20
Free chlorine ≤ 0.4	6	46	32	24	16	12
	7	65	46	35	23	17
	8	92	66	50	33	25
	9	130	93	70	47	35
	6	49	35	26	18	13
	7	70	50	37	25	19
	8	101	72	54	36	27
	9	146	104	78	52	39
1.6	6	52	37	28	19	14
	7	75	52	40	26	20
	8	110	77	58	39	29
	9	159	112	84	56	42
	6	55	39	29	19	15
	7	79	55	41	28	21
	8	115	81	61	41	30
	9	167	118	88	59	46
3.0	6	60	42	32	21	16
	7	87	61	46	30	23
	8	127	89	67	45	36
	9	184	130	97	65	49
	6	21	8.7	7.7	6.3	5.0
	7	21	8.7	7.7	6.3	5.0
	8	21	8.7	7.7	6.3	5.0
	9	21	8.7	7.7	6.3	5.0
Chlorine dioxide	6-9	21	8.7	7.7	6.3	5.0
	6-9	0.97	0.63	0.48	0.32	0.23
Ozone	6-9	1270	735	615	500	370
	6-9	1270	735	615	500	370
Chloramine	6-9	1270	735	615	500	370

Source: Abstracted from Tables E-1 - E-6, E-8, E-10, and E-12 of Guidance Manual (U.S. EPA, 1982).

TABLE 6.7 CT Values (mg/L min) for Achieving Inactivation of Viruses at pH 6 and 7

Disinfectant mg/L	Log inactivation	Temperature, °C				
		≤ 1	5	10	15	20
Free chlorine	2	6	4	3	2	1
	3	9	6	4	3	2
	4	12	8	6	4	3
	4	12	8	6	4	3
Chlorine dioxide	2	8.4	5.6	4.2	2.8	2.0
	3	25.6	17.1	12.8	8.6	6.0
	4	50.1	33.4	25.1	16.7	12.0
	4	50.1	33.4	25.1	16.7	12.0
Ozone	2	0.9	0.6	0.5	0.3	0.2
	3	1.4	0.9	0.8	0.5	0.4
	4	1.8	1.2	1.0	0.6	0.5
	4	1.8	1.2	1.0	0.6	0.5
Chloramine	2	1243	857	643	428	312
	3	2063	1423	1067	712	525
	4	2883	1988	1491	994	740
	4	2883	1988	1491	994	740

Source: Modified from Tables E-7, E-9, E-11, and E-13 of Guidance Manual (U.S. EPA, 1982).

The volume of the clearwell is 70,000 gallons (265 m³). Determine *Giardia* inactivation at water temperature 10°C at the peak hour flow of 100 gpm.

Solution:

Step 1. An overall inactivation of 3 logs for *Giardia* and 4 logs for viruses is required. The Primary Agency can credit the slow sand filter process, which produces water with turbidity ranging from 0.6 to 0.8 NTU, with a 2-log *Giardia* and virus inactivation. For this example, the water system meets the turbidity standards. Thus, disinfection must achieve an additional 1-log *Giardia* and 2-log virus removal/inactivation to meet the overall treatment efficiency.

Step 2. Calculate T_{10} at the clearwell (one half of volume used, see step 7a of Ex. 5). T_{10} can be determined by the trace study at the peak hour flow or by calculation

$$T_{10} = V_{10}/Q = 0.1 \times 35,000 \text{ gal}/100 \text{ gpm} = 35 \text{ min}$$

Step 3. Calculate CT_{dis} in the clearwell

$$CT_{\text{dis}} = 1.0 \text{ mg/L} \times 35 \text{ min} = 35 \text{ (mg/L) min}$$

Step 4. Calculate $CT_{\text{dis}}/CT_{99.9}$ From Table 6.5, for 3-log removal for 1.6 mg/L chlorine residual at 10°C and pH 7.5.

$$CT_{99.9} = 145 \text{ (mg/L) min (by proportion between pH 7 and 8)}$$

$$CT_{\text{dis}}/CT_{99.9} = 35/145 = 0.38$$

Step 5. Calculate contact time at transmission main

$$Q = 100,000 \text{ gal/d} \times 1 \text{ ft}^2/7.48 \text{ gal} \times 1 \text{ d}/1440 \text{ min} = 9.28 \text{ ft}^3/\text{min}$$

$$A = 3.14 (2/12)^2 = 0.0872 \text{ ft}^2$$

$$v = \frac{Q}{A} = \frac{9.28 \text{ ft}^3/\text{min}}{0.0872 \text{ ft}^2} = 106 \text{ ft}/\text{min}$$

$$T = \text{length}/v = 1640 \text{ ft}/106 \text{ ft}/\text{min} = 15.5 \text{ min}$$

Step 6. Calculate the cross-sectional area of the pipe, and v is the flow velocity.

Step 7. Calculate CT_{dis} and $CT_{\text{dis}}/CT_{99.9}$ for the pipeline

$$CT_{\text{dis}} = 1.0 \text{ mg/L} \times 15.5 \text{ min} = 15.5 \text{ (mg/L) min}$$

$$CT_{99.9} = 137 \text{ (mg/L) min}$$

$$CT_{\text{dis}}/CT_{99.9} = 15.5/137 = 0.11$$

27 EFFLUENT DISINFECTION

Effluent disinfection is the last treatment step of a secondary or tertiary treatment process. Disinfection is a chemical treatment method carried out by adding the selected disinfectant to an effluent to destroy or inactivate the disease-causing organisms. The purposes of effluent disinfection are to protect public health by killing or inactivating pathogenic organisms, to disinfect as enteric bacteria, viruses, and protozoans and to improve the effluent discharge characteristics. The disinfection agents (chemicals) include chlorine, ozone, ultraviolet (UV) radiation, chlorine dioxide, and bromine. Design of UV irradiation can be referred to the manual or elsewhere (WEF and ASCE 1996).

The chlorination-dechlorination process is currently widely practiced in the US. Chlorine is added to a secondary effluent for a certain contact time (20–45 min for average flow and 15 min at peak flow), then the effluent is dechlorinated before discharge only during weather when people use water as primary contact. In the US most states adopt a maximum limitation of 200 fecal coliform/100 ml.

Chlorination of effluents is usually accomplished with liquid chlorine. Alternative methods use calcium or sodium hypochlorite or chlorine dioxide. Disinfection kinetics and chlorination are discussed in Chapter 16, numerous literature, and text books. For a complete review of effluent disinfection can be found in Design Manual (US EPA 1986).

27.1 Chlorine Dosage

If a small quantity of chlorine is added to wastewater or effluent, it will react with reducing substances such as hydrogen sulfide and ferrous iron, and be destroyed. Under these conditions, there are no disinfection effects. If enough chlorine is added to oxidize all reducing compounds, then a little more added chlorine will react with organic matter present in wastewater and form chloroorganic compounds, which have slight disinfection effect. Again, if enough chlorine is introduced to react with all reducing compounds, organic materials, then a little more chlorine added will react with ammoniacal nitrogen, inorganic materials, then a little more chlorine added will react with ammoniacal nitrogen, have disinfection capabilities. Therefore chlorine dosage and residual chlorine concentration are important factors of disinfection operation. In addition to its disinfection purpose, chlorine is also applied for prevention of wastewater decomposition, prechlorination of effluent, control of activated sludge bulking, and reduction of BOD.

Chlorinators are designed to have a capacity adequate to produce an adequate residual chlorine density limits specified by the regulatory agency. Usually, multiplications for adequate capacity and to prevent excessive chlorine residuals in the effluent are shown on design average flow (Illinois EPA 1997, GLUMRB 1996).

For small applications, 150-lb (68-kg) chlorine cylinders are typically used. The gas consumption is less than 150 pounds per day. Chlorine cylinders are typically positioned with adequate support brackets and chains at 2/3 of cylinder height. For larger applications where the average daily chlorine gas consumption is more than 1500 pounds, one-ton (909 kg) containers are employed. Tank cars, usually evaporators, are used for large installations (> 10 Mgal/d, 0.44 m³/s). The design evaporators, are used for large installations (> 10 Mgal/d, 0.44 m³/s). The design wide public safety should be evaluated as part of the design consideration.

EXAMPLE 1: Estimate a monthly supply of liquid chlorine for trickling filter plant disinfection. The design average flow of the plant is 3.0 Mgal/d (11.36 m³/d).

Solution:

Step 1. Find the recommended dosage
From Table 7.20, the recommended dosage for trickling filter plant effluent is 10 mg/L.

Step 2. Compute the daily consumption

$$\begin{aligned} \text{Chlorine} &= 3.0 \text{ Mgal/d} \times 10 \text{ mg/L} \times 8.34 \text{ lb}/(\text{Mgal/d}) \cdot (\text{mg/L}) \\ &= 250 \text{ lb/d} \end{aligned}$$

The daily consumption is over 150 lb/d (68 kg/d); thus choose one-ton (2000 lb, 909 kg) containers.

Step 3: Compute the number of one-ton containers required for one month's supply

$$\begin{aligned} \text{Monthly need} &= 250 \text{ lb/d} \times 30 \text{ M/d} \\ &= 7500 \text{ lb/M} \end{aligned}$$

The plant needs 4 one-ton containers, which is enough for one month's consumption.

EXAMPLE 2: Determine the feeding rate in gallons per minute of sodium hypochlorite (NaOCl) solution containing 10 percent available chlorine. The daily chlorine dosage for the plant is 480 kg/d (1060 lb/d).

Solution:

Step 1: Calculate chlorine concentration of the solution

$$10\% = 100,000 \text{ mg/L} = 100 \text{ g/L}$$

TABLE 7.20 Recommended Chlorine Dosing Capacity for Various Types of Treatment Based on Design Average Flow

Type of treatment	Illinois EPA dosage, mg/L	GLUMRB dosage, mg/L
Primary settled effluent	20	
Secondary effluent (unfiltered)	20	
Secondary effluent (filtered)	10	
Trickling filter plant effluent	10	10
Activated sludge plant effluent	6	8
Activated sludge plant with chemical addition	4	
Stabilized effluent		6
Stabilized effluent following mechanical biological treatment	4	6

Illinois EPA (1997), GLUMRB (1996)