STATE OF CALIFORNIA
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WATER QUALITY CRITERIA

Second Edition

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- percentages of undissociated sulfurous acid, HSO_3^-, ulfite ion at various pH values are shown by the ng tabulation:

pH	Percent as H_2SO_3	HSO_3^-	$SO_3^=$
4	0.56	94.7	4.74
5	0.04	66.5	33.46
6	---	16.7	83.3
7	---	2.0	98.0
8	---	0.2	99.8
9	---	0.02	99.98

Very little of the sulfurous acid remains undissociated in the normal pH ranges; at pH 5 and below, HSO_3^- predominates and above 5 the bivalent sulfite ion prevails (911).

In the presence of oxidizing agents such as dissolved oxygen and chlorine, the sulfite ion is gradually oxidized to sulfate, the sulfur changing from a + 4 valence to + 6 (364).

In domestic water, sulfur dioxide and sulfites are deleterious primarily in that they lower the pH value and increase corrosivity. By being oxidized and utilizing dissolved oxygen, on the other hand, sulfites may retard corrosion. Konrich and Haase (1312) fear that a high concentration of sulfite ion in water may cause exzema.

In 1917, Shelford (363) reported that 16 to 19 mg/l of sulfur dioxide killed orange-spotted sunfish in one hour. Ellis (313) quotes references to the effect that concentrations of SO_2 of 10 mg/l in tap water caused trout to float helplessly within 10 minutes, and Ellis (609) also reported that 5.0 mg/l of SO_2 kills trout in one hour. According to Bandt (656), 0.5 mg/l of sulfurous acid is o fish. Sulfurous acid is lethal to tench at a con- on of 1.0 mg/l for two hours (2977).

SULFURIC ACID H_2SO_4

1. General. Like hydrochloric, nitric, and other trong acids, sulfuric acid dissociates almost completely n water to release sulfate ions and hydrogen ions, thereby tending to lower the pH value. At very low pH values 3 and lower), some of the sulfate ion will remain as cid sulfate, HSO_4^-, but at higher pH values dissociaion to sulfate ions is practically complete (911). In conidering the effects of sulfuric acid upon the beneficial ses of water, therefore, it must be recognized that an ncrease in sulfate ions and a lowering of pH are inolved.

Sulfuric acid is the most important and widely used cid. It is employed in nearly all chemical processes and n many other industries, e.g., the production of fertizers, other acids, explosives, and dyestuffs, for the purication of oils, and for pickling of metals (364, 1224). s a result of its wide use, increased sulfate ions and wered pH values are likely to result in many types of dustrial wastes.

2. Cross References. Acidity, pH, Sulfates.

3. Effects Upon Beneficial Uses.

a. Domestic Water Supplies. (see Sulfates, Acidity, nd pH)

b. Fish and Other Aquatic Life. The following con- tions of sulfuric acid in water have been reported or toxic toward fish:

Concentration of H_2SO_4 in mg/l	Time of exposure	Type of water	Species of fish	Reference
1.2	--	--	Sunfish	359
6.0-8.0	6 hours	Distilled, 20°C	Minnows	2942
6.25	24 hours	--	Trout	359
7.36	60 hours	Distilled	Bluegills	313
10.0	--	--	Gamefish	1010, 541
24.5	24 hours	--	Bluegills	359
26.0	15 minutes	Tap	Minnows	362
42	96-hour TL_m	Turbid	Mosquito-fish	2940
49	48-hour TL_m	Tap, 20°C	Bluegill sunfish	2093
59.0	1-1.25 hours	Soft, pH 3.2	Goldfish	313
71.2	--	--	Pickerel	353
80.1	--	--	Whitefish	353
110-120	6 hours	Hard, 20°C	Minnows	2942
138.0	4 hours	Hard, pH 4	Goldfish	313
167	48 hours	--	Fish	3706

Non-toxic or harmless concentrations of sulfuric acid have been reported as follows:

3.68	1 month	Distilled	Bluegills	313
17.0	Over 4 days	Soft	Goldfish	353
20.0	24 hours	--	Minnows	359
100.0	100 hours	Hard	Goldfish	313

Toward other aquatic life, the following concentrations of sulfuric acid were harmful:

29	24-72 hours	Soft, pH 5	*Daphnia magna*	313
33.11	--	--	Bivalve larvae	2989
50	--	--	All aquatic life	541
88	64 hours	Lake Erie	*Daphnia magna*	358
138	--	--	*Daphnia magna*	353

The foregoing tabulations illustrate the fact that the toxicity of sulfuric acid toward aquatic life is a function of the resulting pH, i.e., a dose that would be lethal in distilled water or soft water might be harmless in a highly buffered water. Doudoroff and Katz (361) report that strong mineral acids such as sulfuric can be directly lethal to fully developed fish in most natural waters only when the pH is reduced to 5.0 or lower. Ellis (611) confirms this observation by stating that sulfuric acid must be diluted so as to give a pH of 4.5 or higher in order for fish to survive, and to pH 5.5 to make it possible for other aquatic organisms to thrive and provide food for fish. Death of trout has been reported (2920) at pH 3.9, while for sunfish, bass, and carp (3697) a pH of 3.5 caused death and 4.0 gave pronounced gill irritation. For *Polycelis nigra*, the toxic threshold of sulfuric acid has been reported (353) as 0.63 mg/l of hydrogen ion, or at pH 3.2 in distilled water. When sulfuric acid in streams depresses the pH below 5.0, specialized flora and fauna develop (3608).

c. Shellfish Culture. Oysters are sensitive to changes in pH. A dose of 100 mg/l of sulfuric acid killed 18 percent of oyster spat in five days (317, 523).

SULFUROUS ACID

(see Sulfur Dioxide)

SURFACE ACTIVE AGENTS

(see Chapter X)

SUSPENDED SOLIDS

1. General. In natural waters, suspended solids consist normally of erosion silt, organic detritus, and plankton. The impact of man's activities, however, alter and augment the suspended solids in surface waters by the

discharge of liquid wastes from communities and industries, by increased erosion from deforested and cultivated areas, by gravel washings and mine tailings, by steel mill wastes, and by dusts that are blown into streams (308, 347, 473, 540, 541, 611, 664, 673, 684, 701, 779, 780, 799, 814, 1552, 1700, 3655, 3658).

To differentiate between suspended solids and settleable solids is often difficult, because these two terms are often confused in the literature, although the method of determination of each is clearly described in Standard Methods for the Examination of Water and Wastewater (469). Strictly speaking, until they have settled to the bottom of a water course (or a laboratory sample bottle), all settleable solids are suspended solids. On the other hand, only a fraction of the suspended solids are settleable and this fraction is dependent upon quiescence, temperature, density, flocculation, and many other factors. In this section of the report only those references that deal strictly with the term "suspended solids" are considered.

Where stream classifications and standards have been promulgated, or where effluent standards are used, the test for suspended solids is generally employed as a significant criterion. For details of standards used by state and interstate agencies, see Chapter III.

2. Cross References. Turbidity, Silt, Settleable Solids, and Chapters III and V.

3. Effects Upon Beneficial Uses.

a. Domestic Water Supplies. The 1962 USPHS Drinking Water Standards (2036) do not specify limiting concentrations for suspended solids, but such concentrations are indirectly controlled by the limits on turbidity (5 units) and total solids (500 mg/l). Bean (1745) has proposed that, for drinking water of ideal quality, suspended matter by limited to 0.1 mg/l or less. In raw water sources for domestic use, state and regional agencies generally specify that suspended solids in streams shall not be in sufficient concentration to be objectionable or to interfere with normal treatment processes (see Chapter III for details). Those agencies that employ effluent standards, however, are more specific in delineating concentrations (or percentage removals) of suspended solids in effluents.

b. Industrial Water Supplies. Suspended solids in water interfere with many industrial processes, and cause foaming in boilers (815), or incrustations on equipment exposed to water, especially as the temperature rises (1361, 3698). Water for steel manufacturing should contain not over 25 mg/l of suspended solids (249). Suspended solids are undesirable in water for textile industries (185, 212, 258, 2377); paper and pulp (212, 402); beverages (180, 181); dairy products (816); butadience (251); laundries, dyeing, photography, cooling systems, and power plants (369). For further details, see specific industries as listed in Chapter V.

c. Irrigation Water. Paperboard mill waste waters containing 240 mg/l of suspended solids have been successfully used for spray irrigation of alfalfa. There was no problem from suspended paper fibers (3699).

d. Fish and Other Aquatic Life. Disregarding any possible toxic effects attributable to substances leached out by water, suspended solids may kill fish and shellfish by causing abrasive injuries; by clogging the gills and respiratory passages of various aquatic fauna; and by blanketing the stream bottom, killing eggs, young and food organisms, and destroying spawning beds (illegible). Indirectly, suspended solids are inimical to aquatic life because they screen out light (see Turbidity) and because, by carrying down and trapping bacteria and decomposing organic wastes on the bottom, they promote and maintain the development of noxious conditions and oxygen depletion, killing fish, shellfish and fish food organisms, and reducing the recreational value of the water.

While it appears to be debatable whether wood fibers (673, 688, 3675) and other suspended solids cause the death of healthy fish by clogging their gills, nevertheless, there is agreement that they are harmful to the extent that they blanket the stream bed, prevent normal growth of food organisms and contribute to conditions of decay. It has been pointed out that healthy fish may swim through heavy suspensions of solids without significant injury (2546); yet, in the presence of even low concentrations of toxic substances, fish may be so weakened that the abrasive and clogging actions of suspended solids become more effective and dangerous, and even lethal (313).

Ellis (313, 347, 801) has recommended that all cellulose pulps and sawdust be excluded from streams; that suspended solids of a hardness of one or more (mineralogical scale) be so finely divided as to pass through a 1000-mesh screen; and that the stream bottom not be blanketed to a depth of more than one-quarter inch.

Tests on the survival of rainbow trout in suspensions of inert solids (kaolin and diatomaceous earth) showed that concentrations of 30 mg/l had no observable effect; a few fish died at 90 mg/l, while at 270 mg/l more than half of the fish died in 2 to 12 weeks. No difference could be detected between the lethal effects of kaolin and diatomaceous earth, although the particle size of the former lay mostly in the range of 0.13 to 5.0 microns, and of the latter in the range of 1 to 6 microns (88, 3321). In concurrent field tests in England, it was found that a stream containing 60 mg/l of suspended solids had just as many trout and invertebrates as a clear control stream; but in the River Fal, with 1000 mg/l of suspended matter, trout were only one-seventh and invertebrates only one-third of the densities in control streams. In the polluted River Par, with about 6000 mg/l of suspended solids, trout were one-seventh and invertebrates one-nineteenth of the densities in the control streams (88). Based on the laboratory phase of the investigation, it seems unlikely that reductions in trout populations were caused solely by reductions in food supply.

Waste fibers from a wood grinding mill, built in 1915, have covered and destroyed certain spawning grounds of whitefish in a Swedish river. Since 1923 the total annual catch of fish from this river has been reduced to about 1 pound per acre. Laboratory experiments showed that fish eggs in aquaria whose bottoms were covered with this material had a 36-75 percent mortality rate, whereas in the control aquaria the mortality rate was 3-15 percent (1701).

Destruction of fish and plankton in a long stretch of river polluted by mine wastes was attributed [illegible] the

of any toxic chemicals, but to the deposition on and gills of particles of iron hydroxide (1702).

According to Robinson (2614) concentrations of some suspended materials as high as 1458 mg/l were filtered and passed through the gut of *Daphnia magna* with no apparent harm; but charcoal and montmorillonite were toxic at 100 mg/l, ground glass at 98 mg/l, chlorite at 120 mg/l, and illite at 264 mg/l.

e. Shellfish Culture. In concentrations of suspended matter and silt higher than 750 mg/l, the development of eggs and larvae of the venus clam was decreased (3700).

SYNTHETIC DETERGENTS

(see Chapter X)

SYSTOX

(see Chapter IX)

TANNIC ACID $C_{76}H_{52}O_{46}$

1. General. Tannic acid occurs naturally in the bark and fruit of many plants. In the pure state it is a yellowish brown powder with a faint characteristic odor and an astringent taste. Highly soluble in water and alcohol, it is used as a mordant in dyeing, in the manufacture of ink, for sizing paper and silk, in tanning, for clarifying beer and wine, and for many other commercial purposes.

2. Cross References. Acids, Organic, General.

3. Effects Upon Beneficial Uses.

a. Domestic Water Supplies. Tannic acid has a high chlorine demand and when chlorinated a concentration of 17.1 mg/l gave a sweetish odor (362). Concentrations of 2.0 to 4.0 mg/l give water a woody taste and odor (701).

b. Industrial Water Supplies. To prevent the formation of scale in boilers, 3.0 to 5.0 mg/l of tannic acid have been added to boiler feed waters (1363) and tannins such as quebracho have proved satisfactory for prevention of embrittlement of locomotive boilers (824).

c. Fish and Other Aquatic Life. The lethal doses reported for fish vary widely, depending on the species tested and the conditions of the experiment. At least 0.4 mg/l is required to affect most fish and some species can survive 10 mg/l or more, according to Westfall and Ellis (701); yet Ellis (313) reports that 10 mg/l in hard water was not injurious in 100 hours to goldfish, but that 100 mg/l killed in 9 to 20 hours. Belding (359) quotes references to the effect that the lethal doses to kill in 24 hours were 6.25 mg/l for trout, 71 mg/l for minnows and 142 mg/l for goldfish. Schaut (362) found that minnows lost their appetite in 17.1 mg/l of tannic acid but did not die.

Using highly turbid water and the mosquito-fish (*Gambusia affinis*) as the test organism, Wallen et al. (2940) found the 24- and 48-hour TL_m for tannic acid to be 41 mg/l while the 96-hour TL_m was 37 mg/l. The addition of tannic acid increased the turbidity from an initial 135 mg/l to 170 mg/l, but lowered the pH only from 7.3 to 6.7. The State of Washington Department of Fisheries (2091) found the critical level for young chinook salmon to be 1.73 to 2.85 mg/l for a 72-hour exposure in flowing fresh water and below 1.70 mg/l in flowing sea water.

According to Doudoroff and Katz (361), tannic acid can be toxic to fish without lowering the pH to 5.0. Toxicity is then attributable chiefly to the undissociated acid in solution and hence pH is not a reliable index of dangerous pollution.

In Lake Erie water, according to Anderson (358) the threshold concentration for immobilization of *Daphnia magna* after prolonged exposure at 25°C was 26 mg/l, but it may be as low as 3.0 mg/l.

TARTARIC ACID AND TARTRATES $COOH(CHOH)_2COOH$

Tartaric acid occurs in many fruits, generally in the form of calcium, magnesium, or potassium tartrate. It is produced commercially from argols or wine-lees that are formed in the production of wine. Highly soluble in water, it is used in baking powders, dyeing and printing fabrics, tanning, and many other commercial processes.

The toxicity of tartaric acid to fish and aquatic life depends on the hardness and buffering action of the water. Doudoroff and Katz (361) maintain that tartaric acid can be directly toxic to fully developed fish only when it lowers the pH value to 5.0 or lower and Cambosu (833) points out that the disinfecting action of tartaric acid is lowest in hard water owing to the precipitation of insoluble calcium tartrate.

In hard water, 200 mg/l of tartaric acid was not lethal to goldfish after 100 hours of exposure but in soft water 100 mg/l killed them in three hours. In hard water, 1000 mg/l killed in three to four hours, according to Ellis (313).

In Lake Erie water at 25°C, Anderson (358) shows that the threshold concentration of tartaric acid for immobilization of *Daphnia magna* after prolonged exposure was 135 mg/l. For sodium tartrate, the threshold concentration was 3150 mg/l (352), and the toxicity was attributed to factors other than osmotic pressure. Because tartrates are salts of a weak acid, their addition to water would be expected to raise rather than lower the pH value.

The threshold of toxicity of sodium tartrate to the flatworm *Polycelis nigra* at 15 to 18°C was about 9600 mg/l of tartrate, according to Jones (354).

TARS

1. General. The references abstracted herein deal primarily with tar on tarred roads and the effects of such tar upon nearby streams as a result of rainfall, leaching action, and drainage. For a more thorough treatment of coal tar and its constituents, see the cross references, especially Oil-Petroleum.

2. Cross References. Acridine, Cresols, Cresylic Acid, Hydrocarbons, Naphthalene, Oil-Petroleum, Phenanthrene, Phenol, Pyridine, Quinoline, Thiophene, Xylene, and similar compounds.

3. Effects Upon Beneficial Uses.

a. Domestic Water Supplies. Test sections of tarred roads were washed with distilled water equal to one inch of rainfall and the chlorinated run-off waters were tested for tastes and odors, according to Carpenter and

c. Fish and Other Aquatic Life. Using water from the River Havel, from which the test organisms were recovered, Bringmann and Kuhn (2158, 3343) studied the threshold effects of tungsten added as sodium tungstate. For *Daphnia* the median threshold effect during 48-hour exposure at 23°C occurred at 350 mg/l of tungsten; for *Scenedesmus* at 24°C for 4 days the median threshold level was 110 mg/l as tungsten; for *Microregma* it was 502 mg/l as tungsten; and for *Escherichia coli* at 27°C it was at 167 mg/l of tungsten.

TURBIDITY

1. General. The turbidity of water is attributable to suspended and colloidal matter, the effect of which is to disturb clearness and diminish the penetration of light. Turbidity may be caused by micro-organisms or organic detritus; silica or other mineral substances including zinc, iron, and manganese compounds; clay or silt; or sawdust, fibers, or other materials, either as a result of natural processes or erosion or as a result of the addition of domestic sewage or wastes from various industries, such as mining, dredging, logging, pulp and paper manufacturing, and others.

The turbidity of a water sample is a measure of the extent to which the intensity of light passing through is reduced by the suspended matter. Although in some of the literature the terms "turbidity" and "suspended solids" (or other equivalent words, such as "suspended matter" and "suspensoids") are used almost synonymously, the degree of turbidity is not equal to the concentration (or quantity) of suspended solids, but is an expression of only one effect of suspended solids upon the character of the water.

The measurement of turbidity recommended by Standard Methods for the Examination of Water and Wastewater (469) is based upon a comparison of the amount of light passing through the given water sample with that passing through a standard sample. Turbidity is measured in standard units, defined in terms of the depth of water to which a candle flame can be clearly distinguished.

In his studies of waters suitable for fish, Ellis has introduced another system of measurement based upon the determination of the depth at which the light that penetrates the water is reduced to one-millionth of its intensity at the surface. This depth is designated the "millionth intensity depth" of light penetration, abbreviated as m.i.d. (313, 790, 801). The penetration of light, is also measured by the Secchi disk and by the hydrophotometer.

2. Cross References. Suspended Solids, Silt, Settleable Solids.

3. Effects Upon Beneficial Uses.

a. Domestic Water Supplies. The 1962 USPHS Drinking Water Standards (2036) specify that turbidity shall not exceed 5 units. Bean (1745) has proposed a much stricter limit, viz, 0.1 units for ideal drinking water. State and interstate agencies that have adopted systems of stream classification and standards sometimes designate limits for turbidity in streams that are used for domestic water supply, with values ranging from 5 to 250 units but most commonly the limits of turbidity are expressed in general terms. For further details of state and interstate standards, see Chapter III.

b. Industrial Water Supplies. Turbidity is undesirable in waters for laundries, ice making, bottled beverages and brewing, textiles, pulp and paper, steam boilers and turbine operation, and other industrial processes.

A summary of the limiting values as recommended in the literature is shown in the following table:

RECOMMENDED LIMITS OF TURBIDITY FOR VARIOUS INDUSTRIAL USES OF WATER

Industrial Use	*Turbidity Units*	*Reference*
Beverages	1–2	463, 184, 152
Food products	10	173
Breweries	1–10	186, 152
Boiler feed water	1–20 (according to pressure)	179
Paper and pulp		
Alkaline pulps	25	245
High-grade paper	5–25	552, 879
Fine writing and book paper	10	350, 551
Unbleached kraft paper	100	351
Bleached kraft paper	40	351
Groundwood paper	50	244
Textiles		
Nitrocellulose	0.5	2405
Rayon	1	560, 405
Cotton	25	256
Cotton (callaway mills)	0.3–0.5	255
Baking	10	152
Cooling water	50	152
Ice making	1–5	152
Tanning	20	152

c. Fish and Other Aquatic Life. Excessive turbidity in water affects fish in the following ways:

1. By interfering with the penetration of light, it militates against photosynthesis and thereby decreases the primary productivity upon which the fish-food organisms depend (313, 347, 664, 684, 781, 790, 800, 880, 881, 2780, 3742, 3743). As a consequence, fish production is diminished.

2. At very high concentrations, the particulate matter that produces turbidity can be directly lethal (780, 881, 2409, 3210, 3659, 3745).

3. By excluding light, turbidity makes it difficult for fishes to find food. Conversely, smaller fish may be similarly protected from predators (560, 882, 2780, 3743, 3746).

4. Turbidity modifies the temperature structure of ponds. Bottom temperatures are generally lower in turbid ponds than in clear ones (2731). In many ponds, lower temperatures mean lower productivity.

With respect to productivity, Buck (3742) investigated several farm ponds, hatchery ponds, and reservoirs over a two-year period. For farm ponds, the following results were obtained:

	Clear Ponds	*Intermediate Ponds*	*Muddy Ponds*
Average turbidity, units	less than 25	25-100	over 100
Fish yield, lbs per acre	161.5	94	20.3
Ratio of volumes of net plankton	12.8	1.6	1

In reservoirs, the average volume of plankton in surface waters was 13.8 times greater in the clear reservoir than in the turbid one.

With respect to direct lethality van Oosten (881) concluded from a literature survey that average turbidities

NTU = log(L

aigh as 200 units are harmless to fish. Ward (560, 882) has reported that turbidity as high as 245 units is not harmful to fish. Van Oosten (881) maintains that fish thrive in water with turbidities that range over 400 units and average 200 units. Kemp (780) states that turbidities of 3000 units are considered dangerous to fish when maintained over a 10-day period. In the constantly turbid waters of the Powder River, Oregon (from 1000 to 2500 units), eyed rainbow trout eggs were destroyed within a 6-day period (3659).

Wallen (3745) made a comprehensive study of the effects of turbidity produced from montmorillonite clay with respect to 16 species of fish. His results are summarized as follows:

Common Name of Fish	Range of Temperature °C	Average Time of Test, Days	Fatal Turbidity in mg/l Minimum	Average	Maximum
Golden shiner	20-29	7.1	55,000	166,000	200,000
Mosquito fish	20-28	16.5	120,000	181,500	225,000
Goldfish	24-32	12.0	60,000	167,000	270,000
Green sunfish	20-29	5.5	50,000	169,500	225,000
Black bullhead	22-62	17.0	175,000	222,000	270,000
Red shiner	22-32	9.0	175,000	183,000	190,000
River carpsucker	24-32	9.6	105,000	165,000	250,000
Largemouth bass	16-32	7.9	52,000	101,000	150,000
Pumpkin seed	16-23	13.0	16,500	66,000	120,000
Orangespotted sunfish	22-32	10.0	100,000	157,000	200,000
Channel catfish	24-32	8.3	—	85,000	—
Blackstrip top-minnow	22-26	19.3	—	175,000	—
Black crappie	28-26	2.0	—	145,000	—
Rock bass	—	3.5	—	38,250	—

At turbidities causing death, the opercular cavities were found to be matted with soil and the gills had a layer of soil on them. Symptoms of distress generally appeared at turbidities much lower than those producing death. Harmful effects were observed as the turbidity approached 20,000 units.

Wallen (2780) also found that bullfrog tadpoles and crayfish can withstand over 150,000 units of turbidity without death under laboratory conditions.

Ellis' study of more than 5000 samples of interior waters has indicated a general range of turbidity values from about 84 to 53,887 millimeters, as millionth intensity depth. Only in very clear mountain streams, however, was the figure 53,887 mm; in polluted streams protected from undue erosion, the m.i.d. never dropped below 6000 mm even after heavy rains. In swamp areas, with little erosion silt, the m.i.d. varied from 1000 to 20,000 mm. Ellis has recommended that the millionth intensity depth of water for good fish production should exceed 5000 mm (5 meters) (308, 313, 790, 801).

d. Shellfish Culture. It has been reported that excessive turbidity inhibits feeding and restricts the growth of some species of oysters and fresh-water mussels (331, 804). On the other hand, studies by Lunz have indicated that increased turbidity of water in the vicinity of dredging operations in no way increased the mortality of oysters (795). It is also a fact that some oysters live and propagate successfully in waters carrying large quantities of silt and clay (804). Yet, according to Korringa (1448), silt and other turbidity-producing substances such as kaolin or chalk at concentrations by weight as low as 0.1 mg/l reduced the rate of pumping by oysters.

TURPENTINE

(see Resins)

URANIUM

1. General. Uranium and many of its salts are reported to be highly toxic (364, 2129, 2972), but the literature does not always confirm this observation. In addition to its significance in atomic energy, uranium has been used in photography, in glazing and painting porcelain, and in chemical processes. Many of the salts of uranium are freely soluble in water and, hence, they may constitute a health hazard if present in a water supply. Roubault et al. (3744), however, imply from a limited study of certain areas that natural uranium in the soil, which is absorbed by persons through the water and foodstuffs grown on the land, may be a limiting factor in the incidence of leukemia.

Most of the literature concerning uranium in water relates to the radiological hazards. Results are expressed in terms of radiation parameters rather than in concentrations of uranium in mg/l. Such references are covered in Chapter VIII, Radioactivity. The criteria in the following paragraphs deal with chemical effects without reference to radiological hazards.

2. Cross References. See Radioactivity, Chapter VIII.

3. Effects Upon Beneficial Uses.

a. Domestic Water Supply. The Division of Industrial Hygiene, Ontario Department of Health, has suggested a maximum allowable concentration for neutral uranium in drinking water of 500 to 1000 micrograms per liter (3747).

b. Stock and Wildlife Watering. In tests using two uranium-fluorine compounds, the insoluble uranium tetrafluoride, UF_4, and and soluble uranyl fluoride, UO_2F_2, Maynard et al. (3748) found that 2 percent of UF_4 and 0.05 percent of UO_2F_2 had no toxic effect in the diet of rats. Interference with growth and a depressed body weight were observable during the second year in animals on dietary concentrations of 20 percent UF_4 and 0.15 percent of UO_2F_2. Some tendency toward anemia was discovered in male rats fed diets containing 0.25 and 0.5 percent UO_2F_2. While only mild injury was found in the kidneys of rats whose diets contained 20 percent of UF_4, definite renal tubular damage was found in rats fed diets of 0.15 percent or more of UO_2F_2. In a one-year feeding experiment on dogs the same authors observed doses of 0.01 g/kg UO_2F_2 and 1.0 g/kg UF_4 were without effect on body weight, but animals fed 5 g/kg of UF_4 did not gain weight as almost all other animals did. The minimum dose given for one year that provided unmistakable renal damage in dogs was 0.025 g/kg/day for UO_2F_2 and 0.2 g/kg/day for UF_4. Moxan and Rhian (1481) reported that a concentration of 5 mg/l of uranium in the drinking water increased mortality among rats being fed a ration containing 11 mg/l of selenium.

c. Fish and Other Aquatic Life. Hoffman (769) examined the water of the River March between Czechoslovakia and Germany and found that it contained 0.001 mg/l of uranium. Much of this uranium was absorbed by algae but it was not toxic to them. The alga *Ochromonas* was reported to concentrate natural uranium (U-238) by a factor of 330 from water in 48 hours (3386). In a study of the Black Sea, Pshenim (2919) found yeasts to be more active than bacteria in taking up uranium.