大学环境教育丛书

影印版

W. Wesley Eckenfelder, Jr.

Industrial Water Pollution Control

(Third Edition)

工业水污染控制

（第3版）

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出版前言

在跨入21世纪之际，面临不断恶化的生存环境，人类清醒地认识到要走可持续发展之路。而发展环境教育是解决环境问题和实施可持续发展战略的根本。高等学校的环境教育，是提高新世纪建设者的环境意识，并向社会输送环境保护专门人才的重要途径。为了反映国外环境类教材的最新内容和编写风格，同时也为了提高学生阅读专业文献和获取信息的能力，我们精选了一些国外优秀的环境类教材，组成大学环境教育丛书（影印版），本书即为其中的一册。所选教材均在国外被广泛采用，多数已再版，书中不仅介绍了有关概念、原理及技术方法，给出了丰富的数据，还反映了作者不同的学术观点。

我们希望这套丛书能对高等院校师生和广大科技人员有所帮助，同时对我国环境教育的发展作出贡献。

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ABOUT THE AUTHOR

W. WESLEY ECKENFELDER, JR., received degrees in civil engineering from Manhattan College and environmental engineering from Pennsylvania State University and New York University. In 1990 he received an honorary D.Sc. degree from Manhattan College. He was associate professor at Manhattan College, professor at the University of Texas, and is presently Emeritus Distinguished Professor of Environmental Engineering at Vanderbilt University. He was a founder of the consulting firm of Hydroscience, Inc., a partner in Weston Eckenfelder & Associates (now Roy F. Weston, Inc.) and has served as board chairman of AWARE Incorporated and Eckenfelder, Inc.

He has developed continuing education courses in water pollution control for Manhattan College, the University of Texas, Vanderbilt University, the University of Queensland, Australia, the American Institute of Chemical Engineers, and the Chemical Manufacturers Association. He has organized courses and workshops in 17 countries in Asia, Europe, Africa and Latin America.

He has served as consultant to over 150 industries, municipalities, consulting firms, and governmental agencies.

He is an author or editor of 31 books and over 200 technical papers in water pollution control including *Industrial Water Pollution Control,* McGraw-Hill, (1967 and 1989); *Principles of Water Quality Management,* CBI Publishing (1980); and *Water Pollution Control,* Jenkins Publishing Co. (1978). These books have been translated into Japanese and Chinese and one into French and Italian. Professor Eckenfelder is on numerous editorial boards including *Water Technology Letters* (U.K.) and *Hazardous Waste and Hazardous Materials.*

He is a member of numerous technical societies including the Water Pollution Control Federation (honorary member), the American Institute of Chemical Engineers, and the American Society of Civil Engineers. He is an honorary member of the International Association on Water Quality.

In 1974 he was awarded the Synthetic Organic Chemicals Manufacturers Association gold medal for excellence in environmental chemistry, in 1957 the Rudolfs Medal, and in 1981 the Thomas Camp Medal from the Water Pollution Control Federation. In 1998 he received the Lawrence Cecil Award from the American Institute of Chemical Engineers. In 1999 he received the Gordon Maskew Fair Award from the American Academy of Environmental Engineers.

He is a registered Professional Engineer in the State of Texas.

PREFACE

It has been 30 years since this book was first published and 10 years since the second edition. During that period not only have regulations undergone a vast change, but conventional technologies have been further refined and new technologies have been developed to meet increasingly more stringent water quality criteria. Effluent limitation on specific priority pollutants and toxicity to aquatic organisms have rendered many of the older conventional treatment facilities obsolete. The challenge today is to meet these new requirements in a way that is both environmentally acceptable and cost-effective.

In order to address these new challenges, the present volume reviews the existing theory and addresses the application of state-of-the-art technology to the solution of today's problems in industrial water pollution control.

Of necessity, this book does not develop the detailed principles or the theory of processes applicable to specific areas of water pollution control. Rather it stresses the application of these theories to specific industrial problems. Publications and texts are referenced in the bibliography for the reader who wishes a more detailed development of the theory.

Where applicable, case histories are used to illustrate the application of technology to specific industrial applications. Problems are drawn from field experience.

This book is intended as a text for the student in courses related to industrial water pollution control and as a guide for the engineer in industry, governmental agencies, and consulting engineering firms involved in developing state-of-the-art solutions to industrial water pollution control problems.

While all specific problems cannot be answered in one text, it is hoped that this volume will provide guidance and direction to those faced with the increasingly more complex solutions of water pollution control.

Special thanks to Dr. Alan Bowers of Vanderbilt University for his contribution to the chapter on chemical oxidation.

I would like to express my thanks for many useful comments and suggestions provided by colleagues who reviewed this text during the course of its development, especially to Robert W. Okey, the University of Utah; Bruce DeVantier, Southern Illinois University at Carbondale; Peter Fox, Arizona State University; Clifford W. Randall, Virginia Polytechnic University; and Paul M. Berthouex, University of Wisconsin–Madison.

W. Wesley Eckenfelder

CONTENTS

1

SOURCE AND CHARACTERISTICS OF INDUSTRIAL WASTEWATERS

1.1
UNDESIRABLE WASTEWATER CHARACTERISTICS

Depending on the nature of the industry and the projected uses of the waters of the receiving stream, various waste constituents may have to be removed before discharge. These may be summarized as follows:

1. Soluble organics causing depletion of dissolved oxygen. Since most receiving waters require maintenance of minimum dissolved oxygen, the quantity of soluble organics is correspondingly restricted to the capacity of the receiving waters for assimilation or by specified effluent limitations.
2. Suspended solids. Deposition of solids in quiescent stretches of a stream will impair the normal aquatic life of the stream. Sludge blankets containing organic solids will undergo progressive decomposition resulting in oxygen depletion and the production of noxious gases.
3. Priority pollutants such as phenol and other organics discharged in industrial wastes will cause tastes and odors in the water and in some cases are carcenogenic. If these contaminants are not removed before discharge, additional water treatment will be required.
4. Heavy metals, cyanide, and toxic organics. The EPA has defined a list of toxic organic and inorganic chemicals that now appear as specific limitations in most permits. The identified priority pollutants are listed in Table 1.1.
5. Color and turbidity. These present aesthetic problems even though they may not be particularly deleterious for most water uses. In some industries, such as pulp and paper, economic methods are not presently available for color removal.
6. Nitrogen and phosphorus. When effluents are discharged to lakes, ponds, and other recreational areas, the presence of nitrogen and phosphorus is particularly undesirable since it enhances eutrophication and stimulates undesirable algae growth.

TABLE 1.1
EPA list of organic priority pollutants

Compound name

1. Acenaphthene†
2. Acrolein†
3. Acrylonitrile†
4. Benzene†
5. Benzidine†
6. Carbon tetrachloride† (tetrachloromethane)

Chlorinated benzenes (other than dichlorobenzenes)

7. Chlorobenzene
8. 1,2,4-Trichlorobenzene
9. Hexachlorobenzene

Chlorinated ethanes† (including 1,2-dichloroethane, 1,1,1-trichloroethane, and hexachloroethane)

10. 1,2-Dichloroethane
11. 1,1,1-Trichloroethane
12. Hexachloroethane
13. 1,1-Dichloroethane
14. 1,1,2-Trichloroethane
15. 1, 1,2,2-Tetrachloroethane
16. Chloroethane (ethyl chloride)

Chloroalkyl ethers† (chloromethyl, chloroethyl, and mixed ethers)

17. Bis(chloromethyl) ether
18. Bis(2-chloroethyl) ether
19. 2-Chloroethyl vinyl ether (mixed)

Chlorinated napthalene†

20. 2-Chloronapthalene

Chlorinated phenols† (other than those listed elsewhere; includes trichlorophenols and chlorinated cresols)

21. 2,4,6-Trichlorophenol
22. *para*-Chloro-*meta*-cresol
23. Chloroform (trichloromethane)†
24. 2-Chlorophenol†

Dichlorobenzenes†

25. 1,2-Dichlorobenzene
26. 1,3-Dichlorobenzene
27. 1,4-Dichlorobenzene

Compound name

Dichlorobenzidine†

28. 3,3′-Dichlorobenzidine

Dichloroethylenes† (1,1-dichloroethylene and 1,2-dichloroethylene)

29. 1,1-Dichloroethylene
30. 1,2-*trans*-Dichloroethylene
31. 2,4-Dichlorophenol†

Dichloropropane and dichloropropene†

32. 1,2-Dichloropropane
33. 1,2-Dichloropropylene (1,2-dichloropropene)

34. 2,4-Dimethylphenol†

Dinitrotoluene†

35. 2.4-Dinitrotoluene
36. 2,6-Dinitrotoluene
37. 1,2-Diphenylhydrazine†
38. Ethylbenzene†
39. Fluoranthene†

Haloethers† (other than those listed elsewhere)

40. 4-Chlorophenyl phenyl ether
41. 4-Bromophenyl phenyl ether
42. Bis(2-chloroisopropyl) ether
43. Bis(2-chloroethoxy) methane

Halomethanes† (other than those listed elsewhere)

44. Methylene chloride (dichloromethane)
45. Methyl chloride (chloromethane)
46. Methyl bromide (bromomethane)
47. Bromoform (tribromomethane)
48. Dichlorobromomethane
49. Trichlorofluoromethane
50. Dichlorodifluoromethane
51. Chlorodibromomethane
52. Hexachlorobutadiene†
53. Hexachlorocyclopentadiene†
54. Isophorone†
55. Naphthalene†
56. Nitrobenzene†

TABLE 1.1 *(continued)*

Compound name	Compound name
Nitrophenols† (including 2,4-dinitrophenol and dinitrocresol)	87. Trichloroethylene†
57. 2-Nitrophenol	88. Vinyl chloride† (chloroethylene)
58. 4-Nitrophenol	
59. 2,4-Dinitrophenol†	Pesticides and metabolites
60. 4,6-Dinitro-*o*-cresol	89. Aldrin†
	90. Dieldrin†
Nitrosamines†	91. Chlordane† (technical mixture and metabolites)
61. *N*-Nitrosodimethylamine	
62. *N*-Nitrosodiphenylimine	DDT and metabolites†
63. *N*-Nitrosodi-*n*-propylamine	92. 4,4′-DDT
64. Pentachlorophenol†	93. 4,4′-DDE (*p,p*′-DDX)
65. Phenol†	94. 4,4′-DDD (p,p′-TDE)
Phthalate esters†	Endosulfan and metabolites†
66. Bis(2-ethylhexyl) phthalate	95. α-Endosulfan-alpha
67. Butyl benzyl phthalate	96. β-Endosulfan-beta
68. Di-*n*-butyl phthalate	97. Endosulfan sulfate
69. Di-*n*-octyl phthalate	
70. Diethyl phthalate	Endrin and metabolites†
71. Dimethyl phthalate	98. Endrin
	99. Endrin aldehyde
Polynuclear aromatic hydrocarbons (PAH)†	
	Heptachlor and metabolites†
72. Benzo(a)anthracene (1,2-benzanthracene)	100. Heptachlor
	101. Heptachlor epoxide
73. Benzo(a)pyrene (3,4-benzopyrene)	
74. 3,4-Benzofluoranthene	Hexachlorocyclohexane (all isomers)†
75. Benzo(k)fluoranthene (11,12-benzofluoranthene)	102. α-BHC-alpha
	103. β-BHC-beta
76. Chrysene	104. γ-BHC (lindane)-gamma
77. Acenaphthylene	105. δ-BHC-delta
78. Anthracene	
79. Benzo(ghi)perylene (1,12-benzoperylene)	Polychlorinated biphenyls (PCB)†
	106. PCB-1242 (Arochlor 1242)
80. Fluorene	107. PCB-1254 (Arochlor 1254)
81. Phenanthrene	108. PCB-1221 (Arochlor 1221)
82. Dibenzo(a,h)anthracene (1,2,5,6-dibenzanthracene)	109. PCB-1232 (Arochlor 1232)
	110. PCB-1248 (Arochlor 1248)
83. Indeno (1,2,3-cd) pyrene (2,3-*o*-phenylenepyrene)	111. PCB-1260 (Arochlor 1260)
	112. PCB-1016 (Arochlor 1016)
84. Pyrene	113. Toxaphene†
85. Tetrachloroethylene†	114. 2,3,7,8-Tetrachlorodibenzo-*p*-dioxin (TCDD)†
86. Toluene†	

†Specific compounds and chemical classes as listed in the consent degree.

7. Refractory substances resistant to biodegradation. These may be undesirable for certain water-quality requirements. Refractory nitrogen compounds are found in the textile industry. Some refractory organics are toxic to aquatic life.
8. Oil and floating material. These produce unsightly conditions and in most cases are restricted by regulations.
9. Volatile materials. Hydrogen sulfide and volatile organics will create air-pollution problems and are usually restricted by regulation.
10. Aquatic toxicity. Substances present in the effluent that are toxic to aquatic species and are restricted by regulation.

1.2
PARTIAL LIST OF REGULATIONS WHICH AFFECT WASTEWATER TREATMENT REQUIREMENTS WITHIN THE UNITED STATES

It is not the intent of this book to discuss federal and state regulations, but a brief summary of present regulatory requirements relative to industrial water pollution control will serve as guidance to the reader. Details of these regulations can be found in the cited Code of the Federal Register (CFR) as noted.

Air

NESHAP

- Regulates carcinogenic VOCs to mass loading and concentration limits. For example, in the case of benzene anything in excess of 10 mg/l concentration in the wastewater or 10 Mg/yr. Requires off-gas capture and treatment until such limits are achieved.

National Emission Standards for Hazardous Air Pollutants (40 CFR, part 61)

- Regulates 60 VOCs to mass loading and concentration limits. Requires off-gas capture and treatment until a required percent removal is achieved.

Occupational Safety and Health Administration Standards

- Regulates hydrogen sulfide and contaminants which pose exposure risks.

Liquid

Federal Industry Point Source Category Limits (40 CFR, part 405-471)

- Mass-based for raw material processing, e.g., pulp and paper, and concentration-based for synthetic chemicals and pharmaceuticals for conventional pollutants.
- Concentration-based limits for nonconventional pollutants (metals and priority pollutants).

Regional Initiatives (e.g., Great Lakes Initiative)

- For example, concentration-based limits for total phosphorus.

State Water Quality Standards

- Limits for pollutants based on design receiving stream low flow (i.e., 7–Q10, the average 7-day low flow every ten years) for the use classification.

Local Pretreatment Limits (USEPA, PB92-129188, December 1987)

- Those regulated under point source categories, plus those required to ensure POTW (publicly owned treatment works) effluent compliance.

1.3 SOURCES AND CHARACTERISTICS OF WASTEWATERS

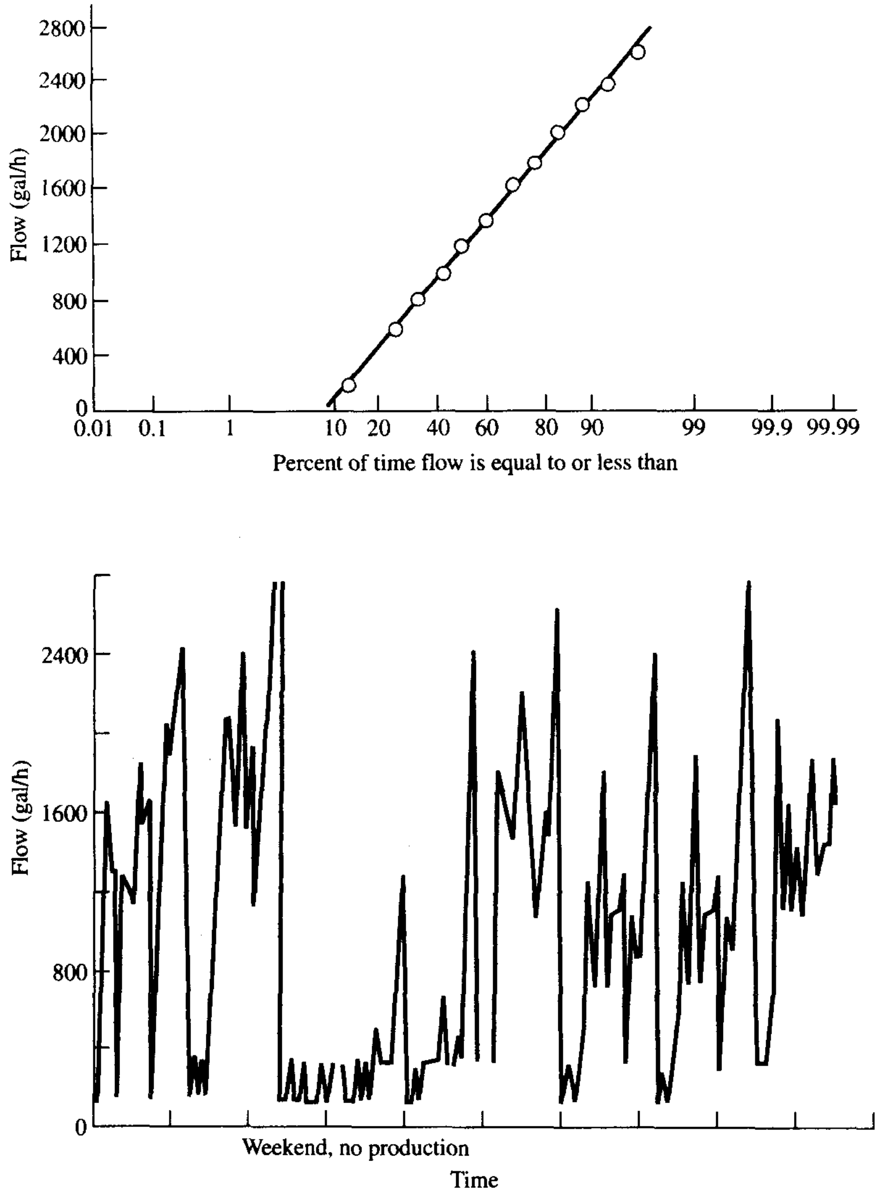
The volume and strength of industrial wastewaters are usually defined in terms of units of production (e.g., gallons per ton† of pulp or cubic meters per tonne‡ of pulp and pounds of BOD per ton of pulp or kilograms of BOD per tonne of pulp for a pulp-and-paper-mill waste) and the variation in characteristic by a statistical distribution. In any one plant there will be a statistical variation in wasteflow characteristic. The magnitude of this variation will depend on the diversity of products manufactured and of process operations contributing waste, and on whether the operations are batch or continuous. Good housekeeping procedures to minimize dumps and spills will reduce the statistical variation. Plots showing the variation in flow resulting from a sequence of batch processes are shown in Fig. 1.1. Variation in waste flow and characteristics within a single plant are shown in Fig. 1.2.

Wide variation in waste flow and characteristics will also appear among similar industries, e.g., the paperboard industry. This is a result of differences in housekeeping and water reuse as well as of variations in the production processes. Very few industries are identical in their sequence of process operations; as a result, an industrial waste survey is usually required to establish waste loadings and their variations. Variations for several industries are shown in Table 1.2. The variation in suspended solids and BOD (biochemical oxygen demand) discharge from 11 paperboard mills is shown in Fig. 1.3.

1.4 INDUSTRIAL WASTE SURVEY

The industrial waste survey involves a procedure designed to develop a flow-and-material balance of all processes using water and producing wastes and to establish the variation in waste characteristics from specific process operations as well as from the plant as a whole. The results of the survey should establish possibilities for water conservation and reuse and finally the variation in flow and strength to undergo wastewater treatment.

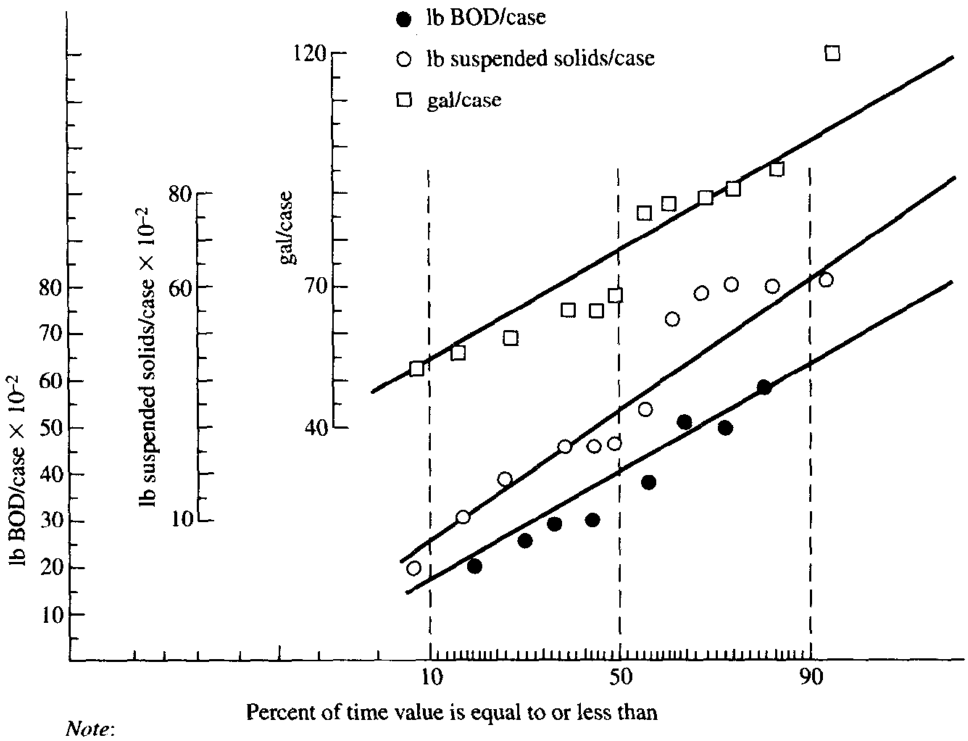
†ton = 2000 lb.
‡tonne = 1000 kg.



Note: gal/h = 3.78×10^{-3} m^3/h

FIGURE 1.1
Variation in flow from a batch operation.

The selected method of flow measurement will usually be contingent on the physical location to be sampled. When the waste flows through a sewer, it is frequently possible to measure the velocity of flow and the depth of water in the sewer and calculate the flow from the continuity equation. Since $Q = AV$, the area in a partially filled circular sewer can be determined given the depth from Fig. 1.4. This method applies only for partially filled sewers of constant cross section. The average velocity of flow can be estimated as 0.8 of the surface velocity timed from a floating object between manholes. More accurate measurements can be obtained by the use of a current meter. In gutters or channels, either a small weir can be constructed or



Note:
lb = 0.45 kg
gal = 3.78 × 10^{-3} m^3

FIGURE 1.2
Daily variation in flow and characteristics: tomato waste.

TABLE 1.2
Variation in flow and waste characteristics for some representative industrial wastes

	Flow, gal/production unit % frequency			BOD, lb/production unit % frequency			Suspended solids, lb/production unit % frequency		
Waste	**10**	**50**	**90**	**10**	**50**	**90**	**10**	**50**	**90**
Pulp and paper†	11,000	43,000	74,000	17.0	58.0	110.0	26.0	105.0	400.0
Paperboard†	7,500	11,000	27,500	10	28	46	25	48	66
Slaughterhouse‡	165	800	4,300	3.8	13.0	44	3.0	9.8	31.0
Brewery§	130	370	600	0.8	2.0	44	0.25	1.2	2.45
Tannery¶	4.2	9.0	13.6	575††	975	1400	600††	1900	3200

† Tons paper production.
‡ 1000 lb live weight kill.
§ bbl beer.
¶ Pounds of hides; sulfides as S vary from 260 mg/l (10%) to 1230 mg/l (90%).
†† As mg/l.

Note:
gal = 3.78 × 10^{-3} m^3
lb = 0.45 kg
ton = 907 kg
bbl beer = 0.164 m^3