HANDBOOK OF ADVANCED WASTEWATER TREATMENT

Second Edition

Russell L. Culp
George Mack Wesner
Gordon L. Culp

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SECOND EDITION

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Van Nostrand Reinhold Environmental Engineering Series

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Preface

The first edition of *Advanced Wastewater Treatment*, which was published in 1971, was the first book available in this relatively new field of engineering endeavor. It has found wide acceptance and use as a reference by design engineers and pollution control authorities. It is used as a text or reference in graduate and undergraduate environmental engineering courses in universities throughout the world. The book is also now available in a Japanese-language translation.

The book was prepared originally in recognition of the fact that the control of water pollution in the United States and many other countries required treatment techniques far more efficient and reliable than the conventional processes of the past. At that time, there was a substantial gap between available, proven technology and that which had actually been brought to bear by the technical and political forces seeking to control pollution. One purpose of the book was to present the basic principles, engineering design information, and actual operating experiences related to treatment techniques which were relatively new to the wastewater treatment field, with the hope that it would assist in closing the then existing gap in practical application of new technology.

Since 1971, advanced wastewater treatment processes have been employed to a much greater extent than predicted by the most optimistic forecasts of that time. They have been used in a wide variety of ways to upgrade the quality of effluents, improve stream conditions, facilitate wastewater reuse, and improve the reliability of treatment plants. The national goal of zero discharge of pollutants by 1983 established in Public Law 92-500 gives added impetus to advanced wastewater treatment (AWT). Although this goal has yet to be quantitatively defined, there is little doubt that Public Law 92-500 reflects a national philosophy which will stimulate the use of advanced wastewater treatment techniques.

Since the original publication, there has been much progress in refining

AWT processes and in developing new methods, a great deal more experience has been gained in the design and operation of AWT plants, and some material in the book has become outdated. In recognition of this situation, a second edition has been prepared. It has been expanded from 300-odd to over 500 pages. A third author, George Mack Wesner, has joined the authors of the first edition. Dr. Wesner's training and experience in this field broadens the base of information which has been incorporated in the revision and expansion of the text. The discussion of treatment methods, as before, is restricted to those designed to remove pollutants normally remaining after conventional secondary treatment.

The major changes in the second edition are the expansion of design examples and case histories; the addition of new chapters on biological nitrogen removal, selective ion exchange, breakpoint chlorination, disinfection, chemical sludge handling, land treatment, demineralization, and estimating costs; and new information on the use and regeneration of powdered activated carbon.

Special thanks are expressed to the consulting engineers, equipment manufacturers, and government officials who were so generous in supplying illustrative material for the text. The encouragement offered by our families and colleagues throughout the preparation of this second edition was essential to its completion.

RUSSELL L. CULP
GEORGE MACK WESNER
GORDON L. CULP

August 11, 1976

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Purpose and benefits of advanced wastewater treatment

PURPOSE

Advanced wastewater treatment technology is designed to remove pollutants which are not adequately removed by conventional secondary treatment processes, previously considered "complete" processes. These pollutants may include soluble inorganic compounds such as phosphorus or nitrogen, which may support algal growths in receiving waters; organic materials contributing biochemical oxygen demand (BOD), chemical oxygen demand (COD), color, taste, and odor; bacteria; viruses; colloidal solids contributing turbidity; or soluble minerals which may interfere with subsequent reuse of the wastewater. The purpose of advanced waste treatment may be to alleviate pollution of a receiving watercourse or to provide a water quality adequate for reuse, or both. The advanced waste treatment process may be used following or in conjunction with the conventional secondary process, or it may replace secondary treatment entirely.

Increasing population and increasing water use has already created, in many locations, pollution problems which cannot be adequately solved by secondary treatment. It is inevitable that the number of these instances will increase in the future. It is also inevitable that the deliberate reuse of treated wastewaters will be required in order to meet future water demands. Indirect water reuse is already commonly practiced, with some estimates indicating that 40 percent of the United States population is using water that has been used at least once before for domestic or industrial purposes. This indirect reuse will also increase in the future. All of these factors indicate that use of advanced wastewater treatment techniques will become increasingly common.

PUBLIC ATTITUDE AND NATIONAL SIGNIFICANCE

The public attitude toward pollution control, which bordered on apathy during the first half of the twentieth century, has undergone drastic change in the early 1970s as part of the surge in public concern for the quality of the environment. The strong desire of the people for adequate pollution control programs is reflected in the overwhelming margins by which very large pollution control bond issues have carried. For example, the voters of the State of New York approved a $1 billion bond issue for pollution control in 1968 by a margin of four to one. The people of St. Louis approved a $95 million pollution bond issue by a five-to-one margin. These results reflect the intense public desire to improve our environment. Sincere and concerted public concern will be required over a long period of time to make the necessary changes in society to bring about significant improvements in our environment. Much more than clever technological advances will be needed. Major changes in our political, social, legal, and economic approaches to pollution control will be required.

All municipal wastewater could be completely eliminated as a source of pollution in the United States and converted to a quality adequate to provide a valuable water resource for many types of reuse at a national annual cost of only about one dollar per person per month.

CHARACTERISTICS OF SECONDARY EFFLUENTS

It is only a question of time before conventional secondary processes operating at their highest efficiency will be inadequate in a significant portion of the United States. Materials present in effluent from a properly operating secondary plant which may be of concern can be placed in the general categories of soluble organic compounds, soluble inorganic compounds, particulate solid material, and pathogenic organisms.

Organic Compounds

Efficient secondary processes employ biological treatment to remove essentially all of the soluble, biologically degradable organic material in municipal wastewaters. A portion of the soluble organics removed are converted to biological organic cell material which in turn, can exert oxygen demand in the effluent. Generally, the net removal of biodegradable organics is on the order of 90 percent. The remaining degradable organics will exert a demand on the oxygen resources of the receiving body of water which may or may not have an adverse effect, depending on the assimilative capacity of that body of water.

Nondegradable organics are, of course, not removed by secondary processes using biodegradation techniques. These organics can cause taste and odor problems in downstream water supplies. They also impart a color to the effluent which may make it unsuitable for many reuse applications and may make the receiving stream aesthetically unacceptable for recreation. In some cases, they may cause objectionable tastes in fish residing in the receiving watercourse. They may also pass through downstream water treatment plants or react with disinfectants added, causing as yet unknown long term physiological effects on downstream water users. In some cases, they may cause foam in a receiving stream, although the introduction of biodegradable detergents has done much to reduce this problem.

Inorganic Compounds

Phosphorus and nitrogen are two key elements required by algae for growth which are not significantly removed by conventional secondary processes. Phosphates also may interfere with the coagulation processes used in downstream water treatment plants. A major source of phosphorus is the phosphate builders used in modern detergents. The growth of algae in a receiving body of water may create aesthetically unacceptable conditions for recreation, may create taste and odor problems in downstream water supplies, may cause operating problems in downstream water filtration plants, and may create a significant oxygen demand during nighttime hours or after death of the algae. There remains some debate on the minimum phosphorus and nitrogen concentrations which will support objectionable algal growths. However, removal of phosphorus to a concentration of about 0.1 mg/l has reduced algal growths to an insignificant level in a reservoir made up solely of effluent from the South Lake Tahoe wastewater reclamation plant.

During use of water in a municipality, the mineral quality of the water is altered. Inorganic salts containing calcium, magnesium, sodium, potassium, chlorides, sulfates, and phosphates are among those added. Normal water treatment practices at downstream locations do not remove these salts. As a result, the dissolved solids content increases as a fixed supply source passes through several users in series. It is generally agreed that 500 mg/l of dissolved solids is the upper limit for palatable water. Excessive dissolved solids concentrations can cause laxative action in the user, although no harmful permanent physiological effects are known. Dissolved solids concentrations can also adversely affect irrigation use, industrial use, or stock and wildlife watering. Calcium and magnesium contribute to downstream water hardness.

Particulate Solids

Although an efficient secondary plant removes 90–95 percent of the incoming suspended solids (SS), much poorer removals occur all too frequently during "upsets" of the secondary plant due to poor operation, hydraulic or organic overloads, or mechanical failures. The 90–95 percent removal is not adequate for many reuse applications. Suspended solids can interfere with disinfection of the effluent, leading to the discharge of pathogenic organisms. In cases of gross secondary plant failures and small receiving streams, sludge deposits may result which can exert long-term oxygen demands in addition to being aesthetically unacceptable. The historically inconsistent performance of secondary plants is a major weakness which can be overcome with proper application of advanced waste treatment techniques to remove all suspended solids.

Pathogenic Organisms

Secondary processes provide substantial reductions in incoming viral and bacterial concentrations, but it has been shown that both viruses and bacteria

TABLE 1-1 Water Quality at Various Stages in Treatment

Quality Parameter	Raw Wastewater	EFFLUENT Primary	EFFLUENT Secondary
BOD (mg/l)	300	100	30
COD (mg/l)	480	220	40
SS (mg/l)	230	100	26
Turbidity (JU)*	250	150	50
MBAS (mg/l)**	7	6	2.0
Phosphorus (mg/l)	12	9	6
Coliform (MPN/100 ml)*	50 million	15 million	2.5 million

*JU = Jackson Units.
MBAS = Methylene blue active substance.
MPN = Most probable number.

Table 1-2 Anticipated Performance of Various Unit Process Combinations.

		ESTIMATED AWT PROCESS EFFLUENT QUALITY						
AWT Pretreatment	AWT Process[b]	BOD (mg/l)	COD (mg/l)	Turb. (JU)	PO_4 (mg/l)	SS (mg/l)	Color (units)	NH_3-N (mg/l)
Preliminary[a]	C,S	50–100	80–180	5–20	2–4	10–30	30–60	20–30
	C,S,F	30–70	50–150	1–2	0.5–2	2–4	30–60	20–30
	C,S,F,AC	5–10	25–45	1–2	0.5–2	2–4	5–20	20–30
	C,S,NS,F,AC	5–10	25–45	1–2	0.5–2	2–4	5–20	1–10
Primary	C,S	50–100	80–180	5–15	2–4	10–25	30–60	20–30
	C,S,F	30–70	50–150	1–2	0.5–2	2–4	30–60	20–30
	C,S,F,AC	5–10	25–45	1–2	0.5–2	2–4	5–20	20–30
	C,S,NS,F,AC	5–10	25–45	1–2	0.5–2	2–4	5–20	1–10
High rate	F	10–20	35–60	6–15	20–30	10–20	30–45	20–30
Trickling	C,S	10–15	35–55	2–9	1–3	4–12	25–40	20–30
Filter	C,S,F	7–12	30–50	0.1–1	0.1–1	0–1	25–40	20–30
	C,S,F,AC	1–2	10–25	0.1–1	0.1–1	0–1	0–15	20–30
	C,S,NS,F,AC	1–2	10–25	0.1–1	0.1–1	0–1	0–15	1–10
Conventional	F	3–7	30–50	2–8	20–30	3–12	25–50	20–30
Activated	C,S	3–7	30–50	2–7	1–3	3–10	20–40	20–30
Sludge	C,S,F	1–2	25–45	0.1–1	0.1–1	0–1	20–40	20–30
	C,S,F,AC	0–1	5–15	0.1–1	0.1–1	0–1	0–15	20–30
	C,S,NS,F,AC	0–1	5–15	0.1–1	0.1–1	0–1	0–15	1–10

[a]Preliminary treatment—grit removal, screen chamber, Parshall flume, overflow.
[b]*C,S*—coagulation and sedimentation; *F*—mixed-media filtration; *AC*—activated carbon adsorption; *NS*—ammonia stripping. Lower effluent NH_3 value at 18°C; upper value at 13°C.

TABLE 1-3 Quality of Sewage from Domestic Use of Colorado River Water.

Constituent	Colorado River water (mg/l)	AVERAGE WASTEWATER FLOW 70 gpcd		100 gpcd		120 gpcd	
		incr.	conc.	incr.	conc.	incr.	conc.
BOD	0	310	310	216	216	180	180
COD	0	475	475	330	330	280	280
TSS	0	360	360	250	250	210	210
TDS	750	450	1200	315	1065	260	1010
Set Sd.	0	13	13	9	9	7.5	7.5
P—Tot.	0	13	13	9	9	7.5	7.5
P—Ortho.	0	9	9	6	6	5	5
N—Tot. Org.	0	19	19	13	13	11	11
—NO_3	1.3	0.3	1.6	0.2	1.5	0.15	1.45
—NO_2	0	0.06	0.06	0.05	0.05	0.04	0.04
—NH_3	0	32	32	22	22	19	19
B	0	0.5	0.5	0.4	0.4	0.3	0.3
Na	111	64	175	45	156	38	149
% Na	—	—		—	—	—	
K	5	15	20	11	16	9	14
Ca	88	26	114	18	106	15	103
Mg	33	13	46	9	42	7.5	40
Cl	97	103	200	72	169	60	157
SO_4	327	40	367	27	354	22	349
HCO_3	148	130	278	90	238	75	223
CO_3	1		1	0	1	0	1
E.C.	1160	640	1800	450	1610	375	1535
Grease and float	0	130	130	90	90	75	75
Total heavy metals	0						
F	0.4		1.0		0.7		0.5
SiO_2	8		8		8		8
*p*H	8.3						
Temp (°F)	69						

Source: "Irvine Ranch Sewerage Survey," report for Irvine Ranch Water District, Brown & Caldwell, Engrs. (Nov. 1968).

are normally present in secondary effluents. Infectious hepatitis has been confirmed to be a waterborne viral disease with the virus capable of surviving ten weeks in clean water. Certainly, reuse of secondary effluent for many purposes is not acceptable because of the health hazard.

Wastewater Quality

Wastewater quality depends upon the chemical quality of the raw water supply, per capita water use, and the nature and quantity of materials discharged to sewers. Several illustrative examples follow.