

CONTENTS

PREFACE	xv
ACKNOWLEDGMENTS	xvii
1 WASTEWATER ENGINEERING: AN OVERVIEW	1
1-1 WASTEWATER TREATMENT	
Background Current Status New Directions	
1-2 EFFLUENT AND SLUDGE DISPOSAL AND REUSE	6
Background Current Status and New Directions	
1-3 THE ROLE OF THE ENGINEER	8
REFERENCES	10
2 WASTEWATER FLOWRATES	
2-1 COMPONENTS OF WASTEWATER FLOWS	
2-2 WATER USED FOR PUBLIC SUPPLIES	
Water Withdrawals for Public Water Supplies Variations in Usage in Cities Water Use by Various Establishments and Devices Fluctuations in Water Use Proportion of Water Supply Reaching Sewers	
2-3 WASTEWATER SOURCES AND FLOWRATES	20
Sources and Rates of Domestic Wastewater Flows Sources and Rates of Industrial Wastewater Flows Infiltration/Inflow Variations in Wastewater Flows	
2-4 ANALYSIS OF WASTEWATER FLOWRATE DATA	29
Peaking Factors for Wastewater Flows Peak Infiltration Flows Peak Inflow Design Allowance Sustained Flows Statistical Analysis	
2-5 REDUCTION OF WASTEWATER FLOWS	36
2-6 MEASUREMENT OF WASTEWATER FLOWS	38
Direct-Discharge Methods Velocity-Area Methods	
DISCUSSION TOPICS AND PROBLEMS	53
REFERENCES	54

3 WASTEWATER CHARACTERISTICS	56
3-1 PHYSICAL, CHEMICAL, AND BIOLOGICAL CHARACTERISTICS OF WASTEWATER	56
3-2 WASTEWATER CHARACTERIZATION STUDIES	59
Sampling Sample Preservation Methods for Sample Analysis Expression of Analysis Results	
3-3 WASTEWATER COMPOSITION	64
Constituents in Wastewater and Septage Need for Additional Analyses Mineral Pickup from Water Use	
3-4 UNIT LOADING FACTORS	67
3-5 VARIATIONS IN CONCENTRATIONS OF WASTEWATER CONSTITUENTS	68
Short-Term Variations Seasonal Variations Industrial Variations	
3-6 ANALYSIS OF WASTEWATER LOADING DATA	72
Simple Average Flow-Weighted Average Mass Loadings Sustained Peak Mass Loadings	
3-7 PHYSICAL CHARACTERISTICS: DEFINITION AND APPLICATION	76
Total Solids Odors Temperature Color	
3-8 CHEMICAL CHARACTERISTICS: DEFINITION AND APPLICATION	82
Organic Matter Measurement of Organic Content Inorganic Matter Gases	
3-9 BIOLOGICAL CHARACTERISTICS: DEFINITION AND APPLICATION	104
Microorganisms Pathogenic Organisms Coliform Organisms Ratio of Fecal Coliforms to Fecal Streptococci Bioassay Tests	
DISCUSSION TOPICS AND PROBLEMS	113
REFERENCES	116
4 WASTEWATER-TREATMENT OBJECTIVES, METHODS, AND DESIGN	119
4-1 WASTEWATER-TREATMENT OBJECTIVES AND REGULATIONS	119
4-2 CLASSIFICATION AND APPLICATION OF WASTEWATER-TREATMENT METHODS	121
Classification of Treatment Methods Application of Treatment Methods	
4-3 ELEMENTS OF PLANT ANALYSIS AND DESIGN	125
Treatment-Process Flowsheets Process Design Criteria Solids Balance Hydraulic Profiles Plant Layout	
4-4 OTHER IMPORTANT CONSIDERATIONS	129
Energy and Resource Requirements Cost Analysis Environmental-Impact Assessment Plans and Specifications	
DISCUSSION TOPICS AND PROBLEMS	139
REFERENCES	140

FUNDAMENTALS OF PROCESS ANALYSIS	141
5-1 REACTIONS AND REACTION KINETICS	142
Types of Reactions Rate of Reaction Specific Reaction Rate Effects of Temperature on Specific Rate Constants Analysis of Rate Equations	
5-2 MASS-BALANCE ANALYSIS	149
The Mass Balance Mass Balance for Batch Reactor Solution Procedures Steady-State Simplification	
5-3 REACTORS AND THEIR HYDRAULIC CHARACTERISTICS	154
Types of Reactors Hydraulic Characteristics of Reactors	
5-4 PROCESS ANALYSIS	163
Selection of Reaction Rate Expressions or Loading Criteria Selection of the Type of Reactor	
5-5 REACTION KINETICS AND REACTOR SELECTION	166
Continuous-Flow Stirred-Tank Reactors in Series with Conversion Plug-Flow Reactor with Conversion Comparison of Continuous-Flow Stirred-Tank and Plug-Flow Reactors Plug-Flow Reactors with Axial Dispersion and Conversion Other Reactor Flow Regimes and Reactor Combinations	
5-6 PRACTICAL ASPECTS OF REACTOR DESIGN	174
DISCUSSION TOPICS AND PROBLEMS	175
REFERENCES	179
6 PHYSICAL UNIT OPERATIONS	180
6-1 SCREENING	182
Description Analysis	
6-2 FLOW EQUALIZATION	187
Description Analysis	
6-3 MIXING	196
Description/Application Analysis	
6-4 FLOCCULATION	199
Description Analysis	
6-5 SEDIMENTATION	201
Description Analysis of Discrete Particle Settling (Type 1) Analysis of Flocculant Settling (Type 2) Analysis of Tube Settlers Analysis of Hindered Settling (Type 3) Analysis of Compression Settling (Type 4)	
6-6 FLOTATION	221
Description Analysis	
6-7 GRANULAR-MEDIUM FILTRATION	227
Description of the Filtration Operation Classifications of Filtration Systems Filtration-Process Variables Particle-Removal Mechanisms General Analysis of Filtration Operation Analysis of Wastewater Filtration Need for Pilot-Plant Studies	
DISCUSSION TOPICS AND PROBLEMS	252
REFERENCES	255

7	CHEMICAL UNIT PROCESSES	257
	7-1 CHEMICAL PRECIPITATION	258
	Description of Chemical Precipitation for Improving Plant Performance Description of Chemical Precipitation for Phosphate Removal and for Physical-Chemical Treatment Theoretical Aspects of Chemical Precipitation	
	7-2 GAS TRANSFER	268
	Description Analysis of Gas Transfer Evaluation of Aerator Performance	
	7-3 ADSORPTION	276
	Description Analysis of Activated-Carbon Adsorption Process Analysis	
	7-4 DISINFECTION	284
	Description of Disinfection Methods and Means Mechanisms of Disinfectants Analysis of Factors Influencing the Action of Disinfectants	
	7-5 DISINFECTION WITH CHLORINE	292
	Description of Chlorine Chemistry Breakpoint Reaction Factors That Affect Disinfection Efficiency of Chlorine	
	7-6 DECHLORINATION	303
	Toxicity of Chlorine Residuals Analysis of Dechlorination	
	7-7 DISINFECTION WITH OZONE	306
	Description Analysis	
	7-8 OTHER CHEMICAL APPLICATIONS	307
	DISCUSSION TOPICS AND PROBLEMS	308
	REFERENCES	310
8	DESIGN OF FACILITIES FOR PHYSICAL AND CHEMICAL TREATMENT OF WASTEWATER	312
	8-1 RACKS AND COARSE SCREENS	312
	Racks Coarse Screens Quantities of Screenings Disposal of Screenings	
	8-2 COMMINATION	319
	Description Application and Design	
	8-3 GRIT CHAMBERS	322
	Types Quantities of Grit Disposal of Grit	
	8-4 FLOW EQUALIZATION	330
	Basin Construction Mixing and Air Requirements Pump and Pump Control	
	8-5 OTHER PRETREATMENT OPERATIONS	333
	Skimming Tanks Flocculation Preaeration	
	8-6 PRIMARY SEDIMENTATION TANKS	336
	Basis of Design Tank Type, Size, and Shape Quantities of Sludge	
	8-7 OTHER SOLIDS-REMOVAL OPERATIONS AND UNITS	349
	Flotation Fine Screens Imhoff and Septic Tanks	
	8-8 CHEMICAL PRECIPITATION	355
	Improved Sedimentation Tank Performance Independent Physical-Chemical Treatment Phosphorus Removal Estimation of Sludge Quantities Chemical Storage, Feeding, Piping, and Control Systems	

8-9 GRANULAR-MEDIUM FILTRATION	362
Driving Force, Number, and Size of Filter Units Filter-Bed Selection Filtration Backwashing Systems Filter Appurtenances Filter Problems Filter Control Systems and Instrumentation	
8-10 MICROSCREENING	373
Description Functional Design	
8-11 CHLORINATION	375
Application Chlorine Compounds Chlorination Equipment and Dosage Control Chlorination Facilities	
8-12 ODOR CONTROL	388
DISCUSSION TOPICS AND PROBLEMS	390
REFERENCES	391
9 BIOLOGICAL UNIT PROCESSES	393
9-1 BIOLOGICAL TREATMENT: AN OVERVIEW	394
Some Useful Definitions Role of Microorganisms Treatment Processes	
9-2 SOME FUNDAMENTALS OF MICROBIOLOGY	398
Basic Concepts Important Microorganisms Cell Physiology	
9-3 BACTERIAL GROWTH AND BIOLOGICAL OXIDATION	411
General Growth Patterns in Pure Cultures Growth in Mixed Cultures Bacterial Oxidation	
9-4 KINETICS OF BIOLOGICAL GROWTH	414
Logarithmic Growth: Batch Culture Substrate Limited Growth Cell Growth and Substrate Utilization Effects of Endogenous Metabolism Effects of Temperature Application of Kinetics to Biological Treatment Determination of Kinetic Coefficients Other Rate Expressions	
9-5 AEROBIC SUSPENDED-GROWTH TREATMENT PROCESSES	430
Activated-Sludge Process Suspended-Growth Nitrification Aerobic Aerated Lagoons Aerobic Digestion Aerobic Stabilization Ponds	
9-6 AEROBIC ATTACHED-GROWTH TREATMENT PROCESSES	442
Trickling Filters Roughing Filters Rotating Biological Contactors Packed-Bed Reactors	
9-7 ANOXIC SUSPENDED-GROWTH AND ATTACHED-GROWTH PROCESSES	454
Suspended-Growth Denitrification Fixed-Film Denitrification	
9-8 ANAEROBIC SUSPENDED-GROWTH TREATMENT PRO- CESSES	455
Anaerobic Digestion Anaerobic Contact Process	
9-9 ANAEROBIC ATTACHED-GROWTH TREATMENT PROCESSES	460
Anaerobic Filter Anaerobic Ponds	
9-10 COMBINED AEROBIC/ANOXIC OR ANAEROBIC TREAT- MENT PROCESSES	461
Facultative Lagoons (Ponds) Tertiary-Maturation Ponds	
DISCUSSION TOPICS AND PROBLEMS	463
REFERENCES	465

CONTENTS

DESIGN OF FACILITIES FOR THE BIOLOGICAL TREATMENT OF WASTEWATER	468
10-1 ACTIVATED-SLUDGE (AEROBIC SUSPENDED-GROWTH) TREATMENT	470
Process Design Considerations Process Design Types of Processes and Modifications Use of Pure Oxygen Diffused-Air Aeration Mechanical Aerators Generation of Pure Oxygen Design of Aeration Tanks and Appurtenances Design of Solids-Separation Facilities Operational Difficulties	
10-2 AERATED-LAGOON (AEROBIC SUSPENDED-GROWTH) TREATMENT	523
Process Design Considerations Process Design Solids Separation	
10-3 TRICKLING-FILTER (AEROBIC ATTACHED-GROWTH) TREATMENT	534
Filter Classification Process Design Design of Physical Facilities	
10-4 COMBINED AEROBIC TREATMENT PROCESSES	547
Series Trickling-Filter and Activated-Sludge Processes Series Activated-Sludge and Trickling-Filter Processes	
10-5 STABILIZATION PONDS	548
Pond Classification Application Process Design and Analysis Solids Separation Design of Physical Facilities	
DISCUSSION TOPICS AND PROBLEMS	566
REFERENCES	570
DESIGN OF FACILITIES FOR THE TREATMENT AND DISPOSAL OF SLUDGE	573
11-1 SLUDGE-TREATMENT FLOWSHEETS	575
11-2 SOLIDS AND SLUDGE SOURCES, CHARACTERISTICS, AND QUANTITIES	580
Sources Characteristics Quantities	
11-3 SLUDGE AND SCUM PUMPING	588
Pumps Application of Pumps to Types of Sludge Head-Loss Determination Sludge Piping	
11-4 PRELIMINARY OPERATIONS	595
Sludge Grinding Sludge Degritting Sludge Blending Sludge Storage	
11-5 CONCENTRATION (THICKENING)	600
Application Description of Thickening Equipment Design of Thickeners	
11-6 STABILIZATION: CHEMICAL AND THERMAL PROCESSES	607
Chlorine Oxidation Lime Stabilization Heat Treatment	
11-7 STABILIZATION: ANAEROBIC SLUDGE-DIGESTION PROCESS	609
Process Description Process Design Gas Production, Collection, and Utilization Digester Mixing Digester Heating	
11-8 STABILIZATION: AEROBIC SLUDGE-DIGESTION PROCESS	627
Process Description Conventional-Air Aerobic Digestion Pure-Oxygen Aerobic Digestion Thermophilic Aerobic Digestion	

11-9	CONDITIONING	634
	Chemical Conditioning Elutriation Heat Treatment Other Processes	
11-10	DISINFECTION	
	Pasteurization Long-Term Storage	
11-11	DEWATERING	
	Vacuum Filtration Centrifugation Filter Presses Horizontal Belt Filters Sludge-Drying Beds Lagoons	
11-12	HEAT DRYING	
	Theory Heat-Drying Options	
11-13	COMPOSTING	
	Process Description Cocomposting Options	
11-14	THERMAL REDUCTION	662
	Process Fundamentals Thermal-Reduction Processes	
11-15	PREPARATION OF SOLIDS MASS BALANCES	671
	Basis for Preparation of Mass Balances Performance Data for Sludge-Processing Facilities	
11-16	FINAL SLUDGE AND SOLIDS CONVEYANCE, STORAGE AND DISPOSAL	684
	Conveyance Methods Sludge Storage Final Disposal	
	DISCUSSION TOPICS AND PROBLEMS	690
	REFERENCES	694
12	ADVANCED WASTEWATER TREATMENT	696
12-1	EFFECTS OF CHEMICAL CONSTITUENTS IN WASTEWATER	697
12-2	UNIT OPERATIONS AND PROCESSES AND TREATMENT FLOWSHEETS	698
	Classification Process Selection and Development of Treatment Flowsheets Typical Process Performance Data	
12-3	NITROGEN CONVERSION AND REMOVAL	699
	Forms of Nitrogen Sources of Nitrogen Operations and Processes for the Control of Nitrogen	
12-4	NITRIFICATION	708
	Nitrification Processes Nitrification Stoichiometry Process Analysis (Nitrification) Process Applications	
12-5	DENITRIFICATION AND NITRIFICATION-DENITRIFICATION	721
	Denitrification Processes Denitrification Stoichiometry Process Analysis (Denitrification) Process Application	
12-6	NITROGEN REMOVAL BY PHYSICAL AND CHEMICAL PROCESSES	734
	Air Stripping of Ammonia Breakpoint Chlorination Ion Exchange	
12-7	PHOSPHORUS REMOVAL	744
	Forms of Phosphorus Operations and Processes for Phosphorus Removal	
12-8	REMOVAL OF REFRACTORY ORGANICS	751
	Carbon Adsorption Chemical Oxidation	

12-9 REMOVAL OF DISSOLVED INORGANIC SUBSTANCES	753
Chemical Precipitation Ion Exchange Reverse Osmosis (Hyperfiltration) Electrodialysis	
12-10 ULTIMATE DISPOSAL OF CONTAMINANTS	756
DISCUSSION TOPICS AND PROBLEMS	756
REFERENCES	758
13 LAND-TREATMENT SYSTEMS	760
13-1 DEVELOPMENT OF LAND-TREATMENT SYSTEMS	760
Historical Practice Land Treatment of Wastewater Land Application of Sludge	
13-2 FUNDAMENTAL CONSIDERATIONS IN LAND-TREATMENT SYSTEMS	766
Wastewater Characteristics and Treatment Mechanisms Vegetation Public Health	
13-3 IRRIGATION SYSTEMS	772
Design Objectives Site Selection Preapplication Treatment Climate and Storage Loading Rate Land Requirements Crop Selection Distribution Techniques Underdrainage Surface-Runoff Control Case Study (Muskegon, Michigan)	
13-4 RAPID-INFILTRATION SYSTEMS	794
Design Objectives Site Selection Preapplication Treatment Climate and Storage Loading Rate Distribution Techniques Application Cycles Control of Underground Flow	
13-5 OVERLAND-FLOW SYSTEMS	804
Design Objectives Site Selection Preapplication Treatment Climate and Storage Application Rates Land Requirements Terrace Characteristics Crop Selection Distribution Techniques Runoff Collection	
13-6 OTHER SYSTEMS	809
Wetlands Application Aquaculture	
13-7 LAND APPLICATION OF SLUDGE	814
Design Objectives Sludge Characteristics Site Selection Market Considerations Operational Methods Application Rates	
DISCUSSION TOPICS AND PROBLEMS	823
REFERENCES	824
14 EFFLUENT DISPOSAL AND REUSE	829
14-1 WATER-POLLUTION CONTROL	830
Receiving-Water Standards Effluent Standards Setting of Standards Effluent Disposal by Dilution	
14-2 DISPOSAL INTO LAKES	832
Problem Analysis Stratification in Large Lakes	
14-3 DISPOSAL INTO RIVERS	836
Reoxygenation in Rivers Deoxygenation in Rivers Development of Oxygen-Sag Model Design of River Diffusers	

14-4 DISPOSAL INTO ESTUARIES	845
Mathematical Analysis of Estuaries Determination of Coefficient of Eddy Diffusion	
14-5 DISPOSAL INTO THE OCEAN	849
Estimation of Initial Dilution Dilution Due to Dispersion Dilution Due to Decay Outfall Design	
14-6 DIRECT AND INDIRECT REUSE OF WASTEWATER	859
Municipal Reuse Industrial Reuse Agricultural Reuse Recreational Reuse Groundwater Recharge	
DISCUSSION TOPICS AND PROBLEMS	861
REFERENCES	864
APPENDIXES	865
A Metric Conversion Factors	866
B Physical Properties of Water	875
C Dissolved Oxygen Solubility Data	878
D Most Probable Number (MPN) Tables	879
E Example of Summary Table Listing Basic Design Data for Wastewater Treatment Plant	881
INDEXES	885
Name Index	
Subject Index	