Water and Wastewater Engineering

A major challenge for the twenty-first century is to provide safe and adequate drinking water to everyone. Preventing pollution of the environment due to rampant and untreated discharges of wastewater is another challenge for most developing countries, including India. The water–energy connection is also being recognized as another growing challenge. The design of water and wastewater treatment facilities must be environmentally sensitive, energy efficient and sustainable into the future.

Conceived as a textbook for undergraduate and graduate students who need to understand the basic concepts and design principles related to water and wastewater engineering, this book begins with an introduction to water resources and the need for water and wastewater treatment. This is followed by an evaluation of water demand in terms of quantity and quality. Major mass transfer and transformation processes that are necessary for understanding the complexity of water pollution issues and treatment processes are dealt with in detail. Treatment processes that are used in water and/or wastewater treatment are detailed subsequently so that they can be designed by the student. A few examples of specific water treatment requirements are provided to enable the student to choose and apply only relevant treatment processes in their design. Conventional and non-conventional treatment schemes for water and wastewater treatment are covered to complete the overview of treatment processes. Collection, transportation and distribution aspects of drinking water supply systems are covered along with wastewater collection systems. Problems and issues arising from the inadequacies of conventional treatment practices, and potential methods for resolving these problems have also been incorporated into this text. An overview of relevant regulations, Indian and other, is also provided.

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Preface

'Water and Wastewater Engineering' is a core course in undergraduate programs in civil engineering. The course objective is to ensure that a student is able to evaluate different water resource options for their sustainability, quantity and quality, and to design appropriate municipal water supply and wastewater systems. These water supply systems will necessarily require sourcing of water, its collection, treatment and distribution. Wastewater generated within these systems has to be treated in treatment plants so that it can be reused or disposed of on land or in water bodies after achieving discharge standards. Wastewater reuse has become an extremely important topic these days due to severe water scarcity in many parts of the world, including India.

This textbook covers all aspects of municipal water and wastewater systems and is designed for a one-semester course. Prior to designing water and wastewater treatment plants, it is necessary to identify and develop an appropriate water source. For this, the student must be familiar with different types of water resources: surface water and groundwater, and concepts related to their quantity and quality. These are covered in the first and second chapters of this book. Fundamental concepts from chemistry, microbiology, and chemical engineering are covered in the first part of the book (Chapters 3 and 4) as these are necessary for understanding water quality issues, and designing water and wastewater systems. The second part of the book includes the design of conventional water treatment plants with unit processes like aeration, sedimentation, coagulation, filtration, and disinfection; design of conventional wastewater treatment plants with unit processes like screening, sedimentation, biological processes, activated sludge process and trickling filters or biofilters, sludge treatment, and disposal; water distribution methods; wastewater collection, reuse, and disposal options; and non-conventional treatment strategies for removal of specific pollutants like fluoride, arsenic, nitrate, and natural organic matter.

This textbook started as a spin-off of an online course of the same name. However, several topics that could not be covered in the online course are also included in the textbook. The text material has been expanded and the number of problems increased. Solutions to all problems are provided. Some of the problems will require the use of spreadsheets or other software for graphing and calculations. A word about notation in this book: * symbolizes multiplication in MS Excel and has been retained in all equations instead of 'x'. The online course can be accessed at the following link: http://www.ide.iitkgp.ernet.in/Pedagogy_view/example.jsp?USER_ID=52.

Several pedagogical features have been incorporated in the book, including learning objectives, study outline, and study questions. Learning objectives help the students identify what the outcome of their study should be, while the study outline provides a concise summary of what is important. Several photographs and schematic diagrams are included along with graphical solutions to problems to help the student visualize concepts and solve problems. The book covers only theoretical and empirical principles as they are applied in the field. The practical 'nuts and bolts' of engineering cannot be provided by this textbook! The student should always bear in mind that what is done in practice, i.e., what works, does not always seem to be compatible with theory, i.e., the how and why of what works and what does not work. Research and development is all about bridging the gap between theory and practice.

Finally, while every effort has been made to eliminate typographical and other mistakes from the book, the reader is encouraged to point these out by writing to the author at the following address: sudhagoelcup@gmail.com.

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Other students who have contributed to this book long after the above-mentioned project was completed include Abhishek Singhal, Rahul Meena, Tandra Mohanta, Ved P. Ranjan, Kruttika Apshankar Kher, and Naseeba Parveen. Experimental data for several problems were obtained from students and their work is referenced at relevant points in the book. The author is grateful to all these students for their contributions to this book. Colleagues and staff at IIT Kharagpur and in other institutions have also supported this endeavor and their help is gratefully acknowledged.

Last but not least, the author is grateful to her family, friends, and teachers who have supported her through all these years.

Abbreviations

AL	aerated lagoon
AODC	acridine orange direct cell count
APHA	American Public Health Association
ASP	activated sludge process
ATAD	auto thermal aerobic digestion
AWWA	American Water Works Association
BCM	billion cubic meters
BFR	brominated fire retardants
BOD	biochemical oxygen demand or biological oxygen demand
BODu	ultimate biochemical oxygen demand
CBOD	carbonaceous biochemical oxygen demand
CEA	Central Electricity Authority
COD	chemical oxygen demand
CPCB	Central Pollution Control Board
CSO	combined sewer overflow
CSTR	continuously stirred tank reactor
CWC	Central Water Commission
CWS	continuous water supply
DAF	dissolved air flotation
DBPs	disinfection by-products
DDT	dichloro-diphenyl-trichloroethane
DF	demand factor
DNA	deoxyribose nucleic acid
DO	dissolved oxygen
DOC	dissolved organic carbon
DW	drinking water

ED	electron donor
ED	electrodialysis
EDR	electrodialysis reversal
FAO	Food and Agriculture Organization
FICCI	Federation of Indian Chambers of Commerce and Industry
FSS	fixed suspended solids
GI	galvanized iron
GW	groundwater
HAA	haloacetic acids
HAN	haloacetonitriles
HPC	heterotrophic plate count
IS	Indian Standards
ISO	International Organization for Standardization
IWS	intermittent water supply
Lpcd	liters per capita per day
LUST	leaking underground storage tank
MBR	membrane bioreactor
MLD	million liters per day
MLSS	mixed liquor suspended solids
MLVSS	mixed liquor volatile suspended solids
MSL	mean sea level
NBOD	nitrogenous biochemical oxygen demand
NOM	natural organic matter
NTU	nephelometric turbidity units
PCP	personal care products
PF	peaking factor
PFR	plug flow reactor
RBC	rotating biological contactor
RNA	ribose nucleic acid
SAR	sodium absorption ratio
SBR	sequencing batch reactor
SEM	scanning electron microscope
SF	solids flux
SOC	synthetic organic compounds (compounds)
SOP	synthetic organic polymers
SS	steady-state

SVI	sludge volume index
SW	surface water
TDS	total dissolved solids
TEA	terminal electron acceptor
TEM	transmission electron microscope
TF	trickling filter
TFS	total fixed solids
THM	trihalomethanes
ThOD	theoretical oxygen demand
TKN	total Kjeldahl nitrogen
TOC	total organic carbon
TOX	total organic halogen
TS	total solids
TSS	total suspended solids
TVS	total volatile solids
uPVC	unplasticized polyvinyl chloride
UV	ultraviolet
VC	viable cells
VLOM	village level operation and maintenance
VOC	volatile organic compounds
VSS	volatile suspended solids
WHO	World Health Organization
WQI	water quality index

Symbols and Dimensions

(Mass, Length and Time–MLT system where possible)

a	activity
A	area, L^2
A	specific light absorbance, dimensionless
A/V	= a = specific surface area, 1/L
A_p	projected area or cross-sectional area of particle in flow direction, L^2
b	endogenous decay coefficient, 1/T
C	concentration, M/L^3
C_d	coefficient of drag, dimensionless
D	dispersion coefficient
D_e	eddy diffusion coefficient
D_m	molecular diffusion coefficient, L^2/T
e	electron charge, $1.60219 * 10^{-19}$ Coulombs
E_a	activation energy for a reaction, kJ/mol
F	flow rate for fire-fighting or fire demand, L^3/T
F/M	food to microorganism ratio, kg BOD_5/kg MLVSS-d
G	velocity gradient, 1/T
h	elevation or height, L
h_f	head loss through filter, L
I	current, amperes
I	impermeability factor or runoff coefficient (ratio of runoff to rainfall)
I	ionic strength, M/L^3
k	Boltzmann constant, $1.38066*10^{-23}$ J/degree Kelvin
K	hydraulic conductivity or coefficient of permeability, L/T
k	maximum substrate utilization rate per unit mass of microbes, mg substrate/mg cells-time, M/M-T
k	reaction rate constant, units vary with reaction order

k_d	deoxygenation constant, 1/T
K_L	overall mass transfer coefficient, M/T
k_o	oxygenation or reaeration constant, 1/T
K_{ow}	octanol-water partitioning coefficient
K_s	half-velocity constant, M/L^3
L	length, L
L_0	ultimate carbonaceous BOD (CBOD) and L_t = ultimate CBOD at time t
M	molality of a solution, moles/L
n	any number
n	Manning's coefficient or coefficient of roughness
N	number of microbes or cells/L
N_A	Avogadro's number, $6.02205*10^{23}$ molecules/mol
P	population, persons; P_0 = population at t = 0; P_s = saturation population in the logistic model
P	power or pressure
Q	flow rate, L^3/T or heat flux, Joules/cm^2-s
q	hydraulic loading rate or surface overflow rate, L/T
R	electrical resistance, ohms
R	ideal gas constant, 8.314 J/mol–K
R	rainfall intensity, L/T
r	rate of change, M/T
R_0	maximum instantaneous growth rate in the logistic model, 1/T
Re	Reynolds number, dimensionless
r_H	hydraulic radius, L
S	growth limiting substrate concentration in solution, M/L^3
S	slope or hydraulic gradient, or drop in head or head loss per unit length = $-h_L/L$, length of pipe, L/L
T	temperature
t	time, T
t_c	critical time,
v	velocity, L/T
V	volume of a solution, L^3
v_s	settling velocity of particle, M/T
X	increment or mass or mass fraction or biomass or cell concentration
Y	maximum yield coefficient, dimensionless

Z	charge of ion
γ (gamma)	activity coefficient, dimensionless
η (eta)	porosity (% of total volume) or Coulombic efficiency, %
Θ (theta)	temperature correction factor or normalized time, i.e., t/τ
κ^{-1}(1/kappa)	double layer thickness, L
μ (mu)	dynamic viscosity
Π (pi)	osmotic pressure
ρ (rho)	density of water or other materials, M/L^3
τ (tau)	V/Q = design hydraulic residence time, T
Ø (phi)	sphericity of the particle, dimensionless