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Handbook of Environmental Engineering Calculations

Second Edition

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- Calculations presented with fully illustrated steps
- Contains both SI and U.S. Customary units
- Calculations cover all aspects of environmental engineering

C. C. Lee • Shun Dar Lin

HANDBOOK OF ENVIRONMENTAL ENGINEERING CALCULATIONS

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DR. C. C. LEE is the Fuel Cell Research Program Manager at the National Risk Management Research Laboratory of the U.S. Environmental Protection Agency in Cincinnati, Ohio.* He has more than 30 years of experience in conducting various engineering and research projects which often involve multimedia environmental issues ranging from air and water pollution control to solid waste disposal. He has been recognized as a worldwide expert in the thermal treatment of medical and hazardous wastes, witness his leading discussions on medical waste disposal technologies at a meeting conducted by the Congressional Office of Technology Assessment. He initiated and served as the Chairman of the First and Second International Congresses on Toxic Combustion Byproducts (ICTCB) in 1989 and 1991, respectively. The ICTCB has been holding its meetings every two years since its creation in 1989. Also, at the initiation of the U.S. State Department, he served as head of the U.S. delegation to the Conference on National Focal Points for Low- and Non-Waste Technology (it was sponsored by the United Nations and held in Geneva, Switzerland on August 28–30, 1978). He has been invited to lecture on various issues regarding solid waste disposal in numerous national and international conferences, and he has authored 18 books and has published more than 175 papers and reports in various environmental areas. Until recently, he was an adjunct professor with the University of Cincinnati in Ohio and was an assistant professor at the North Carolina State University before joining EPA in 1974. He received a B.S. from the National Taiwan University in 1964, and a MS and PhD from the North Carolina State University in 1968 and 1972, respectively.

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**Note*: This book was written and edited by Dr. C. C. Lee in his private capacity. No official support or endorsement by the U.S. Environmental Protection Agency is intended nor should be inferred.

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PREFACE

Because environmental problems are uncovered almost daily, this second edition has been created to meet the challenge of solving them. Environmental engineering encompasses many areas. It ranges from solid waste disposal, wastewater treatment, air pollution control, to life analysis. Although there are many publications relative to the descriptions of concepts and methodologies in the environmental control area, the actual calculations relative to the field seldom appear in these publications. In addition to the scarcity of environmental calculations thousands of environmental regulations from federal, state, and local regulators impact environmental engineering design every day. Just keeping abreast of such regulations is an enormous task for engineers. The main objective of this book is, therefore, to provide step-by-step, practical calculational procedures on various environmental subjects. More importantly, this book integrates the regulatory requirements into environmental designs so the result can make these designs more acceptable to regulators. The major subjects covered in the second edition include:

1. Calculations of water quality assessment and control
2. Solid waste treatment calculations
3. Air pollution control calculations
4. Air toxic risk assessment
5. Fuel cell technologies

A majority of the calculational examples provided in this book were developed by the authors themselves and the materials were excerpted from previous USEPA publications. Since its creation in 1970, the USEPA has published many environmental regulations and engineering reports. Many very interesting calculational examples were scattered throughout these publications. The huge volume of EPA regulations and reports makes a search for example calculations extremely difficult and time consuming. To help resolve this difficulty, many of these examples were collected and edited in a format for readers to easily understand. The citing of references for each example calculation is provided herein. This is to expeditiously assist users in locating additional information, if needed.

This book is intended to be a reference tool for those who are involved in the protection of air, water, and land resources. It is believed that the book will make many environmental jobs much easier. Lastly, the editor wishes to express his deep appreciation to the contributing authors who have spent so many of their days and nights to make this book possible.

C. C. LEE

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HANDBOOK OF ENVIRONMENTAL ENGINEERING CALCULATIONS

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P • A • R • T • 1

CALCULATIONS OF WATER QUALITY ASSESSMENT AND CONTROL

Part 1 of this book is written for use by the following readers: students taking coursework relating to public water supply, waste-water engineering or stream sanitation, practicing environmental (sanitary) engineers; regulatory officers responsible for the review and approval of engineering project proposals; operators, engineers, and managers of water and/or wastewater treatment plants; and any other professionals, such as chemists and biologists, who have gained some knowledge of water/wastewater issues. This work will benefit all operators and managers of public water supply and of wastewater treatment plants, environmental design engineers, military environmental engineers, undergraduate and graduate students, regulatory officers, local public works engineers, lake managers, and environmentalists.

The chapters in Part 1 present the basic principles and concepts relating to water/wastewater engineering and provide illustrative examples of the subject. To the extent possible, examples rely on practical field data. Each of the calculations provided herein are solved step-by-step in a streamlined manner that is intended to facilitate understanding. Calculations (step-by-step solutions) range from calculations commonly used by operators to more complicated calculations required for research or design.

Advances and improvements in many fields are driven by competition or the need for increased profits. It may be fair to say, however, that advances and improvements in environmental engineering are driven instead by regulation. The US Environmental Protection Agency (EPA) sets up maximum contaminant levels, which research and project designs must reach as a goal. The step-by-step solution examples provided in this book are informed by the integration of rules and regulations on every aspect of waters and wastewaters. The author has performed an extensive survey of literature on surface and groundwaters encountered in environmental engineering and compiled them in the following chapters. Rules and regulations are described as simply as possible, and practical examples are given.

The following chapters include calculations for basic science, surface waters ground water, drinking water treatment, and wastewater engineering. Chapter 1.1 covers conversion factors between the two measurement systems, the United States (US) customary system and the System International (SI), basic mathematics for water and wastewater plant operators, fundamental chemistry and physics, and basic statistics for environmental engineers.

Chapter 1.2 comprises calculations for river and stream waters. Stream sanitation had been studied for nearly 100 years. By the mid-twentieth century, theoretical and empirical models for assessing waste assimilating capacity of streams were well developed. Dissolved oxygen and biochemical oxygen demand in streams and rivers have been comprehensively illustrated in this chapter. Apportionment of stream users and pragmatic approaches for stream dissolved oxygen models are also covered. From the 1950s through the 1980s, researchers focused extensively on wastewater treatment. In 1970s, rotating biological contactors also became a hot subject. Design criteria and examples for all of these are included. Some treatment and management technologies are no longer suitable in the United States. However, they are still of some use in developing countries.

Chapter 1.3 is a compilation of adopted methods and documented research. In the early 1980s, the USEPA published Guidelines for Diagnostic and Feasibility Study of Public Owned Lakes (Clean Lakes Program, or CLP). This was intended to be used as a guideline for lake management. CLP and its calculation (evaluation) methods are present in this chapter. Hydrological, nutrient, and sediment budgets are presented for reservoir and lake waters. Techniques for classification of lake water quality, assessment of the lake trophic state index, and of lake use support are presented.

Calculations for groundwater are given in Chapter 1.4. They include groundwater hydrology, flow in aquifers, pumping and its influence zone, setback zone, and soil remediation. Well setback zone is regulated by the state EPA. Determinations of setback zones are also included in the book. Well function for confined aquifers is presented in Appendix B.

Hydraulics for environmental engineering is included in Chapter 1.5. This chapter covers fluid (water) properties and definitions; hydrostatics; fundamental concepts of water flow in pipes, weirs, orifices, and in open channel; and of flow measurements. Pipe networks for water supply distribution systems and hydraulics for water and wastewater treatment plants are included.

Chapters 1.6 and 1.7 cover each unit process for drinking water and wastewater treatments, respectively. The USEPA developed design criteria and guidelines for almost all unit processes. These two chapters depict the integration of regulations (or standards) into water and wastewater design procedure. Water fluoridation and the CT values are incorporated in Chapter 1.6. Biosolids are discussed in detail in Chapter 1.7. These two chapters are the heart Part 1, providing the theoretical considerations of unit processes, traditional (or empirical) design concepts, and integrated regulatory requirements.

Most calculations provided herein use U.S. Customary units. Readers who use the International System (SI) may apply the conversion factors listed in Chapter 1.1. Answers are also generally given in SI for most of problems solved using U.S. units.

The current edition corrects certain computational, typographical, and grammatical errors found in the previous edition. Drinking water quality standards, wastewater effluent standards, and several new examples have also been added. *The author also wishes to acknowledge Meiling Lin, Heather Lin, Robert Greenlee, Luke Lin, Kevin Lin, Jau-hwan Tzeng, and Lucy Lin for their assistance.* *Any reader suggestions and comments will be greatly appreciated.*

Shun Dar Lin

CHAPTER 1.1

BASIC SCIENCE AND FUNDAMENTALS

Shun Dar Lin

1 CONVERSION FACTORS

The units most commonly used by water and wastewater professionals in the United States are based on the complicated U.S. Customary System of Units. However, laboratory work is usually based on the metric system due to the convenient relationship between milliliters (mL), cubic centimeters (cm^3), and grams (g). The International System of Units (SI) is used in all other countries. Factors for converting U.S. units to the SI are given below (Table 1.1) to four significant figures.

EXAMPLE 1: Find degrees in Celsius of water at 68°F.

Solution:

$$°C = (°F - 32) \times \frac{5}{9} = (68 - 32) \times \frac{5}{9} = 20$$

TABLE 1.1 Factors for Conversions

U.S. Customary units	Multiply by	SI or U.S. Customary units
Length		
inches (in)	2.540	centimeters (cm)
	0.0254	meters (m)
feet (ft)	0.3048	m
	12	in
yard (yd)	0.9144	m
	3	ft
miles	1.609	kilometers (km)
	1760	yd
	5280	ft
Area		
square inch (sq in, in^2)	6.452	square centimeters (cm^2)
square feet (sq ft, ft^2)	0.0929	m^2
	144	in^2
acre (a)	4047	square meters (m^2)
	0.4047	hectare (ha)
	43,560	ft^2
	0.001562	square miles
square miles (mi^2)	2.590	km^2
	640	acres
Volume		
cubic feet (ft^3)	28.32	liters (L)
	0.02832	m^3
	7.48	US gallons (gal)
	6.23	Imperial gallons
	1728	cubic inches (in^3)
cubic yard (yd^3)	0.7646	m^3
gallon (gal)	3.785	L
	0.003785	m^3
	4	quarts (qt)
	8	pints (pt)
	128	fluid ounces (fl oz)
	0.1337	ft^3
million gallons (Mgal)	3785	m^3
quart (qt)	32	fl oz
	946	milliliters (mL)
	0.946	L
acre · feet (ac · ft)	1.233×10^{-3}	cubic hectometers (hm^3)
	1233	m^3
Weight		
pound (lb, #)	453.6	grams (gm or g)
	0.4536	kilograms (kg)
	7000	grains (gr)
	16	ounces (oz)
grain	0.0648	g
ton (short)	2000	lb
	0.9072	tonnes (metric tons)
ton (long)	2240	lb
gallons of water (US)	8.34	lb
Imperial gallon	10	lb

TABLE 1.1 Factors for Conversions (*contd.*)

U.S. Customary units	Multiply by	SI or U.S. Customary units
Unit weight		
ft^3 of water	62.4	lb
	7.48	gallon
pound per cubic foot (lb/ft^3)	157.09	newton per cubic meter (N/m^3)
	16.02	kg force per square meter (kgf/m^2)
	0.016	grams per cubic centimeter (g/cm^3)
Concentration		
parts per million (ppm)	1	mg/L
	8.34	lb/Mgal
grain per gallon (gr/gal)	17.4	mg/L
	142.9	lb/Mgal
Time		
day	24	hours (h)
	1440	minutes (min)
	86,400	seconds (s)
hour	60	min
minute	60	s
Slope		
feet per mile	0.1894	meter per kilometer
Velocity		
feet per second (ft/sec)	720	inches per minute
	0.3048	meter per second (m/s)
	30.48	cm/s
	0.6818	miles per hour (mph)
inches per minute	0.043	cm/s
miles per hour (mi/h)	0.4470	m/s
	26.82	m/min
	1.609	km/h
knot	0.5144	m/s
	1.852	km/h
Flowrate		
cubic feet per second (ft^3/s, cfs)	0.646	million gallons daily (MGD)
	448.8	gallons per minutes (gpm)
	28.32	liter per second (L/s)
	0.02832	m^3/s
million gallons daily (MGD)	3.785	m^3/d (CMD)
	0.04381	m^3/s
	157.7	m^3/h
	694	gallons per minute
	1.547	cubic feet per second (ft^3/s)
gallons per minute (gpm)	3.785	liters per minute (L/min)
	0.06308	liters per second (L/s)
	0.0000631	m^3/s
	0.227	m^3/h
	8.021	cubic feet per hour (ft^3/h)
	0.002228	cubic feet per second (cfs, ft^3/s)
gallons per day	3.785	liters (or kilograms) per day
MGD per acre · ft	0.4302	gpm per cubic yard
acre · feet per day	0.01427	m^3/s
Application (loading) rate		
pounds per square foot (lb/ft^2)	4.8827	kilograms per square meter (kg/m^2)

TABLE 1.1 Factors for Conversions (*contd.*)

U.S. Customary units	Multiply by	SI or U.S. Customary units
pounds per 1000 square foot per day ($lb/1000\ ft^2 \cdot d$)	0.00488	kilograms per square meter per day ($kg/m^2 \cdot d$)
pounds per cubic foot (lb/ft^3)	16.017	kilograms per cubic meter (kg/m^3)
pounds per 1000 cubic foot per day ($lb/1000\ ft^3 \cdot d$)	0.016	kilograms per cubic meter per day ($kg/m^3 \cdot d$)
pounds per foot per hour ($lb/ft \cdot h$)	1.4882	kilograms per meter per hour ($kg/m \cdot h$)
pounds per horse power per hour ($lb/hp \cdot h$)	0.608	kilograms per kilowatts per hour ($kg/kW \cdot h$)
pounds per acre per day ($lb/acre \cdot d$)	1.121	kilograms per hectare per day ($kg/ha \cdot d$)
gallons per acre (gal/acre)	0.00935	m^3/ha
million gallons per acre (Mgal/acre)	0.93526	m^3/m^2
million gallons per acre · ft ($Mgal/acre \cdot ft$)	0.43	gpm/yd^3
gallons per square foot per day ($gal/ ft^2 \cdot d$)	0.04074	cubic meter per square meter per day ($m^3/m^2 \cdot d$)
	0.04356	$Mgal/acre \cdot d$
gallons per minute per square foot (gpm/ ft^2)	58.674	$m^3/m^2 \cdot d$
square root of gpm per square foot $(gal/min)^{0.5}/ft^2$	2.7	$(L/s)^{0.5}/ m^2$
gallons per day per foot ($gal/d \cdot ft$)	0.01242	$m^3/d \cdot m$
square foot per cubic foot (ft^2/ ft^3)	3.28	m^2/m^3
cubic foot per gallon (ft^3/gal)	7.48	m^3/m^3
cubic foot per pound (ft^3/lb)	0.06243	m^3/kg
	62.43	L/kg
cubic foot per 1000 cubic foot per minute ($ft^3/1000\ ft^3 \cdot min$)	1	$L/ m^3 \cdot min$
Force		
pounds	0.4536	kilograms force (kgf)
	453.6	grams(g)
	4.448	newtons (N)
Pressure		
pounds per square inch (lb/in^2, psi)	2.309	feet head of water
	2.036	inches head of mercury
	51.71	mmHg
	6895	newtons per square meter (N/m^2) = pascal (Pa)
	0.0703	kgf/cm^2
	703.1	kgf/m^2
	0.0690	bars
pounds per square foot (lb/ft^2)	4.882	kgf/m^2
	47.88	N/m^2 (Pa)
pounds per cubic inch	0.01602	gmf/cm^3
	16.017	gmf/L
tons per square inch	1.5479	kg/mm^2
millibars (mb)	100	N/m^2
inches of mercury	345.34	kg/m^2
	0.0345	kg/cm^2
	0.0334	bar
	0.491	psi (lb/in^2)

TABLE 1.1 Factors for Conversions (*contd.*)

U.S. Customary units	Multiply by	SI or U.S. Customary units
inches of water	248.84	pascals (Pa)
atmosphere	101,325	Pa
	1013	millibars (1 mb = 100 Pa)
	14.696	psi (lb/in^2)
	29.92	inches of mercury
	33.90	feet of water
pascal (SI)	1.0	N/m^2
	1.0×10^{-5}	bar
	1.0200×10^{-5}	kg/m^2
	9.8692×10^{-6}	atmospheres (atm)
	1.40504×10^{-4}	psi (lb/in^2)
	4.0148×10^{-3}	in, head of water
	7.5001×10^{-4}	cm head of mercury
Mass and density		
slug	14.594	kg
	32.174	lb (mass)
pound	0.4536	kg
slug per foot^3	515.4	kg/m^3
density (γ) of water	62.4	lb/ft^3 at 50°F
	980.2	N/m^3 at 10°C
specific wt (ρ) of water	1.94	$slugs/ft^3$
	1000	kg/m^3
	1	kg/L
	1	gram per milliliter (g/mL)
Viscosity		
pound-second per foot^3 or slug per foot second	47.88	newton second per square meter (Ns/m^2)
square feet per second (ft^2/s)	0.0929	m^2/s
Work		
British thermal units (Btu)	1.0551	kilo joules (kj)
	778	ft lb
	0.293	watt-h
	1	heat required to change 1 lb of water by 1°F
hp-h	2545	Btu
	0.746	kW-h
kW-h	3413	Btu
	1.34	hp-h
Power		
horsepower (hp)	550	ft lb per sec
	746	watt
	2545	Btu per h
kilowatts (kW)	3413	Btu per h
Btu per hour	0.293	watt
	12.96	ft lb per min
	0.00039	hp
Temperature		
degree Fahrenheit (°F)	$(°F - 32) \times (5/9)$	degree Celsius (°C)
(°C)	$(°C) \times (9/5) + 32$	(°F)
	$°C + 273.15$	Kelvin (K)