THIRD EDITION

Shun Dar Lin

WATER AND WASTEWATER CALCULATIONS MANUAL

水和废水计算手册 下册

影印版

哈爾濱工業大學出版社
HARBIN INSTITUTE OF TECHNOLOGY PRESS

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影印版说明

Shun Dar Lin 博士是世界水和废水处理领域权威的知名科学家之一，拥有近 60 年的理论研究和工程实践经验，*Water and Wastewater Calculations Manual*（3rd Ed.）就是在此基础上编写的。

本手册由 WEF(Water Environment Federation) 组织，由美国 McGraw-Hill Education 公司出版，第一版于 2001 年面市，此后一直受到专业人士的好评和关注。为飨读者，我社特将 2014 年最新版——第三版进行了原文影印，以期让读者在最短时间内了解该领域的最新动态。

本手册不仅有比较深入的理论和实践介绍，提供了地表水、地下水、饮用水处理和废水处理工程中的基本原则、最佳实践以及计算的详细方法，而且提供了大量计算题，使读者易于理解和学习书中介绍的计算方法。

本手册给出了大量案例，其解决方案是基于实际的现场数据和最新的协会标准而确定的。

本手册包含了 130 多幅插图和 100 多个表格，读者可以很快地在其中找到所需的关键数据。

本手册可作为给水排水工程、环境工程等专业科技人员的工具书，也可作为相关专业人士的学习参考书。

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Water and Wastewater Calculations Manual

Shun Dar Lin

Third Edition

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New York Chicago San Francisco
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Singapore Sydney Toronto

ABOUT THE AUTHOR

Shun Dar Lin, Ph.D., is one of the world's leading water and wastewater scientists with more than 50 years of practical and academic experience in the field. He is Professor Emeritus at the University of Illinois at Urbana-Champaign. A registered professional engineer in Illinois and in Taiwan. Dr. Lin has published more than 100 papers, articles, and reports related to water and wastewater engineering, and to water resources. He has taught and conducted research since 1960 at the Institute of Public Health of the National Taiwan University. In 1986, Dr. Lin received the Water Quality Division Best Paper Award for "*Giardia lamblia* and Water Supply" from the American Water Works Association. He developed the enrichment-temperature acclimation method for recovery enhancement of stressed fecal coliform which has been adopted in the *Standard Methods for the Examination of Water and Wastewater* since the 18th Edition (1990). Dr. Lin is a life member of the American Society of Civil Engineers, the American Water Works Association, and the Water Environment Federation. He currently serves on many Task Force Committees for the *Standard Methods*. Dr. Lin was appointed by the Governor of Illinois to the Illinois Pollution Control Board as a Board Member (2008-2010). He is a consultant to the governments of Taiwan and the United States and for private firms.

ABOUT WEF

Founded in 1928, the Water Environment Federation (WEF) is a not-for-profit technical and educational organization of 36,000 individual members and 75 affiliated Member Associations representing water quality professionals around the world. WEF members, Member Associations and staff proudly work to achieve our mission to provide bold leadership, champion innovation, connect water professionals, and leverage knowledge to support clean and safe water worldwide. To learn more, visit www.wef.org.

***Cover:** The Stickney Water Reclamation Plant in Cicero, Illinois, shown in 2013. The facility is owned and operated by the Metropolitan Water Reclamation District of Greater Chicago (MWRD). Stickney is the largest wastewater treatment facility in the world and serves 2.38 million people in a 260 square mile area including the central part of Chicago and 43 suburban communities.*

Preface

This manual presents the basic principles and concepts relating to water/wastewater engineering and provides illustrative examples of the subject covered. To the extent possible, examples rely on practical field data and regulatory requirements have been integrated into the environmental design process. Each of the calculations provided herein is solved step-by-step in a streamlined manner that is intended to facilitate understanding. Examples (step-by-step solutions) range from calculations commonly used by operators to more complicated calculations required for research or design. For calculations provided herein using the US customary units, readers who use the International System may apply the conversion factors listed in Appendix E. Answers are also generally given in SI units for most of problems solved by the US customary units.

This book has been written for use by the following readers: students taking coursework relating to "Public Water Supply," "Wastewater Engineering," and "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 other professionals, such as chemists and biologists, who need 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.

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 (US 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 guided by the integration of rules and regulations on every aspect of water and wastewater. The author has performed an extensive literature survey as well as with his 50 years environmental engineering experiences on natural water, drinking water supply, and wastewater treatments to compile them in this book. Rules and regulations are described as simply as possible, and practical examples are given.

The text includes calculations for surface water, groundwater, drinking water treatment, and wastewater engineering. Chapter 1 comprises calculations for river and stream waters. Stream sanitation had been studied for nearly 100 years. By 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 book. Apportionment of stream users and pragmatic approaches for stream dissolved oxygen models also first appeared in this manual. From the 1950s through the 1980s, researchers focused extensively on wastewater treatment. In the 1970s, rotating biological contactors became a hot subject. Design criteria and examples for all of these are included in this volume. 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 is a comprehensive documentation on evaluation of water qualities of streams and reservoirs.

Chapter 2 is a compilation of adopted methods and documented research. In the early 1980s, the US EPA published Guidelines for Diagnostic and Feasibility Study of Public Owned Lakes (Clean Lakes Program, or CLP). This was intended to be as a guideline for lake management. CLP and its calculation (evaluation) methods are presented for the first time in this volume. Hydrological, nutrient, and sediment budgets and evaporation are presented for reservoir and lake waters. Techniques for conducting diagnostic/feasibility study on lakes and reservoirs, classification of lake water quality, and assessment of the lake trophic state index, and lake use support are also presented.

Calculations for groundwater are given in Chapter 3. 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 4. This chapter covers fluid (water) properties and definitions, hydrostatics, fundamental concepts of water flow in pipes, weirs, orifices, and in open channels, and flow measurements. Pipe networks for water supply distribution systems and hydraulics for water and wastewater treatment plants are also included.

Chapters 5 and 6 cover the unit process for drinking water and wastewater treatments, respectively. The US EPA 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 procedures. Drinking water regulations and membrane filtration are updated in Chapter 5. The section of "Health Risks" has been deleted in this edition. For the interested readers, please refer to the second edition. Pellet softing and log-removed by disinfection are unique in this book. Calculations for log-removal of pathogens are illustrated. Although the pellet softening process is not accepted in the United States, it has been successfully used in many other countries. It is believed that this is the first presentation of pellet softening in US environmental engineering books.

The collection and treatment (conventional and advanced) are covered in Chapter 6. Sludge treatments and biosolid manaagement (uses and disposal) are also included. Complecated calculations for the application of biosolids on agricultural lands are presented. Chapters 5 and 6 are the heart of the book and provide the theoretical considerations of unit processes, traditional (or empirical) design concepts, and integrated regulatory requirements. Drinking water quality standards, wastewater effluent standards, and several new examples have also been added.

The current edition corrects certain computational, typographical, and grammatical errors found in the previous edition.

Dr. Achlesh Daverey and Prof. Jih-Gaw Lin, both of National Chiao Tung University, Hsinchu, Taiwan, and Mr. Der-ming Lee of Leaderman & Associates Co, Taipei, Taiwan, prepared the draft of Section 28.4, SNAD process. Maggi Lan of Leaderman & Associates Co. provided the data inputs for the SNAD process. Raghavi Khullar did excellent editing the final draft. Amy Stonrbreaker of McGraw-Hill managed this project. The author also wishes to acknowledge Meiling Lin, for typing the manuscript. Ben Movahed, President of WATEK Engineering, reviewed a part of the section of membrane filtration. Alex Ya Ching Wu, Plant Manager of Cheng-Ching Lake Advanced Water Purification Plant in Taiwan, provided the operational manual for pellet softening. Jessica Moorman, Editor of *Water & Waste Digest*, provided 2006 drinking water regulatory updates. Thanks to Dr. Chuan-jui Lin, Dr. C. Eddie Tzeng, Nancy Simpson, Jau-hwan Tzeng, Heather Lin, Christine Murphy (in Brazil), Tracy Pierceall, and Karen Swanson. Robert Greenlee, Luke Lin, Kevin Lin, and Lucy Lin for their assistance. Any reader suggestions and comments will be greatly appreciated.

Shun Dar Lin
Chicago, Illinois

Contents

Chapter

6

Wastewater Engineering

1 What Is Wastewater?

"Wastewater," also known as "sewage," originates from household wastes, human and animal wastes, industrial wastewaters, storm runoff, and groundwater infiltration. Wastewater, basically, is the flow of used water from a community. It is 99.94% water by weight (Water Pollution Control Federation, 1980). The remaining 0.06% is material dissolved or suspended in the water. It is largely the water supply of a community after it has been fouled by various uses.

2 Characteristics of Wastewater

An understanding of the physical, chemical, and biological characteristics of wastewater is very important in the design, operation, and management of collection, treatment, and disposal of wastewater. The nature of wastewater includes the physical, chemical, and biological characteristics which depend on the water usage in the community, the industrial and commercial contributions, weather, and infiltration/inflow.

2.1 Physical properties of wastewater

When fresh, wastewater is gray in color and has a musty and not unpleasant odor. The color gradually changes with time from gray to black. Foul and unpleasant odors may then develop as a result of septic sewage. The most important physical characteristics of wastewater are its temperature and its solids concentration.

Temperature and solids content in wastewater are very important factors for the wastewater treatment processes. Temperature affects chemical reaction and biological activities. Solids, such as total suspended solids (TSS), volatile suspended solids (VSS), and settleable solids, affect the operation and sizing of treatment units.

Solids. Solids comprise matter suspended or dissolved in water and wastewater. Solids are divided into several different fractions, and their concentrations provide useful information for characterization of wastewater and control of treatment processes.

Total solids. Total solids (TS) is the sum of total suspended solids and total dissolved solids (TDS). Each of these groups can be further divided into volatile and fixed fractions. Total solids is the material left in the evaporation dish after it has dried for at least 1h or overnight (preferably) in an oven at 103 to 105°C and is calculated according to *Standard Methods* (APHA *et al.*, 2012)

$$\text{mg TS/L} = \frac{(A - B) \times 1000}{\text{sample volume, mL}} \tag{6.1}$$

where A = weight of dried residue plus dish, mg
B = weight of dish, mg
1000 = conversion of 1000 mL/L

Note: Samples can be natural waters, wastewaters, even treated water.

Total suspended solids. Total suspended solids are referred to as nonfilterable residue. The TSS is a very important quality parameter for water and wastewater and is a wastewater treatment effluent standard. The TSS standards for primary and secondary effluents are usually set at 30 and 12 mg/L, respectively. TSS is determined by filtering a well-mixed sample through a 0.2 μm pore size, 24 mm diameter membrane; the membrane filter is placed in a Gooch crucible, and the residue retained on the filter is dried in an oven for at least 1h at a constant weight at 103 to 105°C. It is calculated as

$$\text{mg TSS/L} = \frac{(C - D) \times 1000}{\text{sample volume, mL}} \tag{6.2}$$

where C = weight of filter and crucible plus dried residue, mg
D = weight of filter and crucible, mg

Total dissolved solids. Dissolved solids are also called filterable residues. Total dissolved solids in raw wastewater are in the range of 250 to 850 mg/L.

TDS is determined as follows. A well-mixed sample is filtered through a standard glass fiber filter of 2.0 μm normal pore size, and the filtrate is evaporated for at least 1h in an oven at 180 ± 2°C. The increase in dish weight represents the total dissolved solids, which is calculated as

$$\text{mg TDS/L} = \frac{(E - F) \times 1000}{\text{sample volume, mL}} \tag{6.3}$$

where E = weight of dried residue plus dish, mg
F = weight of dish, mg

Fixed and volatile solids. The residue from TS, TSS, or TDS tests is ignited to constant weight at 550°C. The weight lost on ignition is called volatile solids, whereas the remaining solids represent the fixed total, suspended, or dissolved solids. The portions of volatile and fixed solids are computed by

$$\text{mg volatile solids/L} = \frac{(G - H) \times 1000}{\text{sample volume, mL}} \tag{6.4}$$

$$\text{mg fixed solids/L} = \frac{(H - I) \times 1000}{\text{sample volume, mL}} \tag{6.5}$$

where G = weight of residue plus crucible before ignition, mg
H = weight of residue plus crucible or filter after ignition, mg
I = weight of dish or filter, mg

The determination of the volatile portion of solids is useful in controlling wastewater treatment plant operations because it gives a rough estimation of the amount of organic matter present in the solid fraction of wastewater, activated sludge, and in industrial waste.

Determination of volatile and fixed solids does not distinguish precisely between organic and inorganic matter. Because the loss on ignition is not confined only to organic matter, it includes losses due to decomposition or volatilization of some mineral salts. The determination of organic matter can be made by tests for biochemical oxygen demand (BOD), chemical oxygen demand (COD), and total organic carbon (TOC).

Settleable solids. Settleable solids is the term applied to material settling out of suspension within a defined time. It may include floating material, depending on the technique. Settled solids may be expressed on either a volume (mL/L) or a weight (mg/L) basis.

The volumetric method for determining settleable solids is as follows. Fill an Imhoff cone to the 1-L mark with a well-mixed sample. Settle for 45 min, gently agitate the sample near the sides of the Imhoff cone with a rod or by spinning, then continue to settle for an additional 15 min and record the volume of settleable solids in the cones as mL/L.

Another test to determine settleable solids is the gravimetric method. First, determine total suspended solids as stated above. Second, determine nonsettleable suspended solids from the supernatant of the same sample which has settled for 1 h. Then determine TSS (mg/L) of this supernatant liquor; this gives the nonsettleable solids. The settleable solids can be calculated as

$$\text{mg settleable solids/L} = \text{mg TSS/L} - \text{mg nonsettleable solids/L} \tag{6.6}$$