Air Contaminants, Ventilation, and Industrial Hygiene Economics

The Practitioner's Toolbox and Desktop Handbook

Roger Lee Wabeke

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AIR CONTAMINANTS, VENTILATION, AND INDUSTRIAL HYGIENE ECONOMICS

The Practitioner's Toolbox and Desktop Handbook

I dedicate this book to:

Mary, my best friend, wife, and life companion; our wonderful children: Lisa, Lori, and Michael and their spouses, Richard, John, and Andrea, respectively; and our beautiful grandchildren: Abigail, Charlotte, Grace, Kettler, and Veronica;

present and former colleagues and my students who, through support and guidance, offered constructive criticism, shared their many solved problems, and gave insights without which this book would not have sufficient richness and value;

my manuscript reviewers: Drs. Patricia A. Brogan, MSc, PhD, CIH, ROH, and Ernest P. Chiodo, MD, JD, MPH, MSc, MBA, CIH,

all who strived, currently endeavor, as well as future practitioners who work to improve our environmental air quality applying fundamental industrial hygiene practices, and

my publisher, Taylor & Francis/CRC Press, who with their endorsement and oversight, nudged me to embark on this project.

Disclaimer

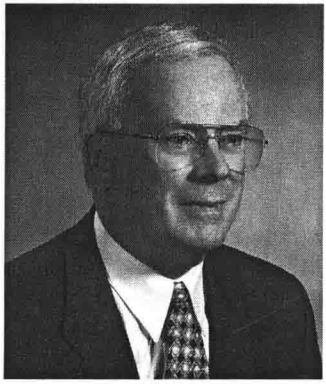
Conscientious effort was made to ensure the contents of this book and every problem, in particular, are technically accurate, complete, and useful in the day-to-day practice of contemporary industrial hygiene and air pollution control engineering. All calculations and problems were critically peer reviewed. However, when thousands of informational items are entered into a published work, a few typographical errors may result even with the best efforts of everyone involved in the process. To ensure completeness and accuracy of these calculations, users are encouraged to send any corrections, additions, and comments that enhance usefulness of this handbook to the author or to the publisher.

Roger Lee Wabeke
Detroit, Michigan

Man is here for the sake of other men—and for all unknown souls with whose fate we are connected by a bond of sympathy.

Albert Einstein

Author



The author spent 47 years in full-time professional practice as a chemical safety engineer, industrial hygienist, and occupational toxicologist. Throughout a richly diverse practice, he encountered many challenging situations that he wished to share with those who follow. This is the overarching purpose of this book.

Air Contaminants and Industrial Hygiene Ventilation, published in 1998 by Lewis Publishers/Taylor & Francis/CRC Press, was his first book. Included here are 450 solved problems with comments from the book. Added were 275 problems, and the original 450 were expanded and modified to reflect current ventilation engineering and industrial hygiene practices plus advances in knowledge of atmospheric toxicants and control by elimination, substitution, process changes, ventilation, personal protective equipment, warnings, wet methods, and other time-tested interventional and prevention strategies.

Someone once jokingly said that every equation in a book cuts potential sales by one half. If so, this book, replete with numerous, but simple, equations, will never be a best seller. Regardless, the publisher and author disagree and expect ample acceptance.

Preface

A few problems and calculations in this book were initially developed to assist industrial hygienists preparing for their board-certification examinations. After the author passed (albeit probably marginally) two-day board-certification examinations in 1973 in Boston, he and a few other certified industrial hygienists from the Detroit area organized a one-day—admittedly brief, review course for others preparing for their examinations. Now, almost four decades later, that process is the primary launch point for this book.

The course was offered semi-annually, on Saturdays, at Wayne State University School of Medicine in the Department of Occupational and Environmental Health. The Michigan Industrial Hygiene Society provided ample refreshments. The registrants and instructors brought "brown bag" lunches. There were no fees; instructors provided *pro bono* lectures. Nine discussion rubrics covered air sampling and analysis, ventilation, toxicology, calculations, radiation, respiratory protection, industrial hygiene chemistry, noise, and heat stress and strain. With 50 minutes for each subject, only the industrial hygiene "pearls" could be presented. After the didactic lectures, many met afterwards for pizza, libations, and to discuss questions. Today, of course, there are several high-quality one-week review courses offered around the country for a reasonable fee. The depth and scope of these courses are far more encompassing and preparative than our early initiative one-day course.

This is the author's second book addressing air quality, ventilation, toxicology, and other industrial hygiene issues. The first book, *Air Contaminants and Industrial Hygiene Ventilation* (1998), was widely received throughout the world. Several persons encouraged the author to write a second book expanding upon the first publication. Over recent years, he developed more lectures to assist his students in professional development, provided case studies that incorporate the business model and enterprise economics, and tips to prepare for the Certified Industrial Hygienist board examinations. In some aspects, this book could partly be considered the second edition of the first book because every problem in that book is included here, but expanded. Additional text was added to further clarify initial existing problems, and 275 new problems were added. In part, over a long career with many potholes, the author hopes that this book removes some bumps and rough spots for those who follow. The author, now late in his career and at the 47th year of full-time professional practice in 18 countries and in every state except Hawaii and Idaho is still learning and desires to share these quantitative and practical experiences and tips from his journey.

Many problems in this book were acquired during the author's career of resolving industrial hygiene exposures of workers and others in different environments. These included evaluations of numerous workplace poisonings, fatalities, chemical spills, and catastrophic air emissions. A few were provided over the years by present and former colleagues, mentors, and graduate students far too numerous to mention.

Some were air modeling calculations. Still others served as the foundation for homework assignments and examination questions for graduate students in classes the author presented at Wayne State University Schools of Medicine and Pharmacy and Health Sciences, the University of Michigan School of Public Health, and undergraduate students at Henry Ford Community College.

How to Use This Book

This handbook is intended primarily for use by

- Industrial and occupational hygienists
- Heating, ventilation, and air conditioning (HVAC) system engineers
- Air pollution control engineers
- Chemical safety engineers
- Hazardous material managers
- Inhalation and application toxicologists
- Air contaminant emergency responders
- Health care and public health professionals concerned with air quality
- Environmental evaluation and control engineers
- Atmospheric scientists and meteorologists
- Professors and teachers of these subjects
- Graduate and undergraduate students of these subjects
- Risk managers

Several typical plus some uncommon industrial hygiene problems that require mathematical solutions are covered. Tips are given to help one prepare for and take the board-certification examinations. Common formulae, equations, conversions, and other information worthy of committing to memory and practice are also included.

This book was prepared to be browsed. To simply read this book offers little. The problems must be studied. Once the ramifications of a problem are explored, the underlying concepts must be encoded to help ensure future relevance to practitioners.

Those preparing for board-certification examinations should master introductory sections and, at a minimum, the following 14 problems: 140, 304–306, 308–314, 271, 276, and 277. Once these are successfully handled, problems 1–7, 10–14, 16–20, 27, 29, 30, 32, 70, 79, 88, 93, 101, 102, 108, 297, 316, 321, and 406 should be understood. Those in the best position to achieve a high score on these aspects in the certification examinations will begin preparing at least one year in advance. If only six problems are mastered daily for four months during the examination preparatory year, every problem and exercise in this book will be covered.

The teacher of these subjects can extract selected, relevant course problems for student assignments and homework. With only slight modifications, each problem can be custom "tailored" to make it unique with pedagogic relevance to the course materials and content. Many problems can serve as a launch point to discuss industrial hygiene control methods and consequences to workers' health if preventive steps are not taken. The author has assigned several problems to be solved by his students with supporting industrial hygiene and environmental control methods. Students defend their selections of control methods incorporating cost savings and technical solutions when feasible.

The seasoned and experienced professional is encouraged to browse this book as well. Colleagues have suggested that solving these problems might be used to help maintain board-certification maintenance points. This concept could be raised with the American Board of Industrial Hygiene. Moreover, the Board could select some key problems from this casebook to be included in the revolving examinations.

The problems in this workbook are not grouped into categories. Few problems in industrial hygiene fall neatly into a specified "type." Rather, problems faced by today's industrial hygienists embrace several diverse topics. For example, a complex chemical spill issue could entail compound calculation sets of evaporation rates, air contaminant concentrations, worker's dose determinations, additive mixtures, community evacuation parameters, dilution ventilation requirements, and chemical contaminant half-lives and environmental fate. Several problems encompass such a broad scope and are of this nature (e.g., see Problem 316, referred to by a colleague as the "mother of all industrial hygiene problems"). While daunting, Problem 316 is not as challenging as a few others. Some problems, understandably, are far more rigorous and robust than others. Certain key types of problems are presented in various ways.

Since the problems in this handbook cannot be easily sorted into groups, it is the author's hope that industrial hygienists, chemical safety engineers, students and their teachers, atmospheric toxicant scientists, ventilation engineers, and all others will frequently peruse the problems. Only in this way will users begin to develop calculation methods and their "mental index" of the broad scope and diversity of a plethora of problems and their own systematic schema to easily define and solve them.

Another purpose of this handbook is to provide an assortment, a repository, and a reference set of calculations to assist industrial hygienists throughout their careers. Calculations to arrive at solutions for many of these types of problems are performed frequently by industrial hygiene practitioners. Others are done less often, some rarely, but the examples are included to assist resolution of uncommon problems. The author hopes that students of these problems will not only be challenged, but will also see the diversity of issues industrial hygienists and chemical safety engineers encounter, and that they will be stirred to regularly return to this handbook and engage themselves by these problems. In so doing, those responsible for conserving health and providing for the comfort of workers and the public's health and safety might see solutions applicable to situations they regularly, or perhaps even rarely, encounter during their professional practice.

Many problems can be solved by a variety of methods. The calculations are not always necessarily the "best" or the quickest way; however, the author was comfortable with the approach that was taken and fully recognized that stated solution steps might not be the most expedient method to arrive at the answers. Most problems, hopefully, balance theory and practical applications. A tad of levity is injected into some problems to help break the tedium and chore of some of the more daunting, lengthy calculations.

These problems do not require mathematical skills beyond college algebra and elementary statistics. Most calculations are simple arithmetic, but all require humility and critical, logical thinking based on sound understanding of basic industrial hygiene principles relating to evaluation of exposures to air contaminants. Since the

science aspects of industrial hygiene (as contrasted with intuitive "art" parts) are quantitative in nature, those who are adept at number "crunching" and mathematical logic should have no difficulty solving these problems. Once the principles of a problem are understood, then it becomes, as the engineers say, simply a matter to methodically "plug and chug" the often ponderous numerical arithmetic parts. Several problems in this workbook are variations on a common theme. The author believes that, to fully understand some of the key concepts, one must be able to see a multifaceted problem from all aspects and be able to solve for the different variables.

Finally, these problems are a work practice module. For those preparing for the board-certification examinations, little will be gained by sitting down and simply reading these problems and skipping the exercises. One will reap only nominal benefit from the problems unless they are systematically analyzed, comprehended, and completed.

Remember that the certification examination questions are highly quantitative in nature. Over half of the core aspects examination questions may involve questions that require calculations, whereas the comprehensive practice portion may be 20% or more questions requiring calculations in air pollution, noise, radiation, heat strain, chemistry, ventilation, statistics, toxicology, safety engineering, ergonomics, and other rubrics.

Note: Throughout the book, unless otherwise stated, the concentrations of vapors and gases are expressed as parts per million by volume (ppm = ppm_v), not parts per million by mass or weight (ppm_m). Likewise, listed concentrations of air contaminants in high concentrations may be expressed as percent by volume ($\%_v$), or just %. Assume NTP (25°C, 760 mm Hg, dry air) unless otherwise stated. With knowledge of geography, we assume that port and sea level cities have a barometric pressure of 760 mm Hg unless otherwise stated. Although the author is knowledgeable in significant numbers, you will encounter calculations where this principle was not applied because application will not offer more insight.

CONTENTS

1. 725 practical (and some unusual, but helpful), solved problems with relevant, timely comments and helpful application tips covering:
   - Air contaminants, toxicants, and toxins released from our mobile and stationary sources that can adversely affect the health and comfort of people at worksites and those in residential, public, and ambient atmospheric environments with a major emphasis on industrial hygiene practice
   - Industrial ventilation system design engineering, testing, and intervention.
   - Inhaled, dermally absorbed, and ingested doses of toxicants and toxins
   - Air-sampling statistics and probability
2. 154 win–win business economic case studies demonstrating how to preserve your clients' financial resources, promote industrial hygiene, foster worksite safety, learn the financial ropes of business economics, and help control your

clients' potential adverse environmental impact and, in so doing, greatly enhancing career progress
3. Tips on preparing for, and passing, Certified Industrial Hygienist board examinations
4. Keys to professional development and future success for every industrial hygiene student, early-career professionals, and those launching careers as consultants in workplace safety, health, risk management, and environmental engineering

Introduction

TIPS FOR THE AMERICAN BOARD OF INDUSTRIAL HYGIENE CERTIFICATION EXAMINATIONS

1. Bring a scientific calculator with fresh batteries. Be able to apply all major functions. The calculator should have scientific notation, $\log_{10}$ and natural logarithms, common conversions (e.g., gallons to liters, lb to kg, °F to °C, and so on), exponential notation, and basic statistical functions.
2. Bring sharp pencils and new ball point pens to the exams. You might consider hard candy, mints, and gum (nonbubble type). How about a canteen of cold juice? Or a Thermos® of coffee? Cans of caffeinated soda (Mountain Dew®, Coke®, Pepsi®)? An eye moisturizer (e.g., Visine®) might provide ocular relief as needed.
3. Do not "cram" on the nights before the examinations. Kick back. Consider going to a light air pollution opera or to a nice movie—preferably a good industrial hygiene comedy or a documentary on the correct application of Pitot tubes and velometers.
4. Get a good night's sleep. Arrive refreshed and confident and fearlessly, boldly stroll into the examination room. Intimidate those about you in these competitive tests by sneering and insinuating that these examinations are just a "walk in the park." The examination is difficult. Some have sat for the examination as many as four times before passing. Having interviewed several who sat at least twice, I quickly learned they initially failed to take the time and apply hard work to prepare.
5. Wear comfortable clothes, for example, big, soft, over-sized shoes are nice at examinations. Sit in the center of the examination room to avoid any cold drafty walls and windows, solar heat, and excessive glare and contrasty shadows. Select a comfortable chair seat. Consider bringing a chair seat pan cushion.
6. Eat a light, well-balanced, nourishing breakfast and a similar lunch. Avoid heavy pancakes, fatty food, highly fibrous food, greasy donut "sinkers," and so on. Sugars from fresh fruits and a couple of proteins might not be a bad idea. Active brains need amino acids. Bring chunks of cheese to the examinations. Studies show we reason better when well hydrated. Taking a laxative the night before is not prudent. Be mindful that the residence time of food in the gastrointestinal tract can be 24 or more hours. Third helpings of stewed prunes after a beans, cabbage, and turnips dinner the day before examination are foolish menu choices. Pray that those seated around you did not eat such a meal.
7. Your first examination calculation must be:

$$\frac{\text{examination duration (in minutes)}}{\text{total number of questions}} = \frac{\text{average number of minutes allocated}}{\text{question}}$$

Be mindful of this average, and do not spend too much time on a single question. Try to pace yourself. Questions and problems involving calculations will normally require more time than others and might be weighted more heavily. Wear a wrist watch to keep track of the time and your mental pacing schedule.

8. Answer every question. There are no penalties for guessing. A chimpanzee will get about 20% correct answers if there are five choices and the multiple answers and his or her guesses are truly randomized. But, knowing absolutely nothing, you must do at least three to four times better than the chimp to be considered for a passing grade. Yet, three times nothing is still zero.
9. There is an ancient bromide: If you must guess at the answer, stick with your first hunch. If you erase it and replace it with a second guess, odds are you will be farther from the scientific truth. And the Board is searching for the scientific truth.

   Having stated that, while scientific principles are critical in the practice of industrial hygiene, professional judgment is as well. We often encounter exposure scenes where controls are obviously indicated, but a standard or guideline has not been exceeded. This must never deter us from intervening on behalf of workers at the risk of the six Ds: **D**iscomfort, health **D**isorders, reversible **D**iseases, irreversible **D**iseases, **D**eaths, and significant property **D**amages.
10. Disregard previous answers; that is, if you guessed (or correctly answered) choice "C" on the previous five questions, do not think "C" for the next answer is incorrect if you must guess. There is a 20% chance it is correct.
11. Always ask yourself once you have selected an answer: "*Does my answer make sense*?" I have seen some absurd answers from students who, when rushed, did not take time to ask this simple question, yet they could otherwise correctly solve the problem. Wild answers included 154.7×106 ppm_v, a TWAE of 879 gram of dust/m^3, and a 30-minute exposure of a worker to 2300 ppm_v HCN, followed by a 7-$\frac{1}{2}$ hour exposure to the same gas at 0.01 ppm! But then she/he will no longer be working after an inhalation or two. Where is it written that one cannot evaluate the exposure of a corpse?
12. Memorize equations, constants, formulae, atomic weights, conversions, and so on given on the following introductory pages. Equations and constants in boxes are especially important and are "must knows."
13. Watch decimal points and orders of magnitude! Watch units! Ensure that they are consistent—10 thimbles do not a gallon make. Five cm ≠ 11'. Be able to perform *dimensional analysis* to convert to other units, for example: from 100 fpm to mph, from 173 mg/sec to tons/day, and 2.3 mg/m^3 to lb/ft^3:

$$\frac{100\,\text{feet}}{\text{minute}} \times \frac{60\,\text{minutes}}{\text{hour}} \times \frac{\text{mile}}{5280\,\text{feet}} = \frac{1.14\,\text{miles}}{\text{hour}}, \text{barely a light breeze}$$

$$\frac{173\,\text{mg}}{\text{sec}} \times \frac{60\,\text{sec}}{\text{min}} \times \frac{60\,\text{min}}{\text{hr}} \times \frac{24\,\text{hr}}{\text{day}} \times \frac{\text{g}}{1000\,\text{mg}} \times \frac{\text{lb}}{453.59\,\text{g}} \times \frac{\text{ton}}{2000\,\text{lb}} = \frac{0.0165\,\text{ton}}{\text{day}}$$

$$\frac{2.3\,\text{mg}}{\text{m}^3} \times \frac{\text{m}^3}{35.315\,\text{ft}^3} \times \frac{\text{g}}{1000\,\text{mg}} \times \frac{0.00220\,\text{lb}}{\text{g}} = \frac{1.43 \times 10^{-7}\,\text{lb}}{\text{ft}^3}$$

Note how fractions are arranged so identical units cancel each other. Two final practices: convert 1.8 mcg/m^3/second into lb/ft^3/year (= 0.00354 lb/ft^3/year), and if men's facial hair growth rate is an average of 0.5 cm/day, calculate a beard-second (a standard unit for "slow," a counterpart to light-year) (5.79×10^{-9} cm/sec). The speed of light is 29,979,245,800 cm/sec. So, the ratio of beard-second to the speed of light is (5.79×10^{-9} cm/sec)/2.9979×10^{10} cm/sec = 1.93×10^{-19}—of highly redeeming social and scientific value. OK, let us try the inverse of a beard-second to the speed of light to arrive at values closer to which we can understand: ($1/5.79 \times 10^{-9}$ cm/sec)/2.9979×10^{10} cm/s = 0.00576. Now, most can deal easily with that number. The inverse of beard-second is an in-grown whisker which divided by speed of light is 0.00576 centimeter/second.

An excellent Website for conversions is www.onlineconversion.com where you can convert almost any metric to virtually any reasonable other—some amusingly silly.

14. Finally, *PREPARE, DON'T PRAY!* If you want to successfully solve the problems, *PRACTICE, PRACTICE, and PRACTICE* some more! If you work with other industrial hygienists, ask to solve *their* problems! Ask them to share examples of problems they might have in their notes and professional repertoire.

Dr. Steven Levine (professor emeritus, University of Michigan's School of Public Health) offered a few of the following examination tips. Heed Dr. Levine's sage advice. He is certified in both the *Comprehensive Practice and Chemical Aspects of Industrial Hygiene*. The author added to and augmented Dr. Levine's tips.

AT LEAST SIX MONTHS BEFORE THE EXAMINATION

1. Take a comprehensive review course. Refrain from sight-seeing and going "out on the town" while attending this course; instead, study every night. Review the notes for the next day's lectures. Prepare questions for instructors in areas where your concepts and skills are fuzzy.
2. Outline the notes in the book from the comprehensive review course.
3. Condense the outline on 3" × 5" flip cards. The outlining and condensing "process" will be a valuable learning tool.

4. Buy and use a computerized study and simulated examination program. These programs give practice in answering multiple choice questions.
5. Practice every type of calculation you can find. Ten of the most important types of calculations in the area of air contaminants, risk assessment, and ventilation are
   - "Dr. Clum Z. Chemist" who spilled a bottle of a volatile solvent with known vapor pressure in a room of a given volume with described ventilation parameters
   - Exponential relationships (e.g., radioactive decay, half-value thickness shielding, dilution ventilation, and half-life concentrations)
   - Inverse square law
   - Converting air contaminant concentrations (e.g., converting mg/m^3 into ppm_v)
   - Vapor pressure calculations; saturation concentrations in confined, unventilated spaces; gas and vapor migration
   - Ventilation air volume and hood capture velocity and duct velocity calculations
   - Additive mixture rule for multiple airborne toxicants
   - Time-weighted average dose calculations including consideration for overtime
   - TLV®s and OSHA PELs for air contaminant mixtures
   - The three fan laws; ventilation hoods ventilation capture velocities, characteristics of mechanical local exhaust hoods and systems, and dilution ventilation

If you understand these basic types of problems, you will be able to do a significant number, perhaps all, air sampling and ventilation types of examination calculations.

6. Exercise during your study breaks. Being physically fit will help you mentally and emotionally and gives you the stamina needed for this rigorous examination.
7. Do not reward yourself for wasting study time. For example, if you have a full day to study, and find yourself unable to focus, do "nothing" until you can. If, instead, you do other productive work, you will feel good about your alternative productivity, but you will not have accomplished any studying. Every now and then, that is OK.
8. Keep an honest record of concepts you do, and do not, know. Never hesitate to ask for help—an earmark of professionals who know their limitations, weaknesses.
9. Know how to operate your calculators quickly and accurately.
10. Bring an extra calculator—same type (and extra batteries).
11. Study diligently daily. For example, if only six problems are studied from this book every day, 120 days ($\cong$ 4 months) are needed to study all but three of them. If handled this way, these study tasks are not so daunting.