Subsurface Ventilation Engineering.

Dedication: This work has been undertaken in fulfillment of a long-standing promise to my former teacher, mentor and dear friend,

Professor Frederick Baden Hinsley

The book is dedicated to his memory.

Subsurface Ventilation Engineering

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Foreword to the Web version of the book.

In preparing this updated version of the textbook originally published in 1993 and under the title of Subsurface Ventilation and Environmental Engineering, the opportunity has been taken to update material that has seen significant change since the first version was written. The word 'Environmental' has been removed from the title as this term has increasingly come to refer to the surface environment. Several of the major changes are particularly applicable to developments in software that have taken place for planning the ventilation and condition of the underground environment.

The book remains a reference and text for professional engineers, researchers and teachers as well as for undergraduate and graduate students who have an interest in the planning and control of the environment in underground mines or other subsurface openings. Accordingly, the theoretical underpinnings of the subject are dealt with in some detail.

While the practical techniques of topics such as ventilation surveys or the use of computer software are included, this text is not intended specifically to be a ventilation officer's handbook. Such handbooks are best prepared within individual countries or institutions to reflect local methodologies, conditions and legislation.

In addition to printed copies, this updated text is available at no cost for downloading from the Internet address of Mine Ventilation Services, Inc. at: http://www.mvsengineering.com/

Contents

PART 4. Heat and humidity

PART 5. Dust

PART 6. Fires and explosions

PREFACE TO THE ORIGINAL TEXT

This book has been written as a reference and text for engineers, researchers, teachers and students who have an interest in the planning and control of the environment in underground openings. While directed primarily toward underground mining operations, the design procedures are also applicable to other complex developments of subsurface space such as nuclear waste repositories, commercial accommodation or vehicular networks. The book will, therefore, be useful for mining, civil, mechanical, and heating, ventilating and air-conditioning engineers involved in such enterprises. The chapters on airborne pollutants highlight means of measurement and control as well as physiological reaction. These topics will be of particular interest to industrial hygienists and students of industrial medicine.

One of the first technical applications of digital computers in the world's mining industries was for ventilation network analysis. This occurred during the early nineteen sixties. However, it was not until low-cost but powerful personal computers proliferated in engineering offices during the 'eighties that the full impact of the computer revolution was realized in the day-to-day work of most mine ventilation engineers. This book reflects the changes in approach and design procedures that have been brought about by that revolution.

While the book is organized into six parts, it encompasses three broad areas. Following an introductory background to the subject, chapters 2 and 3 provide the fundamentals of fluid mechanics and thermodynamics that are necessary for a complete understanding of large three-dimensional ventilation systems. Chapters 4 to 10, inclusive, offer a comprehensive treatment of subsurface airflow systems while chapters 11 to 21 deal with the airborne hazards that are encountered in underground openings.

Each chapter is self-contained as far as is practicable. The inter-related features of the topics are maintained by means of copious cross-references. These are included in order that practicing engineers may progress through a design project and be reminded of the wider repercussions of decisions that might be made. However, numerous cross-references can be a little distracting. The student is advised to ignore them during an initial reading and unless additional information is sought.

Many of the chapters are subdivided into theoretical and descriptive sections. Again, these can be read separately although a full understanding of the purpose and range of application of design procedures can be gained only through a knowledge of both. When used as a refresher or text by practicing engineers, it is suggested that the relevant descriptive section be consulted first and reference made back to the corresponding analysis or derivation when necessary.

The use of the book as an aid to teaching and learning can be moulded to suit any given curriculum. For the full education of a subsurface ventilation engineer, chapters 1 to 10 may be employed during a course on ventilation, i.e. airflow processes, leaving the chapters on gases, heat, dust, and fires and explosions for further courses. Alternatively, undergraduate courses my concentrate on the practical aspects of the subject, leaving the more theoretical analyses to graduate school. In any event the teacher may compile his or her own syllabus at any given level by choosing relevant sections from selected chapters.

In most countries, mining activities are regulated by specific state or national legislation. This book has been written for an international audience and reflects the author's experience of teaching and practice in a number of countries. While guideline threshold limit values are given, the reader is frequently reminded to consult the relevant local regulations for specific mandatory requirements and limitations on practical procedures. To reflect the international readership, Systéme Internationale (SI) units are employed and a comprehensive list of conversion factors is provided.

ACKNOWLEDGMENTS

There are many people without whose contributions the original edition of this book could not have been written. First, I thank Shirley, my wife, for her patience and understanding not only through the long hours of midnight oil burning that took place during the writing but, more particularly, for the extended periods, stretching over many years, when she was left alone to look after the home and family while I was deep under the surface of some faraway country.

I am grateful to former colleagues in the Department of Mining Engineering, University of Nottingham, England, for sowing seeds of ideas that later produced practical designs and procedures, many of which are reflected in this book; especially Ian Longson with whom I rediscovered the fascinations of thermodynamic logic, Leslie H. Morris, Dr. Jim R. Brown and, most of all, Professor F. Baden Hinsley to whom the book is dedicated. I am also privileged in having worked with excellent students from whom I learned a great deal, at Nottingham, the University of California, Berkeley, and at Virginia Tech.

Despite having been involved in numerous research investigations, my knowledge of subsurface ventilation and environmental engineering has been advanced primarily by working on feasibility studies and practical projects with mining engineers in many countries. Most of the case studies and examples in the book originated in such work. In particular, I am truly grateful for having had the opportunity of interacting with dedicated professional engineers in the United Kingdom, the countries of East and West Europe, South Africa, Australasia, India, South America, the United States of America and Canada.

I am indebted to the two ladies who shared typing the original manuscript. First, my daughter Alison D. McPherson who took great delight in correcting some of my mathematics, and Lucy Musante, my Secretarial assistant at Mine Ventilation Services, Inc. the most skilled and dedicated secretary with whom I have ever worked. Most of the initial reviews of chapters were undertaken by staff of Mine Ventilation Services, namely Daniel J. Brunner, Justus Deen, Martha O'Leary and, most particularly, Keith G. Wallace who willingly volunteered far more than his fair share of the work. Several chapters were reviewed by Dr. Felipe Calizaya, formerly at Berkeley and now at the University of Utah.

Some of the analyses described in the book arose directly out of funded research. The physiological model in chapter 17 was developed for the U.S. Department of Energy via Sandia National Laboratories as part of an investigation into climatic conditions in a deep geological repository for nuclear waste. Some of the heat transfer and climatic simulation studies in chapters 15 and 16, and investigations into the installation of booster fans outlined in chapter 9 were assisted by funding from the Generic Mineral Technology Center in Mine Systems Design and Ground Control, Office of Mineral Institutes, U.S. Bureau of Mines under Grant No. G1125151. I am indebted to those organizations for financing the work.

Finally, but also foremost, I thank the Good Lord for guiding my career to a point when I could prepare this book.

TABLE OF CONVERSION FACTORS BETWEEN IMPERIAL AND SI UNITS

Quantity	Imperial to SI				SI to Imperial		
Length	1 ft	= 0.304 8	m		1 m	= 3.280 8	ft
	1 yd	= 0.914 4	m			= 1.093 6	yd
	1 in	= 0.025 4	m			= 39.370 1	in
Area	1 ft^2	= 0.092 9	m^2		1 m^2	= 10.763 9	ft^2
	1 in^2	= 0.000 645	m^2			= 1550.003	in^2
Acceleration	1 ft/s^2	= 0.304 8	m/s^2		1 m/s^2	= 3.280 8	ft/s^2
Force	1 lbf	= 4.448 2	N		1 N	=0.2248	lbf
	1 imp.ton f	= 9964.02	N				
Velocity	1 ft/s	= 0.304 8	m/s		1 m/s	= 3.2808	ft/s
	1 ft/min	= 0.005 08	m/s			= 196.85	ft/min
Volume	1 ft^3	= 0.028 32	m^3		1 m^3	= 35.315	ft^3
	1 yd^3	= 0.764 56	m^3			= 1.308	yd^3
	1 imp. gal	= 4.545	litre		1 litre	= 0.2200	imp. gal
	1 U.S. gal	= 3.785	litre		(0.001 m^3)	= 0.2642	U.S. gal
Volume Flow	1 ft^3/s	= 0.028 32	m^3/s		1 m^3/s	= 35.315	ft^3/s
	1 ft^3/min	= 0.000 472	m^3/s			= 2118.9	ft^3/min
	1 imp gal/h	= 0.004 55	m^3/h		1 m^3/h	= 220.0	imp. gal/h
	1 imp gal/min	= 0.004 55	m^3/min		1 m^3/min	= 220.0	imp. gal/min
		= 4.545	litre/min		1 litre/min	= 0.220	imp. gal/min
		= 0.075 75	litre/s		1 litre/s	= 13.20	imp. gal/min
	1 U.S. gal/min	= 0.06313	litre/s			= 15.84	U.S. gal/min
Mass	1 lb	= 0.453 592	kg		1 kg	= 2.204 62	lb
	1 imp. ton (2240 lb)	= 1.016 05	t		1 t = 1000 kg	= 0.984 20	imp. ton
	1 short ton (2000 lb)	= 0.907 18	t			= 1.1023	short ton

Quantity	**Imperial to SI**				**SI to Imperial**		
Pressure, stress	1 lbf/ft2	= 47.880	N/m2 = Pa		1 N/m2 = Pa	= 0.020 88	lbf/ft2
	1 lbf/in2	= 6894.76	N/m2			0.000 145	lbf/in2
	1 in w.g.	= 249.089	N/m2			= 0.004 015	in w.g.
	1 ft w.g.	= 2989.07	N/m2			= 0.000 3346	ft w.g.
	1 mm w.g.	= 9.807	N/m2			= 0.101 97	mm w.g.
	1 in Hg	= 3386.39	N/m2			= 0.000 2953	in Hg
	1 mm Hg	= 133.32	N/m2			= 0.007 501	mm Hg
		= 1.333 2	mb			= 0.01	mb
	Note: The millibar (1 mb = 100 N/m2) is included here as it is a familiar metric unit of pressure. It is not, however, an SI unit.						
Airway resistance	1 Atk	= 0.059 71	Ns2/m8		1 Ns2/m8	= 16.747	Atk
	1 PU	= 1.118 3	N s2/m8			= 0.894 2	PU
Airway specific resistance	1 in w.g. per 10 000 ft3 /min	= 22.366	Ns2/m8			= 0.044 7	in w.g. per 10 000 ft3/min
Friction Factor	1 lbf min2/ft4	= 1.8554 x l06	kg/m3		1 kg/m3	= 539.0 x 10-9	lbf min2/ft4
Density	1 lb/ft3	= 16.018 5	kg/m3		1 kg/m3	= 0.062 43	lb/ft3
	1 imp. ton/yd3	= 1328.94	kg/m3			= 0.000 753	imp. ton/yd3
	1 short ton/yd3	= 1186.55	kg/m3			= 0.000843	short ton/yd3
Energy, work, heat	1 ft lbf	= 1.355 82	J		1 J	= 0.737 56	ft/lbf
	1Btu	= 1055.06	J			= 0.000 948	Btu
	1 cal	= 4.186 8	J			= 0.238 89	cal
	1 therm	= 105.506	MJ			= 0.009 478	μtherm
	1 kWh	= 3.6	MJ			= 0.000 278	Wh
Power	1 hp	= 745.700	W		1 W	= 0.001 341	hp
Heatflow	1 ft lbf/min	= 0.0226	W		1 W	= 44.254	ft lbf/min
	1 Btu/min	= 17.584	W			= 0.056 87	Btu/min
	1 RT Refrigeration (imp.) ton	= 3517	W			= 0.000 2843	RT

Quantity	Imperial to SI				SI to Imperial		
Specific energy	1 ft lbf/lb	= 2.989	J/kg		1 J/kg	= 0.3345	ft lbf/lb
Calorific value	1 Btu/lb	= 2326	J/kg		1 J/kg	= 0.000 430	Btu/lb
	1 therm/imp. ton	= 0.103 8	MJ/kg			= 9.634	µtherm/imp . ton
	1 therm/short ton	= 0.116 3	MJ/kg			= 8.602	µtherm/short ton
Gas constants	1 ft lbf/lb °R	= 5.380 3	J/kg K		1 J/kg K	= 0.185 9	ft lbf/lb °R
Specific heat Specific entropy	1 Btu/lb °R	= 4186.8	J/kg K		1 J/kg K	= 0.000 2388	Btu/lb °R
Specific volume	1 ft3 /lb	= 0.062 43	m3 /kg		1 m3 /kg	= 16.018	ft3 /lb
	1 ft3 /imp. ton	= 0.027 87	m3 /t			= 35.881	ft3 /imp. ton
	1 ft3 /short ton	= 0.031 21	m3 /t			= 32.037	ft3 /short ton
	Note: 1 metric tonne (t) = 1 000 kg						
Dynamic viscosity	1 lb/ft s	= 1.488 16	Ns/m2		1 Ns/m2	= 0.671 97	lb/ft s
	1 poise	= 0.1	Ns/m2			= 10	poise
Kinematic viscosity	1 ft2/s	= 0.092 903	m2/s		1 m2/s	= 10.763 9	ft2/s
	1 stokes	= 0.000 1	m2/s			= 10 000	stokes
Permeability	1 Darcy	= 0.98693x10-l2	m2			= 1.01324-12	Darcy
	1 md	= 0.98693x10-l5	m2			= 1.01324-15	md
Thermal conductivity	1 Btu ft/ft2 h ºR	= 1.730 73	W/m K		1 W/mK	= 0.577 79	Btu ft/ft^2 h ºR
Thermal diffusivity	1 ft2/s	= 0.092 303	m2/s		1 m2/s	= 10.764	ft2/s
	1 ft2/h	= 2.5806x10-5	m2/s		1 m2/s	= 38 750	ft2/h

Quantity	Imperial to SI				SI to Imperial		
Thermal gradient	1 ºF/ft	= 1.822 7	ºC/m		1 ºC/m	= 0.548 6	ºF/ft
Moisture content	1 lb/lb	= 1	kg/kg		1 kg/kg	= 1	lb/lb
	1 gr/lb	= 0.000 1429	kg/kg			= 7000	gr/lb
Radiation	1 rad	= 0.01	Gray		1 Gray	= 100	rad
	1 Curie	= 37 x 109	Bq		1 Bq	= 27 x 10-12	Curie
	1 rem	= 0.01	Sv		1 Sv	= 100	rem
	1 Roentgen	= 2.58 x 10-4	C/kg		1 C/kg	= 3876	Roentgen
Notes:	1 Gray	= 1 J/kg			1 Becqueral (Bq)	=1 disintegration/s	
	1 Sievert (Sv)	= 1 J/kg			1 Coulomb (C)	= 1 amp.s	
Temperature	K	= ºC + 273.15					
	ºR	= ºF + 459.67					
	For differential temperatures, 1 Centigrade degree = 1.8 Fahrenheit degrees.						
	For actual temperature, 1.8 x t(ºC) + 32 = ºF						
and	$\frac{t(ºF) - 32}{1.8}$	= ºC					