CRC

HANDBOOK
of
ENVIRONMENTAL CONTROL

VOLUME I: AIR POLLUTION

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*Currently in preparation.

PREFACE TO VOLUME I: AIR POLLUTION

In this, the first volume of the *Handbook of Environmental Control,* the editors have attempted to bring together in tabular form the data needed to provide an approach to a solution to environmental problems in air pollution. Data are provided on contaminants and pollutants in ambient air and from various industrial operations. Control measures found valuable are identified. Broadly speaking, the data are grouped as follows: basic data, sampling and monitoring, effects of air pollutants, emission sources, and control measures.

We hope that this handbook can provide answers to the following kinds of questions:

1. About specific problems that exist, that may exist, or that could exist in the future.
2. About a problem in a general way or by analogy or by extrapolation.
3. About new and innovative approaches that can be developed from the use of building blocks of specific data.

This volume on air pollution should be of use to workers within the broad scope of the disciplines of environmental management, including ecology, earth sciences, resources, recreation, and environmental design and protection. In addition, because of the extension of awareness and concern about the environment, students in the above areas and other professions, such as law, business, political science, and sociology, will find the volume a source of ready information.

Minneapolis, Minnesota
August 1972

R.G. BOND
C.P. STRAUB

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TABLE OF CONTENTS

SECTION 4 AIR POLLUTION CONTROL MEASURES

Section 1

The Atmosphere and Air Pollutants

1.1 ATMOSPHERIC DATA

1.1–1 COMPONENTS OF THE ATMOSPHERE

1.1–1A AVERAGE COMPOSITION OF DRY AIR

For most applications the following accepted values for the average composition of the atmosphere are adequate. These values are for sea level or any land elevation. Proportions remain essentially constant to 50 000 ft altitude.

Gas	Molecular weight	Percentage by volume, mol fraction	Percentage by weight
Nitrogen	N_2 = 28.016	78.09	75.55
Oxygen	O_2 = 32.000	20.95	23.13
Argon	Ar = 39.944	0.93	1.27
Carbon dioxide	CO_2 = 44.010	0.03	0.05
		100.00	100.00

For many purposes the percentages 79% N_2–21% O_2 by volume and 77% N_2–23% O_2 by weight are sufficiently accurate, the argon being considered as nitrogen with an adjustment of molecular weight to 28.16.

Other gases in the atmosphere constitute less than 0.003% (actually 27.99 parts per million by volume), as given in the following table.

1.1–1B MINOR CONSTITUENTS OF DRY AIR

Gas	Molecular weight	Parts per million	
		By volume	By weight
Neon	Ne = 20.183	18.	12.9
Helium	He = 4.003	5.2	0.74
Methane	CH_4 = 16.04	2.2	1.3
Krypton	Kr = 83.8	1.	3.0
Nitrous oxide	N_2O = 44.01	1.	1.6
Hydrogen	H_2 = 2.0160	0.5	0.03
Xenon	Xe = 131.3	0.08	0.37
Ozone	O_3 = 48.000	0.01	0.02
Radon	Rn = 222.	(0.06×10^{-12})	

Minor constituents may also include dust, pollen, bacteria, spores, smoke particles, SO_2, H_2S, hydrocarbons, and larger amounts of CO_2 and ozone, depending on weather, volcanic activity, local industrial activity, and concentration of human, animal, and vehicle population. In certain enclosed spaces the minor constituents will vary considerably with industrial operations and with occupancy by humans, plants, or animals.

The above data do not include water vapor, which is an important constituent in all normal atmospheres.

Source: *Handbook of Tables for Applied Engineering Science,* R.E. Bolz and G. L. Tuve, Eds., The Chemical Rubber Co., Cleveland, O., 1970, p. 533.

1.1–2 U.S. STANDARD ATMOSPHERE

To 300 000 ft; 45° North Latitude, July

SYMBOLS:

Z, ft = geometric altitude, feet
Z, m = geometric altitude, meters
H, ft = geopotential altitude, feet
t, °F = temperature, degrees Fahrenheit
t, °C = temperature, degrees Celsius
P, in. Hg = pressure, inches of mercury. For atmospheres multiply by 0.033 421 0. For psia multiply by 0.491 154

ρ, English = density. For lb_m/ft^3 multiply by 10^{-3}
ρ, metric = density. For kg/m^3 multiply by 10^{-3}
V_s, fps = speed of sound, ft/sec. For m/sec multiply by 0.3048
μ = viscosity. For lb_m/ft sec multiply by 10^{-5} For g/cm sec (poises) multiply by 10^{-5} and by 14.882
k = thermal conductivity. For Btu/sec ft °R multiply by 10^{-5}. For W/cm °K multiply by 10^{-5} and by 62.306

Z, ft	*H*, ft	*Z*, m	*t*, °F	*t*, °C	*P*, in. Hg	ρ, English	ρ, metric	V_s, fps	μ	κ
0	**0**	**0**	**73.5**	**23.1**	**29.93**	**74.4**	**1 192.**	**1.132**	**1.228**	**.417**
1,000	1,000	305	70.7	21.4	28.89	72.2	1,157	1,129	1.223	.415
2,000	2,000	610	68.0	20.0	27.89	70.1	1,123	1,126	1.218	.413
3,000	3,000	915	65.2	18.4	26.91	68.0	1,090	1,123	1.213	.411
4,000	3,999	1,220	62.4	16.9	25.96	65.9	1,057	1,120	1.209	.409
5,000	4,999	1,525	59.7	15.4	25.05	63.9	1,025	1,117	1.204	.407
6,000	5,998	1,830	57.0	13.9	24.16	62.0	994	1,114	1.199	.405
7,000	6,998	2,135	53.9	12.2	23.30	60.1	964	1,111	1.193	.403
8,000	7,997	2,440	50.4	10.2	22.46	58.4	936	1,107	1.187	.401
9,000	8,996	2,745	46.9	8.3	21.65	56.6	908	1,103	1.180	.398
10,000	9,995	3,050	43.4	6.3	20.86	55.0	881	1,100	1.174	.396
11,000	10,994	3,355	40.0	4.4	20.09	53.3	855	1,096	1.168	.393
12,000	11,993	3,660	36.6	2.6	19.35	51.7	829	1,092	1.162	.391
13,000	12,992	3,965	33.2	.7	18.63	50.1	803	1,088	1.155	.389
14,000	13,991	4,270	29.8	−1.2	17.94	48.6	779	1,085	1.149	.386
15,000	14,989	4,575	26.5	−3.1	17.26	47.1	755	1,081	1.143	.384
16,000	15,988	4,880	23.1	−4.9	16.61	45.6	731	1.077	1.137	.381
17,000	16,986	5,185	19.7	−6.8	15.97	44.2	708	1,073	1.130	.379
18,000	17,984	5,490	16.4	−8.7	15.36	42.8	686	1,070	1.124	.377
19,000	18,983	5,795	13.0	−10.6	14.77	41.4	664	1,066	1.118	.374
20,000	19,981	6,100	9.61	−12.5	14.19	40.1	643.	1,062	1.111	.372
21,000	20,979	6,405	6.02	−14.4	13.63	38.8	622	1,058	1.105	.369
22,000	21,977	6,710	2.44	−16.4	13.10	37.6	602	1,054	1.098	.367
23,000	22,975	7,015	−1.14	−18.4	12.57	36.4	583	1,050	1.091	.364
24,000	23,972	7,320	−4.72	−20.4	12.07	35.2	564	1,046	1.084	.361
25,000	24,970	7,625	−8.31	−22.4	11.58	34.0	545	1,042	1.077	.359
26,000	25,968	7,930	−11.9	−24.4	11.11	32.9	527	1,037	1.070	.356
27,000	26,965	8,235	−15.5	−26.4	10.65	31.8	510	1,033	1.063	.353
28,000	27,962	8,540	−19.0	−28.3	10.21	30.7	492	1,029	1.056	.351
29,000	28,960	8,845	−22.6	−30.4	9.79	29.7	476	1,025	1.049	.348
30,000	29,957	9,150	−26.2	−32.3	9.38	28.7	460	1,021	1.043	.346
32,000	31,951	9,760	−33.3	−36.3	8.60	26.7	428	1,012	1.029	.340
34,000	33,945	10,370	−40.4	−40.2	7.87	24.9	399	1,004	1.014	.335
36,000	35,938	10,980	−47.6	−44.2	7.19	23.1	371	995	1.000	.330
38,000	37,931	11,590	−54.7	−48.2	6.56	21.5	344	987	.986	.325
40,000	39,923	12,200	−61.8	−52.1	5.98	19.9	319.	978	.972	.319
45,000	44,903	13,725	−71.5	−57.5	4.71	16.1	258	966	.952	.312
50,000	49,880	15,250	−71.5	−57.5	3.70	12.7	203	966	.952	.312
55,000	54,855	16,775	−71.5	−57.5	2.91	9.95	159	966	.952	.312
60,000	59,828	18,300	−68.8	−56.0	2.29	7.78	125	969	.957	.314
65,000	64,798	19,825	−65.6	−54.2	1.81	6.08	97.5	973	.964	.316
70,000	69,766	21,350	−62.3	−54.4	1.43	4.77	76.4	977	.970	.319
75,000	74,731	22,875	−59.0	−50.6	1.13	3.75	60.3	981	.977	.321
80,000	79,694	24,400	−55.8	−48.8	.898	2.95	47.2	985	.984	.324
85,000	84,655	25,925	−52.5	−46.9	.714	2.33	37.3	989	.990	.326
90,000	89,613	27,450	−48.7	−44.8	.569	1.84	29.4	994	.998	.329
100,000	99,523	30,500	−37.3	−38.5	.364	1.14	18.3	1,008	1.021	.337
125,000	124,255	38,125	−4.6	−20.3	.126	.368	5.90	1,046	1.084	.361
150,000	148,929	45,750	29.3	−1.50	.047	.129	2.06	1,084	1.148	.386
175,000	173,544	53,375	32.5	.28	.019	.0503	.807	1,088	1.154	.388
200,000	198,100	61,000	−1.2	−18.4	.0071	.0205	.329	1,050	1.091	.364
250,000	247,039	76,250	−116.2	−82.3	.0007	.0028	.0444	909	.857	.278
300,000	295,746	91,500	−156.6	−104.8	.00004	.0002	.0025	855	.770	.247

Source: *U.S. Standard Atmosphere Supplements,* U.S. Government Printing Office, 1966.

1.2 AIR POLLUTANT PROPERTIES

Air pollution is the presence in the ambient air of one or more contaminants, which can be naturally occurring or man-made. The quantities, characteristics, and duration of these contaminants are, or may tend to be, injurious to human, plant, and animal life or may interfere with the enjoyment of life or use of property.

1.2–1 CLASSIFICATION OF AIR POLLUTANTS

Major classes	Subclasses	Typical members
Inorganic gases	Oxides of nitrogen (NO_X)	Nitrogen dioxide, nitric oxide
	Oxides of sulfur (SO_X)	Sulfur dioxide, sulfuric acid
	Other inorganics	Ammonia, carbon monoxide, chlorine, hydrogen fluoride, hydrogen sulfide, ozone
Organic gases	Hydrocarbons	Benzene, butadiene, butene, ethylene, isooctane, methane
	Aldehydes, ketones	Acetone, formaldehyde
	Other organics	Acids, alcohols, chlorinated hydrocarbons, peroxyacyl nitrates, polynuclear aromatics
Aerosols	Solid particulate matter	Dusts, smoke
	Liquid particulates	Fumes, oil mists, polymeric reaction-products

Source: *Environmental Biology,* P.L. Altman and D.S. Dittmer, Eds., Federation of American Societies for Experimental Biology, Bethesda, Md., 1966.

1.2–2 CHEMICAL AND PHYSICAL PROPERTIES OF POTENTIAL POLLUTANTS

ABBREVIATIONS USED:

A–specific gravity with reference to air = 1
abs–absolute
al–alcohol
°C–Celsius degrees (all temperatures in Table 1.2–2 are in the Celsius system)
c–cold
cryst–crystal
d–decomposes or decomposed
d h–decomposes hot
dil–dilute
expl–explodes
h–hot
insol–insoluble
ign–ignites
m–meta position
n–normal
o–ortho position
p–para position
prim–primary
sol–soluble
s abs–soluble in absolute alcohol
s h–soluble hot
sl d–slightly decomposed
sl s–slight or slightly soluble
subl–sublimes
v–very
v s–very soluble
v s h–very soluble hot
v sl–very slight or very slightly
v sl s–very slightly soluble
∞–soluble in all proportions
–0 800 loses an atom of oxygen at 800°C
α–alpha form or position
β–beta form or position
ω–omega position

TABLE 1.2–2A

Element, compound, or other substance	Chemical formula	Specific gravity or density	Solubility in 100 parts	
			Water	Alcohol
Acetaldehyde (ethanal)	$CH_3 \cdot CHO$	$0.783_{4}^{13^\circ}$	∞	∞
Acetic acid (ethanoic acid)	$CH_3 \cdot COOH$	$1.049_{4}^{20^\circ}$	∞	∞
Acetic anhydride	$(CH_3CO)_2O$	$1.082_{4}^{20^\circ}$	12 c; d h	∞
Acetone (propanone)	$CH_3 \cdot CO \cdot CH_3$	$0.792_{4}^{20^\circ}$	∞	∞
Acetylene tetrachloride (*sym*-tetrachloroethane)	$Cl_2CH \cdot CHCl_2$	$1.600_{4}^{20^\circ}$	insol	∞
Acrolein (acrylic aldehyde)	$CH_2{:}CH \cdot CHO$	$0.841_{4}^{20^\circ}$	40	sol
Acrylonitrile (vinyl cyanide)	$CH_2{:}CH \cdot CN$	0.811^{20°	sol	–
Allyl ether (diallyl ether)	$(CH{:}CH \cdot CH_2)_2O$	$0.826_{4}^{20^\circ}$	0.3	∞
Ammonia	NH_3	0.817^{-79°	89.9^{0° 7.4^{96°	14.8^{20°
Amyl acetate (iso) (common amyl acetate)	$CH_3CO_2 \cdot (CH_2)_2 \cdot CH{:}(CH_3)_2$	$0.876_{4}^{15^\circ}$	0.25^{15°	∞
Amyl alcohol (prim iso) (2-methyl-butanol-4)	$(CH_3)_2CH \cdot CH_2CH_2OH$	$0.813_{4}^{15^\circ}$	2^{14°	∞
n-Amyl butyrate	$C_2H_5CH_2CO_2(CH_2)_4 \cdot CH_3$	$0.871_{4}^{15^\circ}$	0.05^{50°	∞
n-Amyl formate	$HCO_2 \cdot C_5H_{11}$	0.902^{6°	v sl s	∞
n-Amyl nitrite	$C_5H_{11} \cdot O \cdot NO$	0.853^{20°	sl s	∞
Aniline (aminobenzene)	$C_6H_5 \cdot NH_2$	$1.022_{4}^{20^\circ}$	3.6^{18°	∞
Arsenic (black)	As_4	4.7^{20°	insol	–
Arsenic trichloride (butter of arsenic)	$AsCl_3$	liq 2.163	d	–

1.2–2 CHEMICAL AND PHYSICAL PROPERTIES OF POTENTIAL POLLUTANTS (*Continued*)

TABLE 1.2–2A

Element, compound, or other substance	Chemical formula	Specific gravity or density	Solubility in 100 parts: Water	Solubility in 100 parts: Alcohol
Arsine (arsenous hydride)	AsH_3	2.695(A)	20 cc	–
Asbestos	–	–	–	–
Barium peroxide	BaO_2	4.958	v sl s	–
Benzene (benzol)	C_6H_6	$0.879^{20^\circ}_{4}$	0.07^{22°	∞
Benzoyl chloride	$C_6H_5 \cdot CO \cdot Cl$	$1.212^{20^\circ}_{4}$	d	abs al d h
Benzyl amine (ω-aminotoluene)	$C_6H_5 \cdot CH_2 \cdot NH_2$	$0.982^{20^\circ}_{4}$	∞	∞
Beryllium	Be	–	–	–
Bromine	Br_2	$3.2^{0^\circ}_{4}$	3.13^{30°	sol
Bromobenzene (phenyl bromide)	C_6H_5Br	$1.495^{20^\circ}_{4}$	insol	sol
Bromoethane (ethyl bromide)	$C_2H_5 \cdot Br$	$1.460^{20^\circ}_{4}$	1.06^{0° 0.9^{30°	∞
Bromoethylene (vinyl bromide)	$CH_2{:}CH \cdot Br$	$1.529^{11^\circ}_{4}$	insol	∞
Bromopropane (propyl bromide)	$CH_3 \cdot CH_2 \cdot CH_2 \cdot Br$	$1.353^{20^\circ}_{4}$	0.25^{20°	∞
ω-Bromotoluene (benzyl bromide)	$C_6H_5 \cdot CH_2 \cdot Br$	1.443^{17°	insol; sl d	∞
Bromoxylene (bromo-*o*-xylene[3])	$Br \cdot C_6H_3 \cdot (CH_3)_2$	$1.365^{20^\circ}_{4}$	insol	–
1,3-Butadiene (erythrene)	$CH_2{:}CH \cdot CH{:}CH_2$	$0.621^{20^\circ}_{4}$	insol	∞
Butane (diethyl)	$CH_3 \cdot CH_2 \cdot CH_2 \cdot CH_3$	liq 0.60^{0°	15 $cc^{17^\circ}_{772}$	1 $883^{17^\circ}_{775}$
n-Butanol	$C_2H_5 \cdot CH_2 \cdot CH_2OH$	$0.810^{20^\circ}_{4}$	9^{15°	∞
2-Butanone (methylethyl ketone)	$CH_3 \cdot CO \cdot C_2H_5$	$0.805^{20^\circ}_{4}$	37	∞
1-Butene (butylene)	$C_2H_5 \cdot CH{:}CH_2$	liq 0.6^{9°	insol	v s
n-Butyl acetate	$CH_3CO_2 \cdot (CH_2)_3 \cdot CH_3$	0.882^{20°	0.7	∞
n-Butyl cellosolve	$C_4H_9 \cdot O \cdot CH_2CH_2OH$	$0.903^{20^\circ}_{4}$	∞	∞
n-Butyl formate	$HCO_2 \cdot (CH_2)_3 \cdot CH_3$	0.911^{0°	v sl s	∞
Butyl ether (*n*-dibutyl ether)	$(C_2H_5 \cdot CH_2 \cdot CH_2)_2O$	$0.769^{20^\circ}_{20}$	<0.05	∞
n-Butyl nitrite	$C_4H_9 \cdot O \cdot NO$	0.911^{0°	–	∞
Cacodyl oxide (cacodylic oxide)	$[(CH_3)_2As]_2O$	1.486^{15°	sl s	sol
Cadmium	Cd	8.65^{20°	insol	–
Carbon dioxide	CO_2	solid 1.56^{-79°	179.7 cc^{0° 90.1 cc^{20°	–
Carbon disulfide	CS_2	liq $1.261^{22^\circ}_{20}$	0.2^{0° 0.014^{50°	∞
Carbon monoxide	CO	liq $0.814^{-195^\circ}_{4}$	0.004 4^{0° 0.001 8^{50°	sol
Carbon tetrachloride	CCl_4	$1.595^{20^\circ}_{4}$	0.097^{0° 0.08^{20°	∞

1.2–2 CHEMICAL AND PHYSICAL PROPERTIES OF POTENTIAL POLLUTANTS (*Continued*)

TABLE 1.2–2A

Element, compound, or other substance	Chemical formula	Specific gravity or density	Solubility in 100 parts: Water	Solubility in 100 parts: Alcohol
Cellosolve (2-ethoxy-ethanol-1)	$C_2H_5\cdot O\cdot(CH_2)_2OH$	$0.931^{20^\circ}_{4}$	∞	∞
Cellosolve acetate	$CH_3CO_2C_4H_9O$	$0.975^{20^\circ}_{4}$	22	∞
Chlorine	Cl_2	liq $1.56^{-33.6^\circ}$	1.46^{0° g $310\ cc^{10^\circ}$	–
Chlorine dioxide (chlorine peroxide)	ClO_2	2.4^{11° (A)	$2\,000\ cc^{4^\circ}$	expl
Chlorine monoxide	Cl_2O	2.9 (A)	$20\,000\ cc^{0^\circ}$	expl
Chloroacetone	$Cl\cdot CH_2\cdot CO\cdot CH_3$	1.162^{16°	∞	∞
Chlorobenzene (phenyl chloride)	$C_6H_5\cdot Cl$	$1.107^{20^\circ}_{4}$	insol	∞
2-Chlorobutadiene (chloroprene)	$CH_2:CCl\cdot CH:CH_2$	$0.958^{20^\circ}_{20}$	sl s	∞
o-Chlorodiphenyl (chlorobiphenyl)	$Cl\cdot C_6H_4\cdot C_6H_5$	–	insol	–
Chloroform (trichloromethane)	$CHCl_3$	1.489^{20°	0.82^{20°	∞
Chloronaphthalenes (*see* penta- and trichloronaphthalenes)				
1-Chloro-1-nitropropane	$C_2H_5\cdot CH(Cl)NO_2$	$1.209^{20^\circ}_{20}$	$<0.8^{20^\circ}$	–
Chloropicrin (nitrochloroform)	$NO_2\cdot CCl_3$	$1.651^{22.8^\circ}_{4}$	0.17^{18°	37 cc 80% al
Chloropropane (*n*-propyl chloride)	$CH_3\cdot CH_2\cdot CH_2Cl$	$0.890^{20^\circ}_{4}$	0.27^{20°	∞
3-Chloropropene-1 (allyl chloride)	$CH_2:CH\cdot CH_2Cl$	$0.938^{20^\circ}_{4}$	<0.1	∞
ω-Chlorotoluene (benzyl chloride)	$C_6H_5\cdot CH_2\cdot Cl$	$1.100^{20^\circ}_{20}$	insol	∞
Chlorovinyldichloro-arsine (Lewisite)	$ClCH:CH\cdot AsCl_2$	$1.888^{20^\circ}_{4}$	insol	–
Chloroxylene (*o*-xylylchloride)	$Cl\cdot C_6H_3(CH_3)_2$		insol	∞
Chromic acid (chromium trioxide)	CrO_3	2.70	164.9^{0°	sol
o-Cresol	$CH_3\cdot C_6H_4\cdot OH$	$1.048^{20^\circ}_{4}$	2.5	∞^{30°
m-Cresol	$CH_3\cdot C_6H_4\cdot OH$	$1.034^{20^\circ}_{4}$	0.5	∞
p-Cresol	$CH_3\cdot C_6H_4\cdot OH$	$1.035^{20^\circ}_{4}$	1.8	∞^{36°
Cyanogen	C_2N_2	liq $0.866^{-17.2^\circ}$	$450\ cc^{20^\circ}$	$2\,300\ cc^{20^\circ}$
Cyanogen bromide	$Br\cdot CN$	2.015^{20°	sol	sol
Cyanogen chloride	$Cl\cdot CN$	1.222^{0°	$2\,500\ cc^{20^\circ}$	$10\,000\ cc^{20^\circ}$
Cyclohexane (benzene hexahydride)	$\underbrace{CH_2\cdot(CH_2)_4\cdot CH_2}$	$0.779^{20^\circ}_{4}$	insol	∞
Cyclohexanol (hexahydrophenol)	$\underbrace{CH_2\cdot(CH_2)_4\cdot CHOH}$	$0.962^{20^\circ}_{4}$	3.6^{20°	sol
Cyclohexanone (pimelin ketone)	$\underbrace{CH_2\cdot(CH_2)_4\cdot CO}$	$0.947^{19^\circ}_{4}$	sol	sol
Cyclohexene (benzene tetrahydride)	$\underbrace{CH_2(CH_2)_3\cdot CH:CH}$	$0.810^{20^\circ}_{4}$	v sl s	v s