Air Pollution Control Engineering

Second Edition

Noel de Nevers

CONVERSION FACTORS*

Length:

$$\textbf{1 ft} = 0.3048 \text{ m} = 12 \text{ in.} = \text{mile}/5280 = \text{nautical mile}/6076$$
$$= \text{km}/3281$$
$$\textbf{1 m} = 3.281 \text{ ft} = 39.37 \text{ in.} = \text{km}/1000 = 100 \text{ cm} = 1000 \text{ mm}$$
$$= 10^6 \text{ microns} = 10^6\ \mu\text{m} = 10^9 \text{ nm} = 10^{10} \text{ Å}$$

Mass:

$$\textbf{1 lbm} = 0.45359 \text{ kg} = \text{short ton}/2000 = \text{long ton}/2240 = 16 \text{ oz (av.)}$$
$$= 14.58 \text{ oz (troy)} = \text{metric ton (tonne)}/2204.63 = 7000 \text{ grains}$$
$$= \text{slug}/32.2$$
$$\textbf{1 kg} = 2.2046 \text{ lbm} = 1000 \text{ g} = (\text{metric ton or tonne or Mg})/1000$$

Force:

$$\textbf{1 lbf} = 4.4482 \text{ N} = 32.2 \text{ lbm} \cdot \text{ft/s}^2 = 32.2 \text{ poundal} = 0.4536 \text{ kgf}$$
$$\textbf{1 N} = \text{kg} \cdot \text{m/s}^2 = 10^5 \text{ dyne} = \text{kgf}/9.81 = 0.2248 \text{ lbf}$$

Volume:

$$\textbf{1 ft}^3 = 0.02831 \text{ m}^3 = 28.31 \text{ liters} = 7.48 \text{ U.S. gallons}$$
$$= 6.23 \text{ Imperial gallons} = \text{acre-ft}/43\,560$$
$$\textbf{1 U.S. gallon} = 231 \text{ in.}^3 = \text{barrel (petroleum)}/42 = 4 \text{ U.S. quarts}$$
$$= 8 \text{ U.S. pints} = 3.785 \text{ liters} = 0.003785 \text{ m}^3$$
$$\textbf{1 m}^3 = 1000 \text{ liters} = 35.29 \text{ ft}^3$$

Energy:

$$\textbf{1 Btu} = 1055 \text{ J} = 1.055 \text{ kw} \cdot \text{s} = 2.93 \times 10^{-4} \text{ kwh} = 252 \text{ cal}$$
$$= 777.97 \text{ ft} \cdot \text{lbf} = 3.93 \times 10^{-4} \text{ hp} \cdot \text{h}$$
$$\textbf{1 J} = \text{N} \cdot \text{m} = \text{W} \cdot \text{s} = \text{volt} \cdot \text{coulomb} = 9.48 \times 10^{-4} \text{ Btu}$$
$$= 0.239 \text{ cal} = 10^7 \text{ erg} = 6.24 \times 10^{18} \text{ electron volts}$$

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*These values are mostly rounded. There are several definitions for some of these quantities, e.g., the Btu and the calorie; these definitions differ from each other by up to 0.2 percent. For the most accurate values see the *ASTM Metric Practice Guide*, ASTM Pub. E 380-93, Philadelphia, 1993.

Power:

$$1\ \mathbf{hp} = 550\ \text{ft} \cdot \text{lbf/s} = 33\ 000\ \text{ft} \cdot \text{lbf/min} = 2545\ \text{Btu/h} = 0.746\ \text{kW}$$

$$1\ \mathbf{W} = \text{J/s} = \text{N} \cdot \text{m/s} = \text{volt} \cdot \text{ampere} = 1.34 \times 10^{-3}\ \text{hp} = 0.239\ \text{cal/s}$$
$$= 9.49 \times 10^{-4}\ \text{Btu/s}$$

Pressure:

$$1\ \mathbf{atm} = 101.3\ \text{kPa} = 1.013\ \text{bar} = 14.696\ \text{lbf/in.}^2 = 33.89\ \text{ft of water}$$
$$= 29.92\ \text{inches of mercury} = 1.033\ \text{kgf/cm}^2 = 10.33\ \text{m of water}$$
$$= 760\ \text{mm of mercury} = 760\ \text{torr}$$

$$1\ \mathbf{psi} = \text{atm}/14.696 = 6.89\ \text{kPa} = 0.0689\ \text{bar} = 27.7\ \text{in. } H_2O = 51.7\ \text{torr}$$

$$1\ \mathbf{Pa} = \text{N/m}^2 = \text{kg/m} \cdot \text{s}^2 = 10^{-5}\ \text{bar} = 1.450 \times 10^{-4}\ \text{lbf/in.}^2$$
$$= 0.0075\ \text{torr} = 0.0040\ \text{in. } H_2O$$

$$1\ \mathbf{bar} = 10^5\ \text{Pa} = 0.987\ \text{atm} = 14.5\ \text{psia}$$

Psia, psig:

Psia means pounds per square inch, absolute. Psig means pounds per square inch, gauge, i.e., above or below the local atmospheric pressure.

Viscosity:

$$1\ \mathbf{cp} = 0.01\ \text{poise} = 0.01\ \text{g/cm} \cdot \text{s} = 0.001\ \text{kg/m} \cdot \text{s} = 0.001\ \text{Pa} \cdot \text{s}$$
$$= 6.72 \times 10^{-4}\ \text{lbm/ft} \cdot \text{s} = 2.42\ \text{lbm/ft} \cdot \text{h} = 2.09 \times 10^{-5}\ \text{lbf} \cdot \text{s/ft}^2$$
$$= 0.01\ \text{dyne} \cdot \text{s/cm}^2$$

Kinematic viscosity:

$$1\ \mathbf{cs} = 0.01\ \text{stoke} = 0.01\ \text{cm}^2\text{/s} = 10^{-6}\ \text{m}^2\text{/s} = 1\ \text{cp/(g/cm}^3)$$
$$= 1.08 \times 10^{-5}\ \text{ft}^2\text{/s} = \text{cp/(62.4 lbm/ft}^3)$$

Temperature:

$$\mathbf{K} = {}^\circ\text{C} + 273.15 = {}^\circ\text{R}/1.8 \approx {}^\circ\text{C} + 273 \qquad {}^\circ\mathbf{C} = ({}^\circ\text{F} - 32)/1.8$$

$$^\circ\mathbf{R} = {}^\circ\text{F} + 459.67 = 1.8\ \text{K} \approx {}^\circ\text{F} + 460 \qquad {}^\circ\mathbf{F} = 1.8{}^\circ\text{C} + 32$$

Concentration (ppm):

In the air pollution literature and in this book, ppm applied to a gas always means parts per million by volume or by mol. These are identical for an ideal gas, and practically identical for most gases of air pollution interest at 1 atm pressure. Ppm applied to a liquid or solid means parts per million by mass.

For perfect gases at 1 atm and 25°C, 1 ppm = (40.87 · molecular weight) μg/m^3

Common Units and Values for Problems and Examples:

See inside back cover.

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Cover Photo: A catalytic converter for a small truck, see chapter 13. Those for autos are smaller, normally having only one or two honeycomb catalyst units in place of the three shown here. The oxygen sensor is inserted in the inlet pipe. Photo courtesy of Trunett Environmental Tech Co.

John J. Mooney and Carl D. Keith shared the 2002 National Medal of Technology award from the U.S. government for their development of this type of catalyst while working for Engelhard. The millions of these devices on autos and trucks have greatly improved the air quality in the large cities of the United States starting about 1981 and many other countries since then. If you live in such a city your personal health is presumably improved because of these devices.

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ABOUT THE AUTHOR

Noel de Nevers received a B.S. from Stanford University in 1954, and M.S. and Ph.D. degrees from the University of Michigan in 1956 and 1959, all in chemical engineering.

He worked for the research arms of what is now called the Chevron Oil Company from 1958 to 1963 in the areas of chemical process development, chemical and refinery process design, and secondary recovery of petroleum. He has been on the faculty of the University of Utah from 1963 to the present in the Department of Chemical and Fuels Engineering.

He has worked for the National Reactor Testing Site, Idaho Falls, Idaho, on nuclear problems; for the U.S. Army Harry Diamond Laboratory, Washington, DC, on weapons; and for the Office of Air Programs of the U.S. EPA in Durham, NC, on air pollution.

He was a Fulbright student of Chemical Engineering at the Technical University of Karlsruhe, West Germany, in 1954–1955; a Fulbright lecturer on Air Pollution at the Universidad del Valle, in Cali, Colombia, in the summer of 1974; and then at the Universidad de la República, Montevideo, Uruguay, and at the Universidad Nacional Mar del Plata, Argentina, in autumn 1996.

He was a member of the Utah Air Conservation Committee (the state's air pollution control board) from 1972 to 1984 and its chair in 1983–1984. He served on the Utah Governor's Citizen Advisory Task Force on the Protection of Visibility in 1986, the Utah Legislature's Hazardous Waste Task Force in 1988, the Utah Governor's Clean Air Commission in 1989–1990, and the Western Governor's Conference Grand Canyon Visibility Transport Commission Citizen's Advisory Board, 1992–1996.

His areas of research and publication are in fluid mechanics, thermodynamics, air pollution, technology and society, energy and energy policy, and explosions and fires. He regularly consults on air pollution problems, explosions, and fires.

In 1991, his textbook, *Fluid Mechanics for Chemical Engineers*, Second Edition, was issued by McGraw-Hill.

In 1993 he received the Corcoran Award from the Chemical Engineering Division of the American Society for Engineering Education for the best paper (" 'Product in the Way' Processes") that year in *Chemical Engineering Education.*

In addition to his serious work he has three "de Nevers's Laws" in the latest "Murphy's Laws" compilation, and won the title "Poet Laureate of Jell-O Salad" at the Last Annual Jell-O Salad Festival in Salt Lake City in 1983.

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