Contents

2 Environmental Engineering Calculations

2.1 Values, Units and Dimensions

2.1.1 Variables

2.1.2 Units

Some important rules

- Uppercase and lowercase should be followed at all places.
- Do not put a period after symbols except in "in." for inch.
- Prefixes are not preferred in denominators, except in "kg".
- In compoud units, multiplication is usuallyshown by center dot.
  - Center dot may be omitted in familiear units like "Wh" if no confusion occurs.
  - Center dot may be omitted if symbols are separated by exponents.
  - Hyphens should not be used instead of center dot.
- Do not italicize unit symbols.

SI unit system

American engineering system

Base units, multiple units, derived units

Conversion of units

2.1.3 Dimension

A dimension is a property that can be measured.

2.1.4 Dimensional homogeneity

Every valid equation must be dimensionally homogeneou: that is, all additive terms on both sides of the equation must have the same dimensions.

How to convert an equation in terms of new variables having same dimensions but different units?

1. Define new variables having new units.
2. Write old variables in terms of new variables
3. Substitute the new expressions in the equation.

Exercise

Consider the equation

$$D(\mathrm{ft}) = 3\,t(\mathrm{s}) - 4$$

1. If the equation is valid, what are the dimenstions of the constants 3 and 4?

2. If the equation is consistent in its units, what are the units of 3 and 4?
3. Derive an equation for distance in meters in terms of time in minutes.

Solution

1. **length/time** and **length** respectively.
2. **ft/s** and **ft** respectively.
3. $D'(\text{m}) = 55\, t'(\text{min}) - 1.22$

2.2 Significant Figures

"The significant figures of a number are the digits from the first nonzero digit on the left to either

- the last digit (zero or nonzero) on the right if there is a decimal point, or
- the last nonzero digit of the number if there is no decimal point .

Examples

2300 or 2.3×10^3 : 2 s.f.

2300. or 2.300×10^3 : 4 s.f.

0.035 or 3.5×10^{-2} : 2 s.f.

0.03500 or 3.500×10^{-2} : 4 s.f.

The number of significant figures in the reported value of a measured or calculated quantity provides an indication of the precision with which the quantity is known. The more significant figures, the more precise is the value. Thus, if you report the value of a measured quantity with three significant figures, you indicate that the value of the third of these figures may be off by as much as a half-unit. Thus, if you report a mass as 8.3 g, you indicate that the mass lies somewhere between 8.25 and 8.35 g.

- But, if a quantity is know precisely, like a pure integer or a counter rather than measured quantity, its value implicitly contains an infinite number of significant figures.
- When two or more quantities are combined by multiplication and/or division, the number of significant figures in the result should equal the lowest number of significant figures of any of the multiplicands or divisors.
  - Although if several calculations are to be performed in sequence it is advisable to keep extra significant figures of intermediate quantities and to round off only the final result.
- When two or more numbers are added or subtracted, the positions of the last significant figures of each number relative to the decimal point should be compared. Of these positions, the one farthest to the left is the position of the last permissible significant figure of the sum or difference.
- E.g., 1530 - 2.56 = 1527.44 $\Longrightarrow$ 1530
- A rule of thumb for rounding off numbers in which the digit to be dropped is a 5 is always to make the last digit of the rounded-off number even. E.g. 1.35 $\Longrightarrow$ 1.4 and 1.25 $\Longrightarrow$ 1.2" (Felder, 2005)

2.3 Units and Nomenclature for Basic Environmental Variables

2.3.1 Force, Weight and Mass

"The SI force acting on 1 kg mass due to gravity is not 1 N but is 9.81 N.

In addition to SI units, a North American engineer must master at least one of the other systems that relates mass and force, one whose persistence in the United States is due more to custom than logic: it is the Engineering English system of units. In this system, the conversion factor between force and mass acceleration is not unity. Because of this we must carry an explicit proportionality constant every time we use this unit system. It was decided that the name "pound" would be used both for mass and weight (force). Since mass and force are distinctly different quantities, a modifier had to be added to the pound unit to distinguish which (mass or weight) was being used. This was solved by simply using the phrase pound mass or pound force with the associated abbreviations lbm and lbf, respectively, to distinguish between them.

In the English Engineering system it was decided that a pound mass should weigh a pound force at standard gravity. (Standard gravity accelerates a mass by 32.174 ft/s^2.) This has the helpful convenience of allowing us the intuitive ability to understand immediately what is meant by, say, a force of 15 lbf. It would be the force you would experience if you picked up a rock of mass 15 lbm on the Earth's surface. 1 lbf is defined as the force that will accelerate exactly 1 lbm by exactly 32.174 ft/s^2.

$g_c = 32.174 \frac{\text{lbm}\cdot\text{ft}}{\text{lbf}\cdot\text{s}^2}$

In the English Engineering unit system, Newton's Second Law is: $F = \frac{ma}{g_c}$

The convenient mnemonic for all applications of the Engineering English system is:

> In the Engineering English system, when you see a mass m, divide it by g_c." (Kosky)

Exercise

What is the force necessary to accelerate a mass of 65.0 lbm at a rate of 15.0 ft/s^2?

Solution

30.3 lbf

2.3.2 Chemical Composition

- Moles and molecular weight
- Mass and mole fractions
- Average molecular weight

2.3.3 Concentration

2.3.3.1 Units of Concentration

- Mass chemical/total mass (mg/kg in soil) (mg/kg, ppm_m)
- Mass chemical/total volume (mg/L in water or air) (mg/L, µg/m^3)
- Volume chemical/total volume (ppm_v)
- Moles chemical/total volume (M)

2.3.3.2 PPM by Mass

- Concentration of trace species.
- Usually mass ratios for liquids and mole ratios for gases.

ppm_m = g of **i** in 10^6 g total

$\text{ppm}_\text{m} = \frac{m_i}{m_{total}} \times 10^6$

Exercise

A one-kg sample of soil is analyzed for the chemical solvent trichloroethylene (TCE). The analysis indicates that the sample contains 5.0 mg of TCE. What is the TCE concentration in ppm_m and ppb_m?

Solution

5 ppm_m and 5000 ppb_m

In soil and sediments, mg/kg equals ppm_m and µg/kg equals ppb_m.

2.3.3.3 Mass/Volume in Aqueous Systems

- Assuming density of pure water is approximately 1000 g/L
- Assuming that the dissolved material does not contribute significantly to the mass of the water
- Natural waters and wastewaters

1 mg/L = ? ppm_m

Solution

1 mg/L = 1 ppm_m

Exercise

One liter of water is analyzed and found to contain 5.0 mg TCE. What is the TCE concentration in mg/L and ppmm?

If the drinking water standard for TCE is 5µg/L, is the above TCE concentration within this limit?

Solution

5.0 ppm_m

The limit is 5 ppb. So above the limit.

Exercise: Air

What is the carbon monoxide (CO) concentration expressed in µg/m^3 of a 10-L gas mixture that contains 10^{-6} mole of CO?

MW of CO = 28 g/mole

Solution

2800 µg/m^3

2.3.3.4 Volume/Volume

- Usually used for gas concentrations

ppm or ppm_v

Advantage for gases: units do not change as a gas is compressed or expanded. But, µg/m^3 decrease when gas expands. (Why?)

For component i,

$\text{ppm}_\text{v}= \frac{V_i}{V_{total}} \times 10^6$

$\text{ppm}_\text{v}= \frac{\text{moles}\, i}{\text{moles total}} \times 10^6$

Exercise

Suppose air in the vicinity of a power plant is said to contain 15 ppm SO_2 . What is the mole fraction of SO_2 in the air?

Solution

15×10^{-6}

2.3.3.5 $ppm_v$to µg/m^3

Use ideal gas law

$PV = nRT$

$R = 8.314$ J/mole-K, 0.08205 L-atm/mole-K

At standard conditions (P = 1 atm, T = 273.15 K), one mole of any pure gas will occupy a volume of 22.4 L.

Exercise

A gas mixture contains 0.001 mole of sulfur dioxide and 0.999 mole of air. What is the SO_2 concentration, expressed in units of ppm_v?

Solution

1000 ppm_v

Exercise: ppm_v to µg/m^3

The concentration of SO2 is measured in air to be 100 ppbv. What is this concentration in units of µg/m^3? Assume the temperature is 28°C and pressure is 1 atm.

MW of SO_2 = 64

Solution

4.05 x 10-6 mole SO_2 / m^3 air

X 64 g SO_2 / mole SO_2

X 106 µg /g

= **260 µg/m^3**

2.3.4 Partial Pressure Units

$ppm_v = \frac{P_i}{\mathbf{P}_{total}} \times 10^6$

where P_i is partial pressure of component i, and P_{total} is the total pressure.

2.3.5 Molarity

Molarity (M) is defined as the number of moles of compound per liter of solution.

2.3.6 Concentration as a Common Constituent

"Concentrations can be reported as a common constituent and can therefore include contributions from a number of different chemical compounds. Greenhouse gases, nitrogen, and phosphorus are chemicals that have their concentration typically reported as a common constituent (Mihelcic)."

2.3.6.1 Global warming potential (GWP)

GWP is a multiplier used to compare the emissions of different greenhouse gases to a common constituent, e.g., CO_2. It is determined over a set time period, typically 100 years. GWPs allow policy makers to compare emissions and reductions of specific gases.

CO_2 equivalents (CO_2e) are a metric measure used to compare the mass emissions of greenhouse gases to a common constituent, based on the specific gas's global warming potential.

Type of emission	Multiplier for CO_2e (Global warming potential, GWP)
Carbon dioxide	1
Methan	25
Nitrous oxide	298

Hence 1 ton of N_2O emission is equivalent to 298 tons of CO_2 emission.

Exercise

Convert 386.7 Tg CO_2e of N_2O to Gg of N_2O.

Solution

1.30×10^3 Gg

2.3.7 Particle Concentrations in Air and Water (?)

2.3.8 Reaction Stoichiometry

2.3.9 Retention time

Refer to main notes.

2.4 Length and Time Scales

Refer to main notes.

2.5 Approximations in Engineering calculations

Refer to main notes.

2.6 Procedure for Calculations with Approximations

Refer to main notes.