Chapter 2

Introduction to Engineering Calculations

Principles of Chemical Processes I

Course Learning Outcomes

At the end of this course students will be able to

- **Convert one set of units in a function or equation into another equivalent set**

2.1 Units and Dimensions

- **Dimension** - property that can be measured such as
  - ✓ length
  - ✓ time
  - ✓ mass
  - ✓ temperature
  - ✓ multiplying or dividing other dimensions

- **Unit** - measured and counted quantity has
  - ✓ value (2.35)
  - ✓ unit (2.35 gram)

- It is essential to write the *value* and *unit* in equation
  - ✓ 2 meters, 0.3 second, 4.5 kilograms, 5 gold rings

Properties of Units

- Units can be treated like algebraic variables
  - ✓ added and subtracted when having same units

    3 cm - 1 cm = 2 cm (3x - x = 2x)

    but

    3 cm - 1 mm (or 1 s) = ? (3x - y = ?)

  - ✓ can always be combined by multiplication or divisions

    3 N x 4 m= 12 N.m

$$\frac{5.0\ \text{km}}{2.0\ \text{h}} = 2.5\ \text{km/h}$$

$$\frac{6\ \text{cm}}{2\ \text{cm}} = 3$$

(3 is a dimensionless quantity)

2.2 Conversion of Units

- When having appropriate dimensions, measured quantity can be expressed in term of other units

ft/s → miles/hr → cm/yr

- The equivalence between two expressions is given by ratio known as conversion factor

$$\frac{1\,\text{cm}}{10\,\text{mm}}$$ (1 centimeter per 10 millimeters)

$$\frac{10\,\text{mm}}{1\,\text{cm}}$$ (10 millimeters per 1 centimeter)

Conversion Factors

- A given quantity is expressed into new unit by using a conversion factor *(new unit/old unit)*

$$(36\text{ mg}) \times \frac{1\text{ g}}{1000\text{ mg}} = 0.036\text{ g}$$

- Alternative way to write this equation

$$\begin{array}{c|c} 36\text{ mg} & 1\text{g} \\ \hline & 1000\text{ mg} \end{array} = \boxed{0.036\text{ g}}$$

Method for using Conversion Factor

- Set up a dimensional equation
  - write the given quantity and its unit on the left
  - write the units of conversion factors (new unit/old unit)
  - fill in the values of the conversion factors
  - carry out the indicated arithmetic operations to find the desired values

- *Example* : Convert acceleration of 1 cm/s^2 to km/y^2

Conversion factor and units

- Problems:

1) Change 400 in^3/day to cm^3/min

2) If a plane travels at twice the speed of sound (assume the speed of sound is 1100 ft/s), how fast is it going in miles per hour?

2.3 Systems of Units

- *Base Units* - units for dimensions of mass, length, time, temperature, electrical current, and light intensity
  - ✓ kilogram, meter, kelvin, ampere, candela
- *Multiple units* - multiples or fraction of base unit
  - ✓ minutes, hours, milliseconds or all in term of base unit second
- *Derived units* - obtained in one of two ways
  - ✓ Multiplying and dividing base units (cm^2, ft/min, $kg.m/s^2$) which are known as *compound units*
  - ✓ Defined as equivalents of *compound units* (1 erg = 1 $g.cm/s^2$, 1 lb_f = 32.174 $lb_m.ft/s^2$)

Systems Of Units

- *System Internationale d'Unites*

Length	meter (SI) centimeter(CGS)
Mass	kilogram (SI) gram (CGS)
Moles	gram-mole (mol)
Time	second (s)
Temperature	kelvin (K)
Electric current	ampere (A)
Light intensity	candela (cd)

- *American engineering system*

Length	foot (ft)
Mass	pound mass(lb_m)
Moles	lb_m-mole(lb_mmol)
Time	second (s)
Temperature	Rankin (°R)
Electric current	ampere (A)
Light intensity	candela (cd)

Weight

- ✓ Weight of an object is due to the gravitational force

  $W = mg/g_c$

- ✓ The value of gravitational force (***g***) is varies to location of earth surface
- ✓ The value of the corresponding $\boldsymbol{g/g_c}$ at 45° latitude

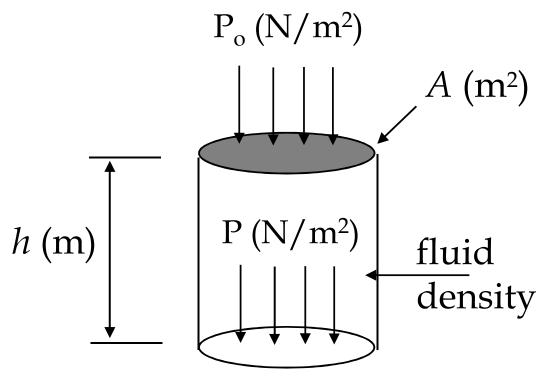
$g = 9.8066\ \text{m/s}^2 \rightarrow g/g_c = 9.8066\ \text{N/kg}$

$g = 980.66\ \text{cm/s}^2 \rightarrow g/g_c = 980.66\ \text{dyne/g}$

$g = 32.174\ \text{ft/s}^2 \rightarrow g/g_c = 1\ \text{lb}_f/\ \text{lb}_m$

Pressure

- ⌖ *Pressure is the ratio of a force to the area*
  - ✓ **Units N/m^2, $dynes/cm^2$, and lb_f/in^2**
  - ✓ **the *SI* pressure unit is N/m^2 or called *pascal* (Pa)**



Temperature

- **Two most common temperature scales are defined using the freezing point (T_f) and boiling point (T_b) of water at 1 atm**

✓ **Celsius (or centigrade) scale**

- T_f is assigned 0°C and T_b is 100°C
- Absolute zero on this scale falls at -273.15°C

✓ **Fahrenheit scale**

- T_f is assigned 32°F and T_b is 212°F
- Absolute zero on this scale falls at -459.67°F

✓ **The Kelvin and Rankin scale are defined at absolute value of Celsius and Fahrenheit**

$$T(K) = T(°C) + 273.15$$
$$T(°R) = T(°F) + 459.67$$
$$T(°R) = 1.8\ T(K)$$
$$T(°F) = 1.8T\ (°C) + 32$$

Degree (^{O}) Definition As Temperature Interval

Degree as Temperature Interval

- **Consider the temperature interval between 0°C and 5°C**
- **There are 9°F and Rankin degree in this interval**
- **An interval of 1°C or Kelvin contains 1.8°F or Rankin degree**

Conversion factor for the interval

$$\frac{1.8\,°F}{1\,°C}, \frac{1.8\,°R}{1\,K}, \frac{1\,°F}{1\,°R}, \frac{1\,°C}{1\,K}$$

Example

Find the number Celsius degrees between 32°F and 212°F

$$\Delta T(°C) = \left.\frac{(212-32)°F}{}\right|\frac{1°C}{1.8°F} = 100°C$$

To find the Celsius temperature corresponding to 32°F *you cannot use this formula*

$$T(°C) = \left.\frac{32°F}{}\right|\frac{1°C}{1.8°F}$$

Temp reading

Temp interval

Dimensional Homogeneity

- Valid equation must be dimensionally homogenous
- Both sides of equation must have same dimensions

$$V(m/s) = V_o(m/s) + g(m/s^2)t(s)$$

Example : Consider the the equation $D(ft) = 3t(s) + 4$

What is the dimension and unit for constants 3 and 4?

Constant 3 →

Constant 4 →

Dimensionless Quantity

- Dimensionless Quantity can be pure numbers (2, ½ , 1.3 etc) or a multiplicative combination of variables with no net dimensions

Example:-

let M (g) = D(cm) u(cm/s) ρ(g/cm^3) and $Mo = \mu$(g/cm.s)

and $M/Mo = Du\rho/\mu$ = $\cancel{cm}\;\Big|\;\frac{\cancel{cm}}{\cancel{s}}\;\Big|\;\frac{\cancel{g}}{\cancel{cm^3}}\;\Big|\;\frac{\cancel{cm}\,.\,\cancel{s}}{\cancel{g}}$

Thus, M/Mo or $Du\rho/\mu$ is also called a dimensionless group

What multiplicative combination of ρ (m), σ (m/s^2) and t(s) would constitute a dimensionless group?