Kessler-Ellis Application Note F021

Gas Equations and Gas Calculations (Metric Units)

This application note uses the S.I. system of units.

Flowing Gas Density

The density of a gas is given by:

$$\rho = \frac{3.483407 \text{ x } G \text{ x } P}{Z \text{ x } T} \quad ---- 1$$

G is the specific gravity of the gas, which is given by $\frac{\text{Molecular weight of the gas}}{\text{Molecular weight of air}} \quad --- 2$

P is the absolute pressure (KPaA) which is equal to line pressure + local barometric pressure

Z is the gas compressibility factor

T is the absolute temperature (ºK) which is equal to line temperature + 273.15ºC

The molecular weight of air is 28.9625, the molecular weight of any given gas can be found from many reference sources. (e.g.) Flow Measurement Engineering Handbook by Richard W. Miller or Perry and Chilton's Chemical Engineer's Handbook.

The compressibility factor for any given gas may be calculated using various methods or can be looked up in standard reference sources. (e.g.)) Flow Measurement Engineering Handbook by Richard W. Miller or Matheson Gas Data Book.

Base Gas Density

The gas density equation remains the same but is referenced to what are known as normal temperature and pressure conditions (NTP). The reference conditions used in general industry are 0ºC and 101.325 Kpa A.

Volumetric and Mass Flow

A flow rate expressed in volume units, (e.g.)M^3 per minute, is known as volumetric flow. A flow rate expressed in mass units, (e.g.) Kg per minute, is known as mass flow. These flow units are linked together in the mass conservation equation.

$$Q_f \times \rho_f = Q_b \times \rho_b \quad \text{---} \quad 3$$

Q is the volumetric flow

ρ is the density

The suffixes f and b refer to flowing and base conditions respectively

Dimensionally the product Q x ρ is a mass quantity

$$\text{(ie)} \quad \frac{M^3}{\text{hour}} \times \frac{\text{Kg}}{M^3} = \frac{\text{Kg}}{\text{hour}}$$

Converting Between Flowing and Base Units

By using the conservation of mass equation shown above we can easily convert between flowing and base conditions. The following example illustrates the procedure.

Example

Carbon dioxide is flowing through a pipe at a rate of 100 M^3 per hour (actual), the line pressure is 400 KPa gauge and the line temperature is 20ºC. The installation is situated at sea level. Calculate the flow rate in normal M^3 per hour.

From the Flow Measurement Engineering Handbook appendix D we find that the molecular weight of air is 28.9625 and that of carbon dioxide is 44.01. The barometric pressure at sea level is 101.325 KPaA.

From equation 2 we find that the S.G. of the gas is $\dfrac{44.01}{28.9625} = 1.519$

The absolute pressure P = 400 + 101.325 = 501.325

The absolute temperature T = 20 + 273.15 = 293.15

The compressibility at pressures below 1000 KPaA can be assumed to be 1

Substituting the above values into equation 1 we get

$$\rho = \frac{3.483407 \times 1.519 \times 501.325}{293.15} = 9.049 \text{ Kg per } M^3$$

Normal conditions are defined as 101.325 KPaA and 0ºC. To find the density of carbon dioxide at these conditions we substitute the values into equation 1. This gives a density of 1.96 Kg per M³.

By substituting flow and density values into equation 3, the conservation of mass equation, we have the following.

$$Q_f \text{ x } \rho_f = Q_b \text{ x } \rho_b$$

$$100 \text{ x } 9.049 = Q_b \text{ x } 1.96$$

$$\text{rearranging the above equation gives } Q_b = \frac{100 \text{ x } 9.049}{1.96} = 461.68 \text{ NM}^3 \text{per hour}$$

Molecular Weights for Gas Mixtures

When gas mixtures are being considered there are no readily available reference tables, it is then necessary to calculate the molecular weight by using the simple combination procedure shown below.

Example

Calculate the molecular weight of the following gas mixture.

Hydrogen	10%
Nitrogen	20%
Carbon dioxide	30%
Oxygen	40%

Gas Component	Gas Fraction	Component Molecular weight (MW)	Fraction x MW
Hydrogen	0.1	2.016	0.2016
Nitrogen	0.2	28.013	5.6026
Carbon dioxide	0.3	44.010	13.2030
Oxygen	0.4	31.998	12.7992
		Sum of MW products	**31.8064**

Specific Heat of a Gas (Cp)

Sometimes it is necessary to calculate the heat content of a flowing gas stream, in order to do this the specific heat of the gas must be known. This data is easily obtained for common gasses by referring to the reference books mentioned above. The units of specific heat are Joules per Kg ºC

The heat of the gas stream is given by:

$$\text{Heat} = \text{Mass x Specific Heat x Temperature}$$

Dimensionally: $$\text{Heat} = \frac{\text{Kg x Joules x } {}^{o}\text{C}}{\text{Kg x } {}^{o}\text{C}} = \text{Joules}$$

Specific Heat of a Gas Mixture (Cp mix)
The specific heat of a gas mixture is calculated as follows:

Specific heat of mixture (Cp mix) = (fraction of component 1 x Cp of component 1) + (fraction of component 2 x Cp of component 2) + ...etc.

Usually KJoules (Joules x 1000) are used instead of Joules.

Example
Calculate the specific heat of the gas mixture given earlier.

Cp of Hydrogen = 29.51 KJoules/Kg ºC
Cp of Nitrogen = 29.26 KJoules/Kg ºC
Cp of Carbon dioxide = 36.78 KJoules/Kg ºC
Cp of Oxygen = 29.43 KJoules/Kg ºC

Cp of mixture = (0.1 x 29.51) + (0.2 x 29.26) + (0.3 x 36.78) + (0.4 x 29.43) = 31.61 KJoules per Kg ºC