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Chapter 1

1.1 Process classification

Classify the following processes as batch, continuous, or Semibatch, and transient or steady-state.

a. A balloon is being filled with air at a steady rate of 2 g/min. (Answer: Semibatch)

b. A bottle of milk is taken from the refrigerator and left on the kitchen table. (Answer: Batch, transient in heat).

c. Carbon monoxide and steam are fed into a tubular reactor at a steady-rate and react to form carbon dioxide and hydrogen. Products and unused reactants are withdrawn at the other end. The reactor contains air when the process is started up. The temperature of the reactor is also constant, and the composition and flow rate of the entering reactant stream are independent of time. Classify the process initially (Answer: Continuous, transient) and after a long period has elapsed (Answer: Continuous, steady state).

1.2 Types of processes

Water (ρ = 1000 kg/m^3) enters a 2.00 m^3 tank at a rate of 6.00 kg/s and is withdrawn at a rate of 3.00 kg/s. The tank is initially half-full.

(a) Is the process continuous, batch or semi-batch? (Answer: Continuous)

(b) Is it transient or steady-state? (Answer: Transient)

(c) Use the general material balance equation to determine how long it will take the tank to overflow. (Answer: 1000 kg/(3 kg/s))

Solution:

Mass of water in the tank = 2.0 m^3 (1000 kg/m^3) = 2000 kg

The tank is half full 2000 kg/2 = 1000 kg

The time necessary to fill the tank = 1000 kg /(3 kg/s) = 333.3 sec

1.3 Unit conversion

How many seconds are in a year? (3600 s/h, 24 hours/day, 365 days/year).

Solution:

$$\cancel{\text{year}}\left|\frac{365\ \cancel{\text{days}}}{\cancel{\text{year}}}\right|\frac{24\ \cancel{\text{h}}}{\cancel{\text{day}}}\left|\frac{3600\,\text{s}}{\cancel{\text{h}}}\right.$$

There is 3.1536E7 seconds/year

1.4 Flowrate through horizontal pipe

Natural gas is flowing through a horizontal pipe at a flowrate of 50 ft^3/s. What is this flowrate in m^3/s, gal/hr? (Use conversion table)

Solution:

Flow rate in m^3 = (50 ft^3/s)(1 m^3/35.3145 ft^3) = 1.41585 m^3/s

Flow rate in gal/hr = (50 ft^3/s)(264.17 gal/35.3145 ft^3)(3600 s/h) = 1.34649E6 gal/h

1.5 Molar flow rate

Propane gas (C_3H_8) flows to a furnace at a rate of 1450 m^3/h at 15°C and 150 kPa (gauge), where it is burned with 8% excess air. Calculate the molar flow rate (moles/s) of propane gas entering the furnace. (Hint: assume ideal gas and use $P\dot{V} = \dot{n}RT$)

Solution:

Using ideal gas low $P\dot{V} = \dot{n}RT$

$$\dot{n} = \frac{P\dot{V}}{RT}$$

Pabs = Pgage + Patm

Pabs = 150 kPa + 101.32 kPa

Pabs = 251.32 kPa

$$\dot{n} = \frac{\left(251.32\ \cancel{kPa}\right)\left|\frac{1000\ \cancel{Pa}}{\cancel{k}Pa}\right.\left(1450\ \cancel{m^3}/h\right)\left|\frac{h}{3600s}\right.}{8.314\frac{\cancel{m^3}.\cancel{Pa}}{mol.\cancel{K}}(15+273\ \cancel{K})}$$

n: number of moles = 42.2218 mol/s

1.6 Dimensional homogeneity

A quantity k depends on the temperature T in the following manner:

$$k\left(\frac{mol}{cm^3.s}\right) = A\ \exp\left(-\frac{Ea}{R\ T}\right)$$

The units of the quantity Ea are cal/mol, and T is in K (Kelvin). What are the units of A and R. (hint: note that the exponent is of unitless values; $E_a / RT = [\ ]$).

Solution:

The units of A [=] mol/cm^{3}s

R [=] cal/mol.K

1.7 Calculation of mass for specific gravity and volume

The specific gravity of gasoline is approximately 0.7. What is the mass (kg) of 10 liters of gasoline? (Answer: 7 kg)

Solution:

Mass = density * volume

Mass = (0.7 *1 kg/L)*10 L = 7 kg

1.8 Convert of equation to other units

The heat capacity of ammonia, $C_p = 2.5\,J/g.^{o}C$. Convert the expression for C_p to $Btu/(lb_m.^{o}F)$.(Hint: note that the ^{o}C and ^{o}F here is the difference in temperature; $\frac{1\ ^{o}C}{1.8\ ^{o}F}; \frac{1K}{1.8\ ^{o}R}; \frac{1\ ^{o}C}{1K}; \frac{1\ ^{o}C}{1K}$).

Answer:

$$C_p = 2.5\frac{J}{g.^{o}C}\left|\frac{453.593\,g}{1\,lbm}\right|\frac{9.486\times10^{-4} Btu/s}{1J/s}\left|\frac{1^{o}C}{1.8\ ^{o}F}\right.$$

$$Cp = 0.597609\frac{Btu}{lbm.^{o}F}$$