CHEMICAL ENGINEERING DESIGN & SAFETY

CHE 4253

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Design/Operations to Prevent Fire and Explosions

EXPLOSION and FIRE PREVENTION

- In Design
  - Explosion resistant equipment
  - Sprinkler Systems
  - Static electricity preventing
- In Operations
  - Inerting
    - Vacuum Purging
    - Pressure Purging
    - Sweep-Through Purging
  - Static Electricity Control
    - Grounding
    - Increasing conductivity in joints with Additives

INERTING

Use N_2 or CO_2 to reduce O_2 concentration in vessel.

- Vessel will contain gas: Perform inerting prior to loading gas.
- Vessel will contain liquid: Perform inerting prior and then continue on vapor phase.

An oxygen analyzer is needed.

Limiting/Minimum Oxygen Concentration (LOC/MOC)

Flammability/LOC: 120-L and 20-L closed vessel results vs. 12-L glass sphere and flammability tube.

Fuel (F)	Vessel	Stoichiometric equation	Mole ratio (R) (O_2/F)	LFL (mol%)	UFL (mol%)	LOC (N_2) (mol%)	Explosion criterion
Hydrogen (H_2)	120-L	$2H_2 + O_2 = 2H_2O$	0.5	7	75.9	4.6	Pressure
	20-L			6		4.7	Pressure
	Flam.[a] tube			4	75.0	5.0	Visual
Carbon monoxide (CO)	120-L	$2CO + O_2 = 2CO_2$	0.5	12.2	72.0	5.1	Pressure
	12-L[b]			12.2	72.5		Visual
	Flam.[a] tube			12.5	74.0	5.5	Visual
Methane (CH_4)	120-L	$CH_4 + 2O_2 = CO_2 + 2H_2O$	2	5.0	15.8	11.1	Pressure
	20-L			4.9	15.9	10.7	Pressure
	12-L[b]			4.9	15.8	11.3	Visual
	Flam.[a] tube			5.0	15.0	12.0	Visual
Ethylene (C_2H_4)	120-L	$C_2H_4 + 3O_2 = 2CO_2 + 2H_2O$	3	2.7	31.4	8.5	Pressure
	12-L[b]			2.7	31.5	8.6	Visual
	Flam.[a] tube			2.7	36.0	10.0	Visual
Propane (C_3H_8)	120-L	$C_3H_8 + 5O_2 = 3CO_2 + 4H_2O$	5	2.0	9.8	10.7	Pressure
	12-L[b]			2.0	10.0	10.5	Visual
	Flam.[a] tube			2.1	9.5	11.5	Visual

Do not have data? Use 10 mol%

Vacuum purging

- Draw some vacuum to a pressure that will not make the vessel implode. Prevent leaks through flanges first.
- Replenish with inert
- Repeat until the oxygen is at the desired level.

Vacuum purging

Moles at High Pressure

$$n_H = \frac{P_H V}{Z_H RT}$$

Moles O_2 at High Pressure

$$\left(n_{oxy}\right)_H = n_H y_{O2}^{orig}$$

Moles at Low Pressure

$$n_L = \frac{P_L V}{Z_L RT}$$

Moles O_2 at Low Pressure

$$\left(n_{oxy}\right)_L = n_L y_{O2}^{orig}$$

After N_2 is added pressure is High. ➔

Mole fraction of O_2 at new High Pressure

$$y_{O2}^{(1)} = \frac{\left(n_{oxy}\right)_L}{n_H} = \frac{n_L y_{O2}^{orig}}{n_H}$$

We are ignoring possible changes in Z and T

Vacuum purging

Mole fraction of O_2 at new High Pressure

$$y_{O2}^{(1)} = \frac{\left(n_{oxy}\right)_L}{n_H} = \frac{n_L y_{O2}^{orig}}{n_H}$$

If the process is repeated, we have

$$y_{O2}^{(2)} = y_{O2}^{orig}\left[\frac{n_L}{n_H}\right]^2$$

For k times

$$y_{O2}^{(k)} = y_{O2}^{orig}\left[\frac{n_L}{n_H}\right]^k$$

Vacuum purging

Problem: Need to reduce the concentration of oxygen to 1 ppm in a 1000 gallon vessel initially filled with air at 75 °F. Nitrogen is available at the same temperature. Vacuum is 20 mm Hg absolute. How many cycles are needed? How much N_2 is needed?

y_{O2}^{orig} = 0.21 y_{O2}^{final} = 10^{-6}

$$y_{O2}^{(k)} = y_{O2}^{orig}\left[\frac{n_L}{n_H}\right]^k \Rightarrow \frac{y_{O2}^{(k)}}{y_{O2}^{orig}} = \left[\frac{P_L}{P_H}\right]^k \Rightarrow k = \frac{\ln\left(y_{O2}^{(k)} / y_{O2}^{orig}\right)}{\ln\left(P_L / P_H\right)}$$ =3.37

That is 4 times!!! N2 needed:

$$\Delta n_{N2} = k(P_H - P_L)\frac{V}{RZT}$$ =1.33 moles

Pressure purging

- Pressurize the vessel with inert to a value admissible.
- Let the pressure go down
- Repeat until the oxygen is at the desired level.

We treat the original state as the high pressure one and P_L *is the initial pressure!! (usually atmospheric).*

$$y_{O2}^{orig} = 0.21\frac{P_L}{P_H} = 0.21\frac{P_{Atm}}{P_H}$$

$$\frac{y_{O2}^{(k)}}{y_{O2}^{orig}} = \left[\frac{P_{Atm}}{P_H}\right]^k$$

Sweep-Through Purging

- Add inert on one opening and let the gas leave the vessel at another.

$$V\frac{dC}{dt} = C_0 Q_v - C Q_v$$

is the concentration of O_2 in the feed inert original (~0)
is the concentration of O_2 in the vessel.

Integrating

$$Q_v t = V \ln\left(\frac{C(t=0) - C_0}{C(t) - C_0}\right)$$

Vacuum purging

Problem: *Need to reduce the concentration of oxygen to 1 ppm in a 1000 ft^3 vessel initially filled with air. Nitrogen is available at the vessel's temperature. How much N_2 containing 0.01% O_2 is needed to reduce the O_2 concentration in the tank to 1.25% by volume?*

$$Q_v t = V \ln\left(\frac{C(t=0)-C_0}{C(t)-C_0}\right) = 1000 \ln\left(\frac{21-0.01}{1.25-0.01}\right)$$

=2830 ft^3