

Energy Balances on Reactive Process

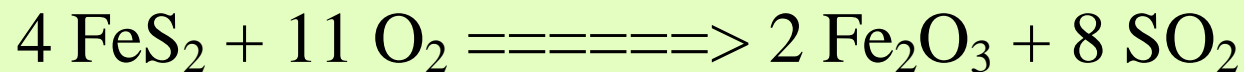


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16-1. Roasting of Iron Pyrite Ore

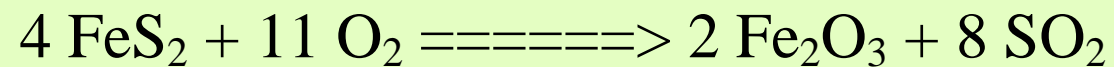
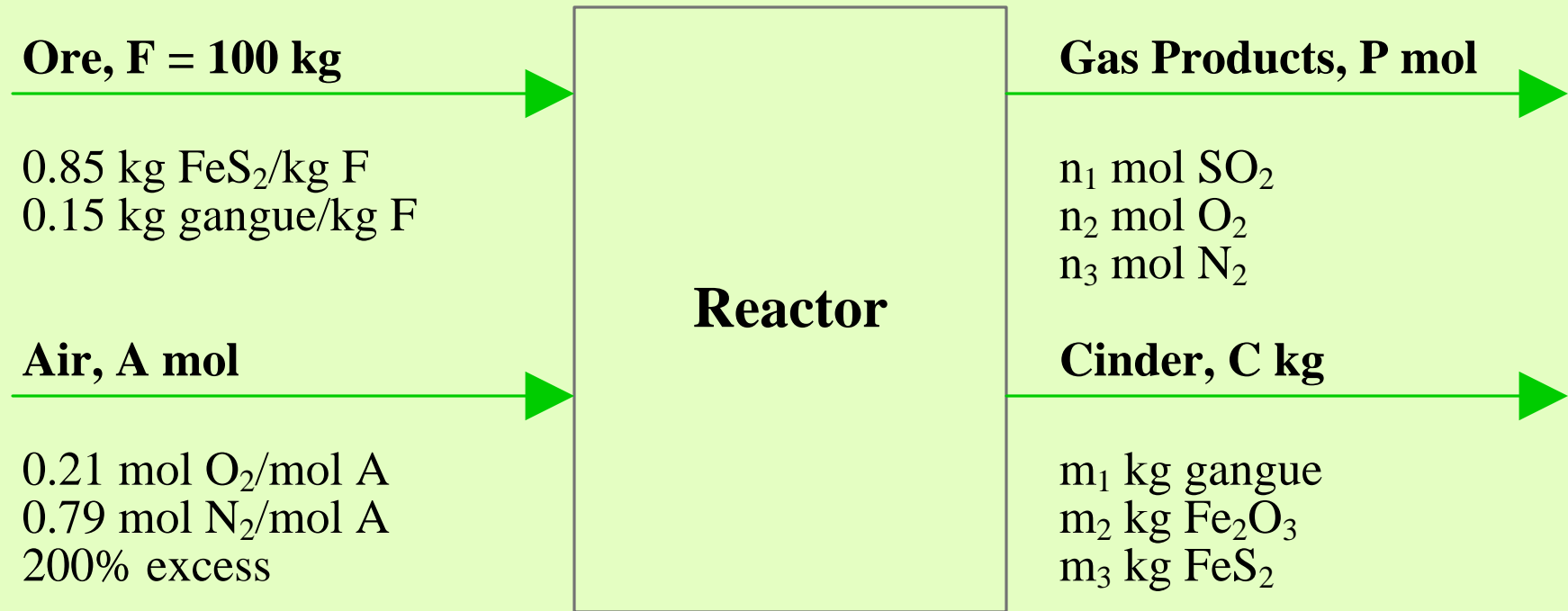
An iron pyrite ore containing 85.0% FeS_2 and 15.0% gangue (inert dirt, rock, etc.) is roasted with an amount equal to 200% excess air according to the reaction



in order to produce SO_2 . All the gangue plus the Fe_2O_3 and unreacted FeS_2 end up in the solid waste product (cinder). Analysis shows the cinder contains 4.0% FeS_2 .

Determine the heat transfer per kilogram of ore to keep the product stream at 25°C if the entering stream streams are at 25°C . Assume that pressure is constant at 1 atm.

16-1. Roasting of Iron Pyrite Ore



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The heat transfer required is calculated from the energy balance equation. Assuming $\Delta K = \Delta P = W_s = 0$, then

$$Q = \Delta H = \Sigma H_{\text{out}} - \Sigma H_{\text{in}}$$

The total enthalpy at the inlet is:

$$\Sigma H_{\text{in}} = (H_{\text{gangue}} + H_{\text{FeS}_2} + H_{\text{N}_2} + H_{\text{O}_2})_1$$

The total enthalpy at the outlet is:

$$\Sigma H_{\text{out}} = (H_{\text{SO}_2} + H_{\text{O}_2} + H_{\text{N}_2} + H_{\text{gangue}} + H_{\text{Fe}_2\text{O}_3} + H_{\text{FeS}_2})_2$$

16-1. Roasting of Iron Pyrite Ore

Hence,

$$Q = (H_{SO_2} + H_{O_2} + H_{N_2} + H_{\text{gangue}} + H_{Fe_2O_3} + H_{FeS_2})_2 - (H_{\text{gangue}} + H_{FeS_2} + H_{N_2} + H_{O_2})_1$$

Since the amount of N_2 and gangue are the same at the inlet and outlet and there are no changes in T and P conditions at the inlet and outlet, then

$$(H_{\text{gangue}})_1 = (H_{\text{gangue}})_2 \text{ and } (H_{N_2})_1 = (H_{N_2})_2$$

And the heat transfer equation becomes,

$$Q = (H_{SO_2} + H_{O_2} + H_{Fe_2O_3} + H_{FeS_2})_2 - (H_{FeS_2} + H_{O_2})_1$$

16-1. Roasting of Iron Pyrite Ore

From Table F.1,

$$(\hat{H}_f^\circ)_{\text{FeS}_2} = -177.9 \text{ kJ/mol}$$

$$(\hat{H}_f^\circ)_{\text{Fe}_2\text{O}_3} = -822.156 \text{ kJ/mol}$$

$$(\hat{H}_f^\circ)_{\text{SO}_2} = -296.90 \text{ kJ/mol}$$

$$(\hat{H}_f^\circ)_{\text{O}_2} = 0.00 \text{ kJ/mol}$$

These are the specific enthalpies at 25°C. The actual enthalpy at the given temperature condition is:

$$\hat{H} = \hat{H}_f^\circ + \int_{T_R}^T C_P dT$$

16-1. Roasting of Iron Pyrite Ore

Since the actual temperature is also at 25⁰C, then

$$\hat{H} = \hat{H}_f^{\circ}$$

The total enthalpy of each component at the inlet and outlet is determined as:

$$H = n\hat{H} = n\hat{H}_f^{\circ}$$

The molar amount of each component can be obtained thru material balances.

16-1. Roasting of Iron Pyrite Ore

From excess air information:

$$\text{Total O}_2 \text{ in} = 5.8437 \text{ kmol}$$

$$\text{Total N}_2 \text{ in} = 21.983 \text{ kmol}$$

$$\text{Gangue Balance: } m_1 = 15.0 \text{ kg}$$

$$\text{N}_2 \text{ Balance: } n_3 = 21.983 \text{ kmol}$$

$$\text{S Balance (kmol)} \quad 2(85.0/120.0) = n_1 + (m_3/120.0)(2)$$

$$\text{Fe Balance (kmol)} \quad (85.0/120.0) = (m_2/159.02)2 + (m_3/120.0)$$

$$\text{O}_2 \text{ Balance (kmol)} \quad 5.8437 = n_2 + n_1 + (m_2/159.02)(1.5)$$

16-1. Roasting of Iron Pyrite Ore

Also,

$$m_3/(15.0 + m_2 + m_3) = 0.04$$

Solving the last 4 equations simultaneously,

$$\text{Fe}_2\text{O}_3: \quad m_2 = 54.63 \text{ kg} \implies 0.342 \text{ kmol}$$

$$\text{FeS}_2: \quad m_3 = 2.90 \text{ kg} \implies 0.0242 \text{ kmol}$$

$$\text{SO}_2: \quad n_1 = 1.368 \text{ kmol}$$

$$\text{O}_2: \quad n_2 = 3.938 \text{ kmol}$$

16-1. Roasting of Iron Pyrite Ore

Solving for the total enthalpy of the inlet:

$$\Sigma H_{\text{in}} = (85.0/120.0 \text{ kmol})(-177.9 \text{ kJ/mol})(1000 \text{ mol/kmol}) \\ + (5.8437)(0)$$

$$\Sigma H_{\text{in}} = - \mathbf{126,007 \text{ kJ}}$$

Solving for the total enthalpy of the outlet:

$$\Sigma H_{\text{out}} = (1.368)(-296.90)(1000) + (0.0242)(-177.90)(1000) \\ + (1.368)(-296.90)(1000)$$

$$\Sigma H_{\text{out}} = - \mathbf{691,641 \text{ kJ}}$$

16-1. Roasting of Iron Pyrite Ore

Solving for Q:

$$Q = -691,641 - (-126,007) = -\mathbf{565,634 \text{ kJ}}$$
 per 100 kg of ore

Per kg of ore:

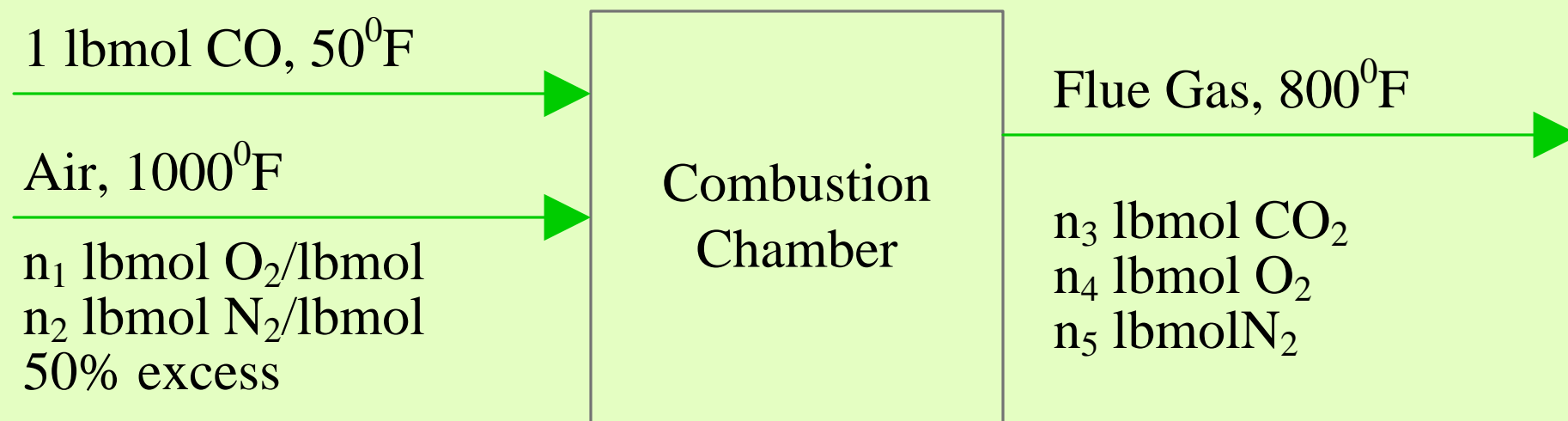
$$Q = -\mathbf{5,656 \text{ kJ}}$$
 per kg of ore

The negative sign indicates that heat must be removed during the process in order to maintain the temperature at 25°C.

Example 16-2. Combustion of Carbon Monoxide

Carbon monoxide at 50°F is completely burned at 2 atm pressure with 50% excess air that is at 1000°F . The products of combustion leave the combustion chamber at 800°F .

Calculate the heat evolved from the combustion chamber expressed as Btu/lbm CO entering.



Example 16-2. Combustion of Carbon Monoxide

With $\Delta K = \Delta P = WS = 0$, the heat evolved is calculated as:

$$Q = \Delta H = \Sigma H_{\text{out}} - \Sigma H_{\text{in}}$$

$$Q = (H_{\text{CO}_2} + H_{\text{N}_2} + H_{\text{O}_2})_2 - (H_{\text{CO}} + H_{\text{N}_2} + H_{\text{O}_2})_1$$

Calculate total enthalpy of each component:

$$H_i = n_i \hat{H}_i = n_i (\hat{H}_f^\circ + \int C_{P_i} dT)$$

The standard heat of formation can be obtained from Table F.1.

Example 16-2. Combustion of Carbon Monoxide

The C_P can be expressed as a function of temperature:

$$C_P = \alpha + \beta T + \gamma T^2$$

Values of the constants for CO, CO₂, O₂, and N₂ can be obtained from Table E.1.

The molar amount of each component can be obtained thru material balance.

$$n_1 = \text{_____ lbmol O}_2 ; n_2 = \text{_____ lbmol N}_2$$

$$n_3 = \text{_____ lbmol CO}_2 ; n_4 = \text{_____ lbmol O}_2$$

$$n_5 = \text{_____ lbmol N}_2$$

Example 16-2. Combustion of Carbon Monoxide

Standard heat of formation (Table F.1):

$$(\hat{H}_f^\circ)_{\text{CO}} = \underline{\hspace{2cm}} \text{ Btu/lbmol}$$

$$(\hat{H}_f^\circ)_{\text{CO}_2} = \underline{\hspace{2cm}} \text{ Btu/lbmol}$$

$$(\hat{H}_f^\circ)_{\text{N}_2} = (\hat{H}_f^\circ)_{\text{O}_2} = 0$$

Heat capacity equations (Table E.1):

(T is in $^\circ\text{F}$ and C_P is $\text{Btu/lbmol-}^\circ\text{F}$)

$$(C_P)_{\text{CO}_2} = \underline{\hspace{1cm}} + \underline{\hspace{1cm}} T \underline{\hspace{1cm}} T^2$$

$$(C_P)_{\text{CO}} = \underline{\hspace{1cm}} + \underline{\hspace{1cm}} T \underline{\hspace{1cm}} T^2$$

$$(C_P)_{\text{N}_2} = \underline{\hspace{1cm}} + \underline{\hspace{1cm}} T \underline{\hspace{1cm}} T^2$$

$$(C_P)_{\text{O}_2} = \underline{\hspace{1cm}} + \underline{\hspace{1cm}} T \underline{\hspace{1cm}} T^2$$

Example 16-2. Combustion of Carbon Monoxide

Solving for the specific enthalpy:

Products

$$\text{CO}_2 : \quad \hat{H}_{\text{CO}_2} = -169,179 + \int_{\underline{\quad}}^{\underline{\quad}} (C_P)_{\text{CO}_2} dT = \underline{\hspace{2cm}} \text{ Btu / lbmol}$$

$$\text{N}_2 : \quad \hat{H}_{\text{N}_2} = (0) + \int_{\underline{\quad}}^{\underline{\quad}} (C_P)_{\text{N}_2} dT = \underline{\hspace{2cm}} \text{ Btu / lbmol}$$

$$\text{O}_2 : \quad \hat{H}_{\text{O}_2} = (0) + \int_{\underline{\quad}}^{\underline{\quad}} (C_P)_{\text{O}_2} dT = \underline{\hspace{2cm}} \text{ Btu / lbmol}$$

Example 16-2. Combustion of Carbon Monoxide

Reactants:

$$\text{CO:} \quad \hat{H}_{\text{CO}} = -47,515 + \int_{\text{---}}^{\text{---}} (C_P)_{\text{CO}} dT = \text{---} \text{ Btu / lbmol}$$

$$\text{N}_2: \quad \hat{H}_{\text{N}_2} = (0) + \int_{\text{---}}^{\text{---}} (C_P)_{\text{N}_2} dT = \text{---} \text{ Btu / lbmol}$$

$$\text{O}_2: \quad \hat{H}_{\text{O}_2} = (0) + \int_{\text{---}}^{\text{---}} (C_P)_{\text{O}_2} dT = \text{---} \text{ Btu / lbmol}$$

Example 16-2. Combustion of Carbon Monoxide

Solving for the total enthalpy of the products and reactants:

$$\Sigma H_{\text{out}} = -143,743 \text{ Btu}$$

$$\Sigma H_{\text{in}} = -22,170 \text{ Btu}$$

And the heat transfer is:

$$Q = \Sigma H_{\text{out}} - \Sigma H_{\text{in}} = -121,570 \text{ Btu per 1 lbmol CO}$$

$$Q = -121,570 \text{ Btu/lbmol CO (1 lbmol CO/28 lbm CO)}$$

$$Q = -4,342 \text{ Btu/lbm CO}$$