

Heat Balance

1) Vaporizer :

Molten sulfur vaporized in the vaporizer, $m_v = 2890.0$ Kmols/day

Latent heat of vaporization, $\lambda_s = 8832.0$ KJ/kmol

Hence, heat required to vaporize the sulfur, $Q_s = m_v \times \lambda_s$

$$= 2890.0 \times 8832.0 = 25.52 \times 10^6 \text{ KJ/day}$$

$$Q_s = 295.42 \text{ KW}$$

2) Reactor :

For the reaction : $\text{CH}_4 + 4 \text{S} \rightarrow \text{CS}_2 + 2 \text{H}_2\text{S}$

Enthalpy of formation of CH_4 , $(\Delta H_f)_{\text{CH}_4} = -74.78$ KJ/mol

Enthalpy of formation of H_2S , $(\Delta H_f)_{\text{H}_2\text{S}} = -20.6$ KJ/mol

Enthalpy of formation of CS_2 , $(\Delta H_f)_{\text{CS}_2} = 117.6$ KJ/mol

Heat of the reaction, $\Delta H_R = (\Sigma \Delta H_f)_{\text{products}} - (\Sigma \Delta H_f)_{\text{reactants}}$

$$= [117.2 + 2 \times (-20.6)] - [-74.78 - 0]$$

$$= 150.68 \text{ KJ/mol}$$

i.e. the reaction is endothermic in nature.

Input : $\text{CH}_4 = 803.0$ Kmols

$\text{S} = 2890.0$ Kmols

Output : $\text{CH}_4 = 73.0$ Kmols

$\text{S} = 262.81$ Kmols

$\text{CS}_2 = 657.03$ Kmols

$\text{H}_2\text{S} = 1314.03$ Kmols

Hence, total heat required for the reaction = $657.03 \times 10^3 \times 150.68 / (24 \times 3600)$ KJ/s

Hence, total heat required for the reaction = 1145.84 KW

Reaction temperature = 600°C

Sensible heat supplied to the furnace, $Q = \sum mc_p \Delta T$

Specific heat of methane, $(C_p)_{CH_4} = 52.25$ KJ/kg°C

Specific heat of hydrogen sulfide, $(C_p)_{H_2S} = 34.2$ KJ/kg°C

Specific heat of carbon disulfide, $(C_p)_{CS_2} = 46.2$ KJ/kg°C

Specific heat of sulfur, $(C_p)_S = 684.0$ KJ/kg°C

$$Q = [73.0 \times 52.25 + 1314.03 \times 34.2 + 657.03 \times 46.2 + 262.81 \times 684] \times 575 \\ = 148.85 \text{ KJ/day}$$

$$Q = 1722.81 \text{ KW}$$

Hence, total heat supplied to the reactor = $295.42 + 1722.81 = 2018.23$ KW

3) Heat Exchanger :

Reaction products are cooled from 600°C to 130°C

Boiling point of sulfur = 444.6°C

Heat given by the reaction products in the heat exchanger,

$Q =$ Sensible heat of the components + heat expelled in cooling sulfur to its boiling point + latent heat of sulfur

$$Q = [73.0 \times 52.25 + 1314.03 \times 34.2 + 657.03 \times 46.2] \times (600 - 130) \\ + 262.8 \times 684 \times (600 - 444.6) + 262.8 \times 8832.0$$

$$= 67.535 \times 10^6 \text{ KJ/day}$$

$$Q = 781.665 \text{ KW}$$

4) Sulfur scrubber :

Input : $CH_4 = 73.0$ Kmols

$$\text{CS}_2 = 657.03 \text{ Kmols}$$

$$\text{H}_2\text{S} = 1314.06 \text{ Kmols}$$

$$\text{S} = 262.81 \text{ Kmols}$$

Entering at a temperature of 130°C

261.49 Kmols of sulfur is scrubbed by liquid sulfur at a constant temperature. Also, as the heat of dissolution is almost zero, there is no heat exchange.

Output : $\text{CH}_4 = 73.0 \text{ Kmols}$

$$\text{CS}_2 = 657.03 \text{ Kmols}$$

$$\text{H}_2\text{S} = 1314.06 \text{ Kmols}$$

$$\text{S} = 1.314 \text{ Kmols}$$

Exit gases at a temperature of 130°C.

5) CS₂ condenser :

30 % of the CS₂, entering as gas is condensed to liquid.
Temperature of the inflow is reduced from 130°C to 40°C.

Heat load = sensible heat required to cool CH₄, H₂S, S and CS₂ + latent heat of condensation of 30% CS₂

$$\text{Latent heat of condensation of 30\% CS}_2 = 0.3 \times 657.03 \times 27.41 \times 10^3 \text{ KJ}$$

$$Q = [(73.0 \times 52.25 + 1314.06 \times 34.2 + 1.314 \times 684) \times (130 - 140) + 657.03 \times 46.2 \times (130 - 46.23)] + [0.3 \times 657.03 \times 27.41 \times 10^3] + [0.7 \times 657.03 \times (46.23 - 40)]$$

$$= 12.546 \times 10^6 \text{ KJ/day}$$

$$Q = 145.21 \text{ KW}$$

6) Absorber :

CS₂ is absorbed under isothermal conditions in the absorber under isothermal conditions.

Assuming ideal solution, heat of mixing is zero.

$$\text{Input : CS}_2 = 459.92 \text{ Kmols}$$

$$\text{H}_2\text{S} = 1314.06 \text{ Kmols}$$

$$\text{CH}_4 = 73.0 \text{ Kmols}$$

$$\text{Oil} = 1947.32 \text{ Kmols}$$

$$\text{Output : CS}_2 = 457.62 \text{ Kmols}$$

$$\text{H}_2\text{S} = 6.5703 \text{ Kmols}$$

$$\text{Oil} = 1947.32 \text{ Kmols}$$

457.62 Kmols of CS_2 and 6.5703 Kmols of H_2S are absorbed in oil.

$$\text{Heat of absorption, } Q = (m\lambda)_{\text{CS}_2} + (m\lambda)_{\text{H}_2\text{S}}$$

$$= 457.62 \times 27.41 \times 10^3 + 6.5703 \times 18.68 \times 10^3$$

$$= 12.66 \times 10^6 \text{ KJ/day}$$

$$Q = 146.59 \text{ KW}$$

This raises the temperature of the oil to $T^\circ\text{C}$, say.

$$\text{Specific heat of oil, } (C_p)_{\text{oil}} = 0.475 \text{ Kcal/Kg}^\circ\text{C}$$

$$= 357.98 \text{ KJ/Kmol}^\circ\text{C}$$

$$Q = (mC_p)_{\text{oil}} \times (T - 40)$$

$$146.59 = 8.068 \times (T - 40)$$

$$\text{Hence, } T = 58.16^\circ\text{C}$$

7) Heat exchanger :

$$\text{Input liquid from absorber (at } 58.16^\circ\text{C)} : \quad \text{CS}_2 = 457.62 \text{ Kmols}$$

$$\text{H}_2\text{S} = 6.5703 \text{ Kmols}$$

$$\text{Oil} = 1947.32 \text{ Kmols}$$

Sensible heat load = sensible heat of CS_2 in raising its temperature from 59.16 to 120°C + sensible heat of oil

$$Q = (mC_p\Delta T)_{CS_2} + (mC_p\Delta T)_{oil}$$

$$= 457.62 \times 46.2 \times (120 - 58.12) + Q_{oil}$$

$$Q = 15.132 + Q_{oil}$$

8) Stripper :

Assuming that the stripper operates at 120°C and atmospheric pressure.

Heat provided by the reboiler = latent heat of CS₂

$$= 457.62 \times 27.41 \times 10^3 \text{ KJ/day}$$

$$= 145.177 \text{ KW}$$

Hence, total heat load required in the absorber cum stripping section
= 15.132 + 145.177

$$Q = 160.309 \text{ KW}$$

9) Distillation column :

Operating temperature is 40°C and pressure is atmospheric pressure.

Enthalpy of condensed liquid from crude CS₂ receiver + enthalpy of feed + heat from the reboiler = condenser load + enthalpy of residue + enthalpy of distillate

Input : (from crude CS₂ receiver, at 40°C) CS₂ = 197.1 Kmols

$$S = 1.314 \text{ Kmols}$$

Feed from stripper(at 120°C) : CS₂ = 457.62 Kmols

$$H_2S = 6.5703 \text{ Kmols}$$

$$\text{Oil} = 19.27 \text{ Kmols}$$

Exit gases : (tops) CS₂ = 657.03 Kmols

$$H_2S = 0.1314 \text{ Kmols}$$

$$S = 1.314 \text{ Kmols}$$

$$\text{Oil} = 19.27 \text{ Kmols}$$

Enthalpy of feed + heat provided by the reboiler = heat given to the condenser + enthalpy of products

$$\text{Enthalpy of the feed} = [457.62 \times 46.2 + 6.5703 \times 34.2 + 19.27 \times 357.9] \times (120 - 40) + Q_b = Q_c + 0$$

Hence, total heat removed from the distillation unit,
 $Q_b - Q_c = 2.2612 \times 10^6 \text{ KJ/Day}$

$$= 2,2612 \times 10^6 \text{ KW}$$

10) Refining column :

Operating at 80°C and 1 atm pressure.

Entering gas stream: $\text{CS}_2 = 657.03 \text{ Kmols}$

$$\text{H}_2\text{S} = 0.1314 \text{ Kmols}$$

$$\text{S} = 1.314 \text{ Kmols}$$

$$\text{Oil} = 19.27 \text{ Kmols}$$

Exit (tops): $\text{CS}_2 = 657.03 \text{ Kmols}$

$$\text{H}_2\text{S} = 0.1314 \text{ Kmols}$$

(bottoms): $\text{S} = 1.314 \text{ Kmols}$

$$\text{Oil} = 19.27 \text{ Kmols}$$

Enthalpy of feed + $Q_b = Q_c +$ enthalpy of products

$$[657.03 \times 46.2 + 0.1314 \times 34.2 + 1.314 \times 684.0 + 19.27 \times 357.9] \times (120 - 80) = Q_c - Q_b$$

$$Q_c - Q_b = 1.5262 \times 10^6 \text{ KJ/day}$$

$$= 17.664 \text{ KW}$$