

HEAT BALANCE

BASIS:

1 HOUR OF OPERATION.

BURNER :

As cited in the literature, the heat of combustion of sulfur is = 2170 Cal/g

And,

Moles of Sulfur burnt = 417.51Kmoles/Hr

Then,

Heat evolved in the reaction is $= 2170 \times 4184 \times 417.5 \times 32$
 $= 1.212 \times 10^{11} \text{ J/Hr}$

As this reaction is exothermic,

We have, $\Delta H = - 1.212 \times 10^{11} \text{ J/Hr}$

The above heat is recovered in the waste heat boiler.

WASTE HEAT BOILER :

Inlet Gas Temperature = 601 °C

Outlet Gas Temperature = 438 °C

SPECIFIC HEAT DATA for the Gas Stream as Available from the literature are tabulated as follows:

| COMPONENT | SPECIFIC HEAT (C _p) Cal/gm-mole K |
|--------------------|--------------------------------------------------|
| 1. N ₂ | $6.42 + 1.34 \times 10^{-3} T$ |
| 2. SO ₂ | $9.52 + 3.64 \times 10^{-3} T$ |
| 3. SO ₃ | $12.13 + 8.12 \times 10^{-3} T$ |
| 4. O ₂ | $6.74 + 1.64 \times 10^{-3} T$ |

Base temperature (assumed) = 25 °C

Gas with maximum temperature = 601 °C

Then,

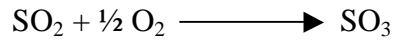
Bulk Temperature of the Gas = 313 °C

= 586 K

The Heat Capacities at this bulk temperature are calculated and tabulated as follows:

| COMPONENT | SPECIFIC HEAT (C _p) KJ/Kg-mole K |
|--------------------|-------------------------------------------------|
| 1. N ₂ | 30.146 |
| 2. SO ₂ | 48.773 |
| 3. SO ₃ | 70.680 |
| 4. O ₂ | 32.221 |

For the reaction,



$$\Delta H = -24.6 + 1.99 \times 10^{-3} T \text{ (KCal/gm-mole)}$$

And at the bulk temperature of the gas,

$$\Delta H = -98047 \text{ (KJ/Kg-mole)}$$

Heat of dilution = 9.304 KJ

Specific heat of Sulfuric acid = 1.4435 KJ/Kg-K

Heat balance is given by,

$$\text{Heat Input} - \text{Heat Output} = m\lambda \longrightarrow \text{(A)}$$

Heat Input is calculated as

$$\begin{aligned} &= \sum [m \times C_p \times (601 - 25)]_{\text{O}_2, \text{N}_2, \text{SO}_2, \text{SO}_3} \\ &= 7.854 \times 10^{10} \text{ J} \end{aligned}$$

Heat Output is calculated as

$$\begin{aligned} &= \sum [m \times C_p \times (438 - 25)]_{\text{O}_2, \text{N}_2, \text{SO}_2, \text{SO}_3} \\ &= 5.633 \times 10^{10} \text{ J} \end{aligned}$$

Substituting in Heat balance equation (A), with the value of λ at base temperature of 298 C

that is,

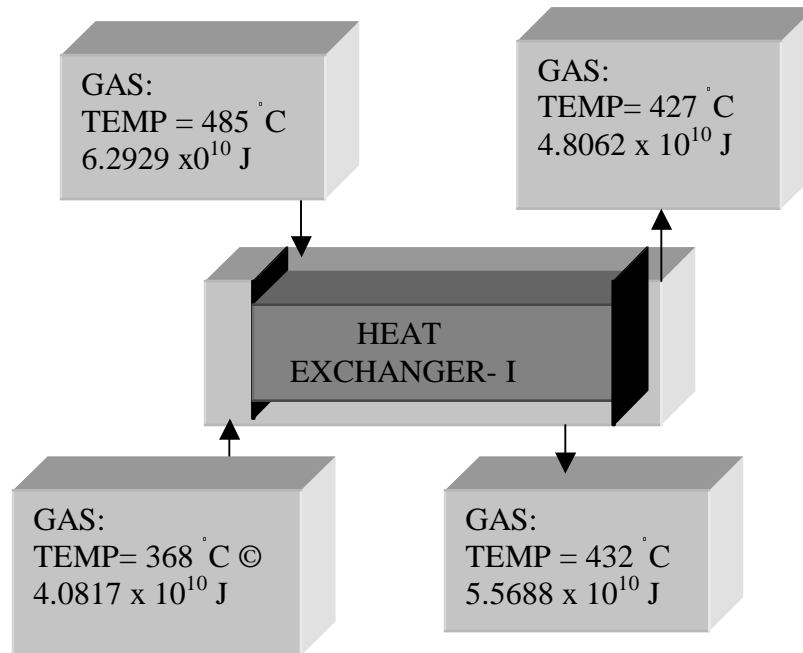
$$\begin{aligned} \lambda &= 2442.5 \times 10^3 \text{ J/Kg} \\ m &= 9094.7 \text{ Kgs/Hr} \end{aligned}$$

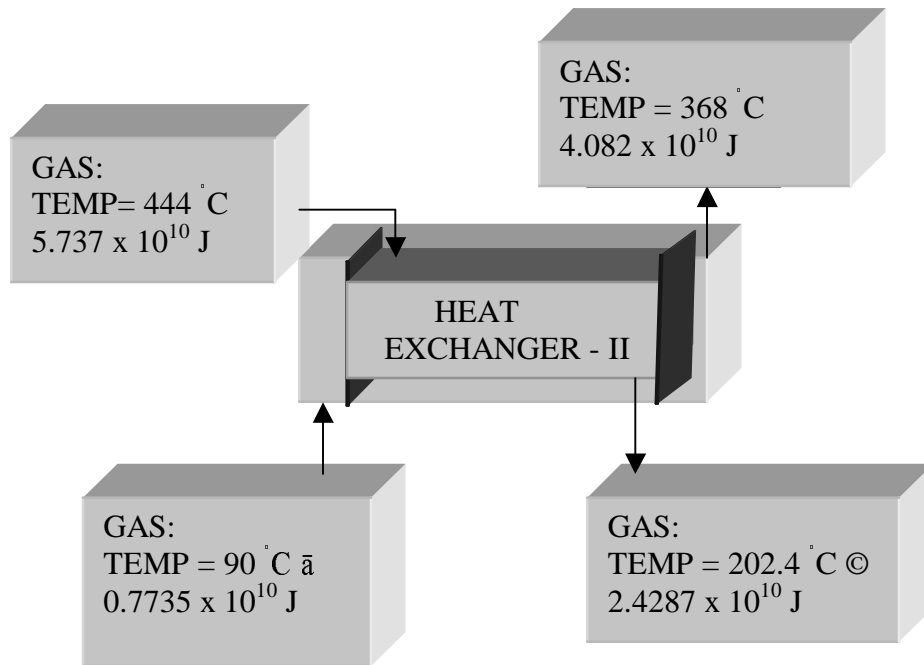
REACTOR :

The table shown below summarizes the heat balance inside the reactor at each bed:

| BED | INLET TEMP. (°C) | OUTLET TEMP. (°C) | HEAT INPUT (J) | HEAT OUTPUT (J) | HEAT EVOLVED (J) | HEAT LOSS (J) |
|-----|------------------|-------------------|------------------------|------------------------|------------------------|-------------------------|
| 1. | 410 | 601 | 5.182×10^{10} | 7.854×10^{10} | 3.03×10^{10} | 0.3570×10^{10} |
| 2. | 438 | 485 | 5.326×10^{10} | 6.292×10^{10} | 0.753×10^{10} | 0.0929×10^{10} |
| 3. | 432 | 444 | 5.568×10^{10} | 5.737×10^{10} | 0.176×10^{10} | 0.0784×10^9 |
| 4. | 427 | 437 | 4.806×10^{10} | 4.928×10^{10} | 0.127×10^{10} | 0.0470×10^9 |

HEAT EXCHANGERS :





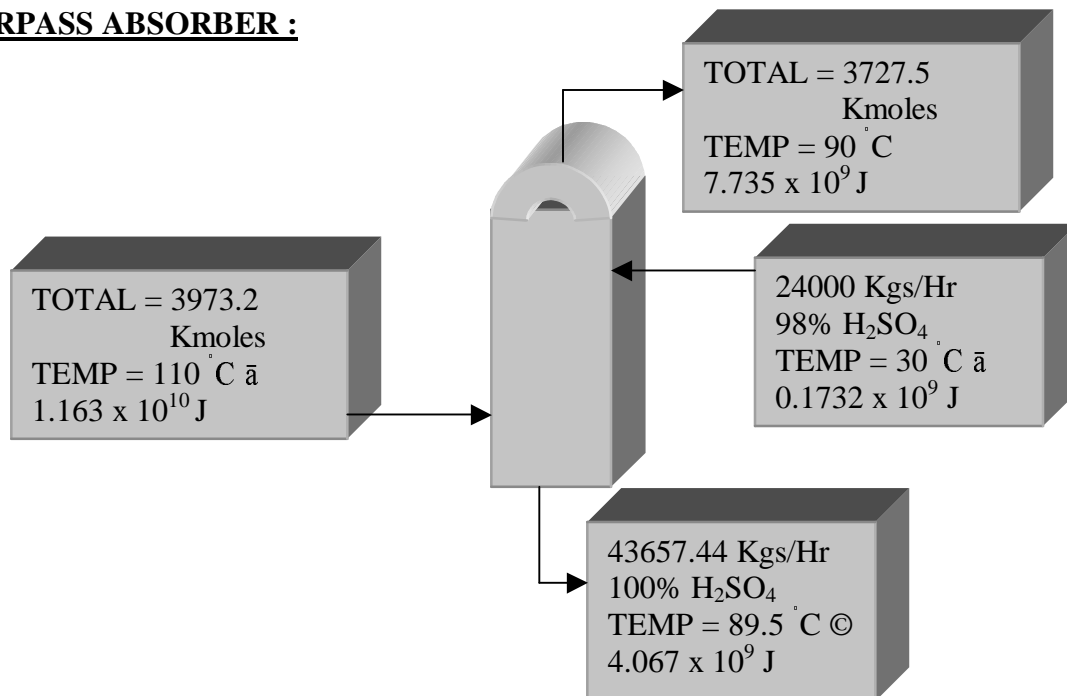
COOLER - I:

Inlet Gas temperature = 202.41 °C
 Outlet Gas temperature (assumed) = 110 °C

Using heat balance equation (A), gives as,
 Heat Input – Heat Output = mλ

Then, with λ = 2442.5 x 10³ J/Kg
 m = 5179 Kgs/Hr

INTERPASS ABSORBER :



We make a heat balance around the absorber,

Heat Input = Heat Output

Then, $1.163 \times 10^{10} + 0.1732 \times 10^9 = 7.735 \times 10^9 + 43657.44 \times 1.4435 \times 10^3 (T-25)$

$$T = 89.55 \text{ }^\circ\text{C}$$

But to account for the absorption of heat, we have assumed a temperature of $120 \text{ }^\circ\text{C}$

TANK – I :

Heat that is coming with the acid ($120 \text{ }^\circ\text{C}$) = $0.5986 \times 10^{10} \text{ J}$
Water for dilution which is fed at $30 \text{ }^\circ\text{C}$ = $4914.36 \times 4184 \times (30-25)$
= $0.1028 \times 10^9 \text{ J}$
Heat evolved due to Dilution = 4915×9304
= $0.0457 \times 10^9 \text{ J}$
Heat coming out from the tank with the acid = $48572 \times 1443.5 \times (T_1-25)$

Heat Balance gives,

$$T_1 = 112.5 \text{ }^\circ\text{C}$$

ACID COOLER :

Inlet Acid temperature = $112.5 \text{ }^\circ\text{C}$
Outlet Acid temperature = $30 \text{ }^\circ\text{C}$
Inlet water temperature = $25 \text{ }^\circ\text{C}$
Outlet water temperature = $40 \text{ }^\circ\text{C}$

Making heat balance,

Heat Input = Heat Output

$$48572 \times 1443.5 \times (112.5 - 30) = p \times 4184 \times (40 - 25)$$

$$p = 92166.64 \text{ Kgs/Hr}$$

ECONOMISER :

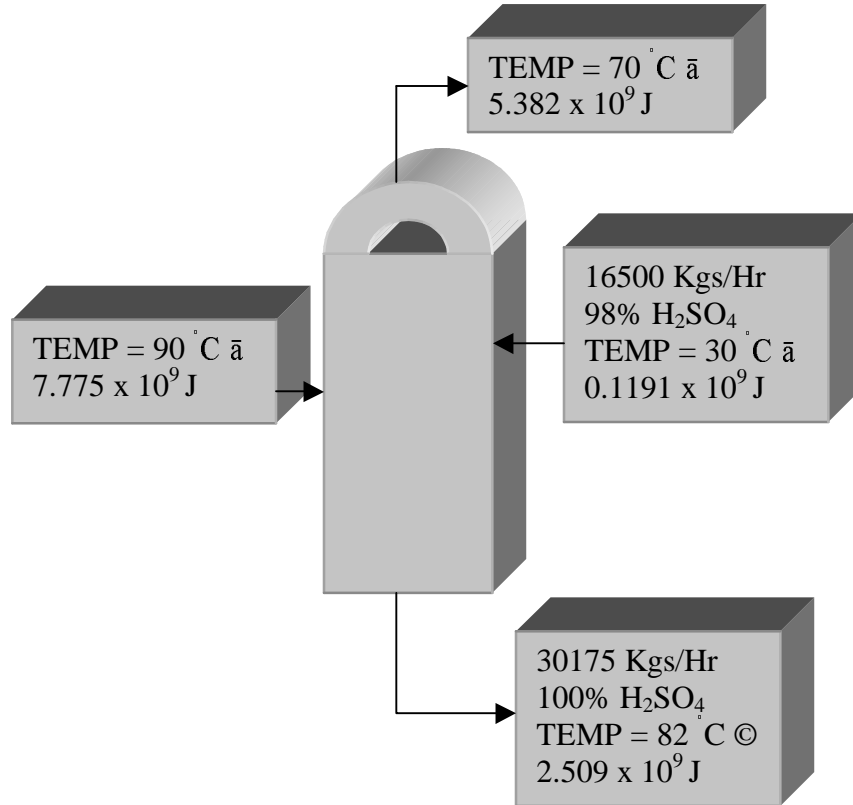
Inlet Gas temperature = $437 \text{ }^\circ\text{C}$
Outlet Gas temperature (assumed) = $90 \text{ }^\circ\text{C}$

Heat Input = $4.928 \times 10^{10} \text{ J}$
Heat Output = $(4.928 \times 10^{10}) \times (90 - 25) / (437-25)$
= $7.775 \times 10^9 \text{ J}$

$$\text{Heat Input} - \text{Heat Output} = a\lambda$$

$$a = 16994.5 \text{ Kgs/Hr}$$

FINAL ABSORPTION TOWER :



TANK – II :

$$\begin{aligned} \text{Heat that is coming with the acid (82.6 °C)} &= 2.509 \times 10^9 \text{ J} \\ \text{Water for dilution which is fed at 30 °C} &= 3419 \times 4184 \times (30-25) \\ &= 0.0715 \times 10^9 \text{ J} \\ \text{Heat evolved due to Dilution} &= 3419 \times 9304 \\ &= 0.0318 \times 10^9 \text{ J} \\ \text{Heat coming out from the tank with the acid} &= 33595 \times 1443.5 \times (T_2-25) \end{aligned}$$

Heat Balance gives,

$$T_2 = 78.85 \text{ °C}$$

T₁ and T₂ are the temperatures at which the sulphuric acid streams are coming out after passing the respective acid coolers from the Tank – I and Tank – II.

Note – The symbols which are used mean the following:

λ – Latent heat at the base temperature.

\bar{a} – The value has been assumed and the further calculations are done based on this value

© - The value has been calculated based on the assumed value