ENERGY BALANCE

1) Balance around feed preheater heat exchanger:

The mixed feed, which is assumed to be at around 30^{o}C & have both liquid & vapour phases enters into the heat exchanger & gets heated to a temperature of 200^{o}C by taking heat from the reactor effluent stream, which is at 750^{o}C.

a) Feed stream entering:

T = 30^{o}C

Hydrogen -1633.2607 kmol/hr

Methane -1156.1750 kmol/hr

Benzene - 1.0591 kmol/hr

Toluene - 191.5207 kmol/hr

Specific heats at 30^{o}C,

Hydrogen –$Cp_{H(g)}$ = 29.5 kJ/kmolK

Methane -$Cp_{M(g)}$ = 36.9 kJ/kmolK

Benzene - $Cp_{B(l)}$ = 136 kJ/kmolK

Toluene - $Cp_{T(l)}$ = 156 kJ/kmolK

b) Reactor effluent stream entering:

T = 750^{o}C

Hydrogen -1499.1962 kmol/hr

Methane -1290.2397 kmol/hr

Benzene - 135.1314 kmol/hr

Toluene - 57.4562 kmol/hr

Specific heats at 750^{o}C,

Hydrogen –$Cp_{H(g)}$ = 29.5 kJ/kmolK

Methane -$Cp_{M(g)}$ = 73.75 kJ/kmolK

Benzene - $Cp_{B(g)}$ = 215 kJ/kmolK

Toluene - $Cp_{T(g)}$ = 265 kJ/kmolK

c) Feed stream leaving:

$T = 200^oC$

Hydrogen –$Cp_{H(g)} = 29.5$ kJ/kmolK

Methane -$Cp_{M(g)} = 45.5$ kJ/kmolK

Benzene - $Cp_{B(g)} = 135$ kJ/kmolK

Toluene - $Cp_{T(g)} = 165$ kJ/kmolK

Boiling point of benzene = 80.1^oC,

Latent heat of vaporisation, $\lambda_B = 94.14$ cal/g = 30736.7 kJ/kmol

Boiling point of toluene = 110.62^oC,

Latent heat of vaporisation, $\lambda_T = 86.8$ cal/g = 33426.98 kJ/kmol

Balance gives,

1633.2607 x 29.5 x (200-30) + 1156.1750 x 36.9 x (200-30) +

1.0591 x [136 x (80.1-30) + 30736.7 + 135 x (200-80.1)] +

191.5207 x [156 x (110.62-30) + 33426.98 + 165 x (200-110.62)] = [1499.1962 x 29.5

+ 1290.2397 x 73.75 + 135.1314 x 215 + 57.4562 x 265] (750-T)

T = <u>602^oC.</u>

2) Balance around heater:

In the heater, the feed stream is heated to the reaction temperature, ie, 750^oC.

The average specific heats taken are,

Hydrogen –$Cp_{H(g)} = 29.5$ kJ/kmolK

Methane -$Cp_{M(g)} = 60$ kJ/kmolK

Benzene - $Cp_{B(g)} = 175$ kJ/kmolK

Toluene - $Cp_{T(g)} = 215$ kJ/kmolK

The heat to be supplied in the reactor = (1633.2607 x 29.5 + 1156.1750 x 60 + 1.0591 x 175 + 191.5207 x 215) (750-200)

= 8.74 x 10^7 kJ/hr

3) Balance around reactor:

In the reactor, exothermic reaction is undergoing & hence some mechanism to remove the heat generated such as quenching or cooling water circulation in shell has to be done to maintain the reactor in isothermal conditions.

Heat of formation of different components are given below.

Hydrogen –H^f = 82930 + 215 x (750-25) = 238805 kJ/kmol

Methane - H^f = 50170 + 265 x (750-25) = 242295 kJ/kmol

Benzene - H^f = $^-$74520 + 73.75 x (750-25) = $^-$21051.25 kJ/kmol

Toluene - H^f = 0 + 29.5 x (750-25) = 21387.5 kJ/kmol

Heat of reaction, $\Delta H^R = \Sigma H^f$, products - ΣH^f, reactants

= (238805 – 21051.25) – (242295 + 21387.5)

= $^-$4.59 x 10^4 kJ/kmol

Number of kmoles reacting per hour = 191.5207 – 57.4562

= 134.0645 kmoles

Therefore, heat to be removed from the reactor per hour = 134.0645 x 4.59 x 10^4 kJ

= 6.16 x 10^6 kJ

4) Heat exchanger cooling reactor effluents:

The effluent stream from the reactor, after heating the feed has to be further cooled to ambient temperature, say 45^oC using water at 30^oC. The temperature of effluent stream is 602^oC & water is heated to 40^oC.

The balance gives,

1499.1962 x 29.5 x (602–45) + 1290.2397 x 60 x (602-45) + 135.1314 x [175(602-80.1) + 30736.7 + 136(80.1-45)] + 57.4562 x [215(602-110.62) + 33426.98 + 156(110.62-45)]
= M (4.187 x 18)(40-30)

M = 620.13 kg/s.

Hence use of multiple heat exchangers will be more suitable.

5) Balance around condenser:

T = 81^oC

Latent heat of vaporisation, λ_B = 94.14 cal/g = 30736.7 kJ/kmol

Latent heat of vaporisation, λ_T = 86.8 cal/g = 33426.98 kJ/kmol

Benzene - 133.4 kmol/hr

Toluene - 5.5583 kmol/hr

Heat duty = 133.4 x 30736.7 + 5.5583 x 33426.98 = <u>4.29 x 10^6 kJ/hr</u>.

6) Balance around reboiler:

T = 110^oC

Benzene - 1.0591 kmol/hr

Toluene - 51.8979 kmol/hr

Heat duty = 1.0591 x 30736.7 + 51.8979 x 33426.98 =<u>1.77 x 10^6 kJ/kmol</u>