ENERGY BALANCE

The first law of thermodynamics demands that energy be neither created nor destroyed. The following is a systematic energy balance performed for each unit of the process. The datum temperature for calculation is taken as 0 $^{\circ}$C.

The different properties like specific heat, heat of reaction, heat of vaporization, etc. are taken to be constant over the temperature range. This does not however, introduce significant error in the calculations. The units are as depicted in the flow sheet (Ch-3, Fig. 3.3)

Energy balance around the refrigeration unit

Inputs:

Temperature of make-up water = 30 $^{\circ}$C

Temperature of recycled water = 30 $^{\circ}$C

Sensible heat of make up water = $m.C_P.\Delta T = 0.4000 \times 4.18 \times (30-0) = 50$ kW

Sensible heat of recycled water = $m.C_P.\Delta T = 7.9034 \times 4.18 \times (30-0) = 991$ kW

Total heat in = 1041 kW

Outputs:

Temperature of water exiting = 11 $^{\circ}$C

Sensible heat of the exit stream = $m.C_P.\Delta T = 8.3034 \times 4.18 \times (11-0) = 382$ kW

Rate of heat removal in the refrigeration unit = 1041-382 = 659 kW

Energy balance around hold tank

Inputs:

Temperature of water = 11 $^{\circ}$C

Temperature of ethylene oxide = -10 $^{\circ}$C

Sensible heat of water stream = $m.C_P.\Delta T$ = 8.3034×4.18×(11-0)= 382 kW

Sensible heat of ethylene oxide = $m.C_P.\Delta T$ = 1.0148×1.9733×(-10-0)= -20 kW

Total heat in = 362 kW

Outputs:

Temperature of the leaving stream = 10 °C

Sensible heat = $m.C_P.\Delta T$ = 9.3182×3.8353×(11-0)= 362 kW

Energy balance around the Heat Exchanger (HE-1)

Inputs:

Temperature of the entering reactant stream = 11 °C

Temperature of the entering glycol stream = 252 °C

Sensible heat of the reactant stream =$m.C_P.\Delta T$= 9.3182×3.8353×(11-0) =362 kW

Sensible heat of the glycol stream =$m.C_P.\Delta T$= 9.3182×4.0124×(252-0) =9413 kW

Total Sensible heat entering the heat exchanger = 9775 kW

Outputs:

Temperature of the leaving reactant stream = 200 °C

Temperature of the leaving glycol stream = 70 °C

Sensible heat of the reactant stream = $m.C_P.\Delta T$ = 9.3182×3.8353×(200-0)=7148 kW

Sensible heat of the glycol stream = $m.C_P.\Delta T$ = 9.3182×4.0124×(70-0)= 2627 kW

Total heat leaving the heat exchanger = 9775 kW

Energy balance around the reactor

Inputs:

Temperature of the reactant stream = 200 °C

Sensible heat of the reactant system = $m.C_P.\Delta T = 9.3182 \times 3.8353 \times (200-0) = 7148$ kW

Heat of reaction = 2265 kW

Total energy in = 9413 kW

Outputs:

Temperature of the glycol stream = 252 $^{\circ}$C

Sensible heat of the product stream = $m.C_P.\Delta T = 9.3182 \times 4.0124 \times (252-0) = 9413$ kW

Energy balance around the evaporator

Inputs:

Temperature of the glycol stream entering = 70 $^{\circ}$C

Heat input through steam = Q_E kW

Sensible heat = $m.C_P.\Delta T = 9.3182 \times 4.0124 \times (70-0) = 2617$ kW

Total heat entering = $(2617 + Q_E)$ kW

Outputs:

Temperature of the leaving condensate stream = 110 $^{\circ}$C

Temperature of the leaving steam = 80 $^{\circ}$C

Temperature of the leaving glycol stream = 80 $^{\circ}$C

Sensible heat of the condensate stream = $m.C_P.\Delta T = 6.5314 \times 4.18 \times (110-0) = 3003$ kW

Heat content of steam = $m.C_P.\Delta T + m.\lambda$

$= 1.4 \times 4.18 \times (80-0) + 1.4 \times 2300$

$= 3688$ kW

Sensible heat of the glycol stream = $m.C_P.\Delta T = 1.3868 \times 3.0540 \times (80-0) = 339$ kW

Total heat leaving the evaporator = 7030 kW

From heat balance, $(2617 + Q_E) = 7030$

Q_E = 4413 kW

Considering 2.5 atm steam (λ=2100 kJ/kg)

Steam requirement = 4413/2100 = 2.1 kg/s

Energy balance around the heat exchanger (HE-2)

Inputs:

Temperature of the entering glycol stream = 80 $^{\circ}$C

Sensible heat of the glycol stream = $m.C_P.\Delta T$ = 1.3868×3.0540×(80-0)= 339 kW

Heat input through steam = Q kW

Total heat input = (339 + Q) kW

Outputs:

Temperature of the glycol stream leaving the exchanger as saturated vapor = 138.6°C

Heat content of the leaving stream = $m.C_P.\Delta T + m.\lambda$

= 1.3868×3.054×(138.6-0) + 1.3868×723.7

= 1591 kW

Making an energy balance,

Q+339 = 1591

Q = 1252 kW

Considering saturated steam at 120 $^{\circ}$C (λ = 2220 kW)

Steam requirement = 1252/2220 = 0.5 kg/s

Energy balance around the distillation column

Inputs:

Temperature of the feed stream entering as saturated vapor = 138.63°C

Heat content of feed stream = $m.C_P.\Delta T + m.\lambda$

= 1.3868×3.054×(138.63-0) + 1.3868×723.7

= 1591 kW

Heat input through reboiler (Reboiler load) = 1450 kW

Total heat input = 3041 kW

Ouputs:

Temperature of distillate leaving as saturated liquid = 136.02°C

Temperature of residue leaving as saturated liquid = 163.64°C

Sensible heat of distillate = $m.C_P.\Delta T = 1.1574 \times 3.1989 \times (136.02-0) = 504$ kW

Sensible heat of residue = $m.C_P.\Delta T = 0.2294 \times 2.3276 \times (163.64-0) = 89$ kW

Condenser heat load = 2444 kW

Total heat output = 3037 kW

Heat losses ~ 4kW

Energy balance around Heat Exchanger (HE-3)

Inputs:

Temperature of the condensate water stream = 110°C

Temperature of the steam recycle = 80°C

Sensible heat of condensate = $m.C_P.\Delta T = 6.5314 \times 4.18 \times (110-0) = 3003$ kW

Heat content of steam = $m.C_P.\Delta T + m.\lambda$

$= 1.372 \times 4.18 \times (80-0) + 1.372 \times 2300$

$= 3614$ kW

(Assuming 0.028 kg/s of steam is lost during evaporator operation)

Total heat input = 6617 kW

Outputs:

Temperature of the leaving water stream = 30°C

Sensible heat content = $m.C_P.\Delta T = 7.9034 \times 4.18 \times (30-0) = 991$ kW

Cooling load q_C = 6617-991 = 5626 kW

(This heat content can be used for producing LP steam)