ENERGY BALANCE

BASIS: 1 HOUR OPERATION

ENERGY BALANCE FOR THE REACTOR:

Products from the reactor.

E.O = 4250 kg = 96.59 kg moles

E = 5409.06 Kg = 193.18 kg moles

O_2 = 92330.29 kg = 2885.32 kg moles

CO_2 = 8500 Kg = 193.18 Kg moles

N_2 = 5032.63 Kg = 179.71 Kg moles

H_2O = 3477.24 Kg = 193.18 Kg moles.

The two reactions taking place in this process are given below.

Main reaction

$$C_2H_4 + \frac{1}{2} O_2 \longrightarrow C_2H_4O$$

Side reaction

$$C_2H_4 + 3O_2 \longrightarrow 2CO_2 + 2H_2O$$

Energy Balance Equation For The Reactor:

$$(m*cp*\Delta T)_{\text{Reactants}} + \Delta H_R + Q \text{ (heat removed by exothermic reaction)}$$

$$= (m*cp*\Delta T)_{\text{Products}}$$

Consider feed to entering at 25°C: T_{ref} = 25°C

$(m*p*\Delta T)_{Reactants} = 0$;

T = 25 – 25 = 0

Q = heat released by exothermic reaction.

T_R is the reaction temperature = **280 °C**

ΔH_R = heat of reaction (E⟶ E.O) + heat reaction of the side reaction

$(m*cp*\Delta T)_{products} = [(m_1*Cp_1)E + (m_2*Cp_2)O_2 + (m_3*Cp_3)EO + (m_4*Cp_4)CO_2$

$+ (m_5*Cp_5)N_2 + (m_6*Cp_6)H_2O]\ [T_{products} - T_{ref}]$

ΔT = [280 – 25] = **255 °C**

Table: 4.1 Heat capacity data for products & unreacted reactants at 280°C.

Component	**Cp, J/Kg-K**
Ethylene oxide (EO)	1714.54
Ethylene (E)	2409.25
Oxygen (O_2)	988.3
Nitrogen (N_2)	1065.6
Carbon dioxide (CO_2)	1046.884
Water (H_2O)	1858

$\sum(m*Cp*\Delta T)_{products}$ = [4250*1714.54 + 5409*2409.25 + 1065.6*5032 +

8500*1046.88 + 92330.2*988.3 + 1858*3477][255]

= **$3.37 *10^{10}$ Joules.**

From the literature the heat of reaction for both the main and side reactions is $=\Delta H_R$ $= 1.1058*10^{10}$ (for EO) + $1.37*10^{11}$

= **$1.478 * 10^{11}$ Joules.**

Heat to be removed = $\Delta H_R - \sum m*Cp*\Delta T$

$= 1.478*10^{11} - 3.37*10^{10}$

= **$1.41*10^{11}$ Joules.**

Water (boiling is used for the removal of the heat)

$(m*Cp*\Delta T)$ water = $1.141*10^{11}$

Cp of $_{water}$ = 4180 Joules/Kg-K

ΔT= 90 – 25 = 65°C.

$(m)_{water}$ = **420000 Kgs.**

ENERGY BALANCE FOR THE COOLER 1:

In the cooler the products vapours are cooled from 280°C -35°C. The removed energy is supplied to the recycle stream. The Cp values are calculated at the temperature of 35°C.

Table: 4.2 Heat capacity data for products & unreacted reactants.

Component	**Cp, J/Kg-K**
Ethylene oxide (EO)	1102.95
Ethylene (E)	1769.14
Oxygen (O_2)	918.52
Nitrogen (N_2)	1040
Carbon dioxide (CO_2)	858.23
Water (H_2O), liquid	4180

$\sum(m*Cp*\Delta T)_{products}$ leaving the cooler = [4250*1102.95 + 5409*1769.14 + 92330.20*918.52 + 8500*858.23 + 5032.6*1040 + 3477.24*4180][35-25]

= **$1.27*10^9$ Joules.**

$\sum(m*Cp*\Delta T)_{products}$ entering the cooler = **$3.37*10^{10}$ Joules.**

Therefore heat removed in the cooler = $3.37*10^{10} - 1.27*10^9$

= **$3.243*10^{10}$ Joules**

ENERGY BALANCE TO THE COMPRESSOR 1

Table: 4.3Heat capacity data for products & unreacted reactants.

Component	**Density, Kg/m^3**	**Mole fraction**
EO	851.61	0.026
E	212.21	0.052
O_2	435.36	0.77
CO_2	464.64	0.052
N_2	314.076	0.048
H_2O	993.719	0.052

Average density = 0.026*851.61 + 0.052*212.21+ 0.77*435.36 + 0.052 * 464.64 + 0.048*314.076 + 0.052* 993.719 = 157.61 Kg/m^3

Work required in the compressor to increase the pressure from 5-10 atms = $W_1 = V*(P_1 - P_2)$ = **3.82 * 10^8 Joules.**

This work will be added to the enthalpy. So the increase in enthalpy

= $1.270*10^9 – 3.82*10^8$

Therefore, the energy leaving the compressor1 = **1.625*10^9 Joules.**

ENERGY BALANCE TO THE ABSORBER:

In the absorber the ethylene oxide is completely absorbed in the water at 25°C. Only the energy is lost from the gases, which are not absorbed in the absorbing liquid. Energy entering the absorber = **$1.625*10^9$ Joules.**

Energy loss from the absorber = 5340*1769.14 + 92330.156*918.52 + 21.2*1102.95 + 8493.6*858.23 + 5032.56*1040 = **$1.06*10^8$ Joules.**

Therefore, energy leaving the absorber with the products = $1.546*10^9$ Joules

The energy leaving the cooler1 with the recycle stream = **$3.13 * 10^{10}$ Joules**

ENERGY BALANCE FOR THE DESORBER:

In the desorber the water used for the absorption is desorbed the energy loss is the work done by the compressor 1. Because the desorber is working at pressure of 5 atm.

The energy leaving the desorber = **$1.164*10^9$ Joules**

The energy lost in the desorber = **$3.82*10^8$ Joules.**

ENERGY BALANCE FOR THE COOLER2 & COMPRESSOR2;

The cooler is used to maintain the temperature of the absorbing water at 25°C. In the compressor the fed stream is compressed to 5 atms.

Energy leaving the compressor = **$1.167*10^9$ Joules.**

ENERGY BALANCE TO THE STRIPPER:

Stripper is vaccum stripper the gases will be vapourised from water. This is done at constant temperature. So there is no energy balance for the stripper.

The energy leaving the stripper = $\mathbf{1.167*10^{9}\ J}$

ENERGY BALANCE FOR THE DISTILLATION COLUMN:

Enthalpy of the feed to the distillation column = H_F = $\mathbf{1.167*10^{9}\ J}$

Temperature of the feed = 35°C

From the T-x-y diagram for the system Ethylene oxide (EO)- water system

The bubble point = **55°C**

Dew point = **93°C**

Enthalpy of the gas = $\mathbf{H_G = y_{EO}*(Cp_{EO}*M_{EO}*(T_G-T_F) + \lambda_{EO}) +}$

$$\mathbf{y_{H2O}*(Cp_{H2O}*M_{H2O}*(T_G-T_F) + \lambda_{H2O})}$$

M is the molecular weight of the species, y is the mole fraction, λ is the latent heat of vaporization of the components.

H_G = 0.33*[2.17*44*(93-25) + 44*461.45] + 0.67*[18*4.18*(93-25) + 2154.79] = 37942.4 KJ/ K moles

$\mathbf{H_G = 1.427*10^{6}\ J}$

Cooling water required in the condenser

$M*Cp*\Delta T = 1.427*10^{6}$ J

Water is getting cooled form 25°C to 50°C

M = $1.427*10^6$ J/(4180*25)

= **13.65 Kg/hr**

$H_D = y_{EO}*[Cp_{EO}*M_{EO}*(35-25)] + y_{H2O}*[Cp_{H2O}*M_{H2O}*(35-25)]$

Cp is liquid enthalpy.

H_D = 39030.64 J

H_{L0} = 39030.64 J

Condenser duty = $Q_C = H_G – H_{L0} - H_D$

= **$1.35*10^6$ J**

Enthalpy of the residue, H_w = 3600.33*4.18*(55-35)

= **301*103 J**

Reboiler duty = $Q_B = D*H_D + W*H_w - F*H_F + Q_C$

= **$1.17 *10^5$ J**