

ENERGY BALANCE

BASIS: 1 HOUR OPERATION

ENERGY BALANCE FOR THE REACTOR:

Products from the reactor.

$$\text{E.O} = 4250 \text{ kg} = 96.59 \text{ kg moles}$$

$$\text{E} = 5409.06 \text{ Kg} = 193.18 \text{ kg moles}$$

$$\text{O}_2 = 92330.29 \text{ kg} = 2885.32 \text{ kg moles}$$

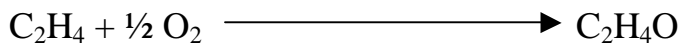
$$\text{CO}_2 = 8500 \text{ Kg} = 193.18 \text{ Kg moles}$$

$$\text{N}_2 = 5032.63 \text{ Kg} = 179.71 \text{ Kg moles}$$

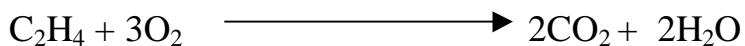
$$\text{H}_2\text{O} = 3477.24 \text{ Kg} = 193.18 \text{ Kg moles.}$$

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

Main reaction



Side reaction



Energy Balance Equation For The Reactor:

$$\begin{aligned} (m \cdot c_p \cdot \Delta T)_{\text{Reactants}} + \Delta H_R + Q \text{ (heat removed by exothermic reaction)} \\ = (m \cdot c_p \cdot \Delta T)_{\text{Products}} \end{aligned}$$

Consider feed to entering at 25°C: $T_{\text{ref}} = 25^\circ\text{C}$

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

$$T = 25 - 25 = 0$$

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

$$(m \cdot c_p \cdot \Delta T)_{\text{products}} = [(m_1 \cdot C_{p1})E + (m_2 \cdot C_{p2})O_2 + (m_3 \cdot C_{p3})EO + (m_4 \cdot C_{p4})CO_2 \\ + (m_5 \cdot C_{p5})N_2 + (m_6 \cdot C_{p6})H_2O] [T_{\text{products}} - T_{\text{ref}}]$$

$$\Delta T = [280 - 25] = \mathbf{255^\circ\text{C}}$$

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 ₂ O)	1858

$$\begin{aligned}\Sigma(m \cdot C_p \cdot \Delta T)_{\text{products}} &= [4250 \cdot 1714.54 + 5409 \cdot 2409.25 + 1065.6 \cdot 5032 + \\ &8500 \cdot 1046.88 + 92330.2 \cdot 988.3 + 1858 \cdot 3477][255] \\ &= \mathbf{3.37 \cdot 10^{10} \text{ Joules.}}\end{aligned}$$

From the literature the heat of reaction for both the main and side reactions

$$\begin{aligned}\text{is } = \Delta H_R &= 1.1058 \cdot 10^{10} \text{ (for EO)} + 1.37 \cdot 10^{11} \\ &= \mathbf{1.478 \cdot 10^{11} \text{ Joules.}}\end{aligned}$$

$$\begin{aligned}\text{Heat to be removed} &= \Delta H_R - \Sigma m \cdot C_p \cdot \Delta T \\ &= 1.478 \cdot 10^{11} - 3.37 \cdot 10^{10} \\ &= \mathbf{1.41 \cdot 10^{11} \text{ Joules.}}\end{aligned}$$

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

$$(m \cdot C_p \cdot \Delta T)_{\text{water}} = 1.141 \cdot 10^{11}$$

$$C_p \text{ of water} = 4180 \text{ Joules/Kg-K}$$

$$\Delta T = 90 - 25 = 65^\circ\text{C.}$$

$$(m)_{\text{water}} = \mathbf{420000 \text{ Kgs.}}$$

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 ₂ O), liquid	4180

$$\begin{aligned} \Sigma(m \cdot C_p \cdot \Delta T)_{\text{products}} \text{ leaving the cooler} &= [4250 \cdot 1102.95 + 5409 \cdot 1769.14 + \\ &92330.20 \cdot 918.52 + 8500 \cdot 858.23 + 5032.6 \cdot 1040 + 3477.24 \cdot 4180][35-25] \\ &= \mathbf{1.27 \cdot 10^9 \text{ Joules.}} \end{aligned}$$

$$\Sigma(m \cdot C_p \cdot \Delta T)_{\text{products}} \text{ entering the cooler} = \mathbf{3.37 \cdot 10^{10} \text{ Joules.}}$$

$$\begin{aligned} \text{Therefore heat removed in the cooler} &= 3.37 \cdot 10^{10} - 1.27 \cdot 10^9 \\ &= \mathbf{3.243 \cdot 10^{10} \text{ Joules}} \end{aligned}$$

ENERGY BALANCE TO THE COMPRESSOR 1

Table: 4.3 Heat 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 ₂ O	993.719	0.052

$$\begin{aligned} \text{Average density} &= 0.026 \cdot 851.61 + 0.052 \cdot 212.21 + 0.77 \cdot 435.36 + 0.052 \cdot \\ &464.64 + 0.048 \cdot 314.076 + 0.052 \cdot 993.719 = 157.61 \text{ Kg/m}^3 \end{aligned}$$

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

This work will be added to the enthalpy. So the increase in enthalpy
 $= 1.270 \cdot 10^9 - 3.82 \cdot 10^8$

Therefore, the energy leaving the compressor1 = $1.625 \cdot 10^9 \text{ Joules.}$

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*10⁹ 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 * 10¹⁰ 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*10⁹ Joules**

The energy lost in the desorber = **3.82*10⁸ 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*10⁹ Joules.**

ENERGY BALANCE TO THE STRIPPER:

Stripper is vacuum 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 = $1.167 \times 10^9 \text{ J}$

ENERGY BALANCE FOR THE DISTILLATION COLUMN:

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

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 = $H_G = y_{EO} \cdot (C_{pEO} \cdot M_{EO} \cdot (T_G - T_F) + \lambda_{EO}) +$
 $y_{H_2O} \cdot (C_{pH_2O} \cdot M_{H_2O} \cdot (T_G - T_F) + \lambda_{H_2O})$

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

$H_G = 0.33 \cdot [2.17 \cdot 44 \cdot (93 - 25) + 44 \cdot 461.45] + 0.67 \cdot [18 \cdot 4.18 \cdot (93 - 25) + 2154.79] = 37942.4 \text{ KJ/ K moles}$

$H_G = 1.427 \times 10^6 \text{ J}$

Cooling water required in the condenser

$M \cdot C_p \cdot \Delta T = 1.427 \times 10^6 \text{ J}$

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

$$M = 1.427 \times 10^6 \text{ J} / (4180 \times 25)$$

$$= \mathbf{13.65 \text{ Kg/hr}}$$

$$H_D = y_{EO} * [C_{pEO} * M_{EO} * (35-25)] + y_{H_2O} * [C_{pH_2O} * M_{H_2O} * (35-25)]$$

Cp is liquid enthalpy.

$$\mathbf{H_D = 39030.64 \text{ J}}$$

$$\mathbf{H_{L0} = 39030.64 \text{ J}}$$

$$\begin{aligned} \mathbf{\text{Condenser duty} = Q_C} &= \mathbf{H_G - H_{L0} - H_D} \\ &= \mathbf{1.35 \times 10^6 \text{ J}} \end{aligned}$$

$$\text{Enthalpy of the residue, } H_w = 3600.33 \times 4.18 \times (55-35)$$

$$= \mathbf{301 \times 10^3 \text{ J}}$$

$$\begin{aligned} \mathbf{\text{Reboiler duty} = Q_B} &= \mathbf{D * H_D + W * H_w - F * H_F + Q_C} \\ &= \mathbf{1.17 \times 10^5 \text{ J}} \end{aligned}$$

