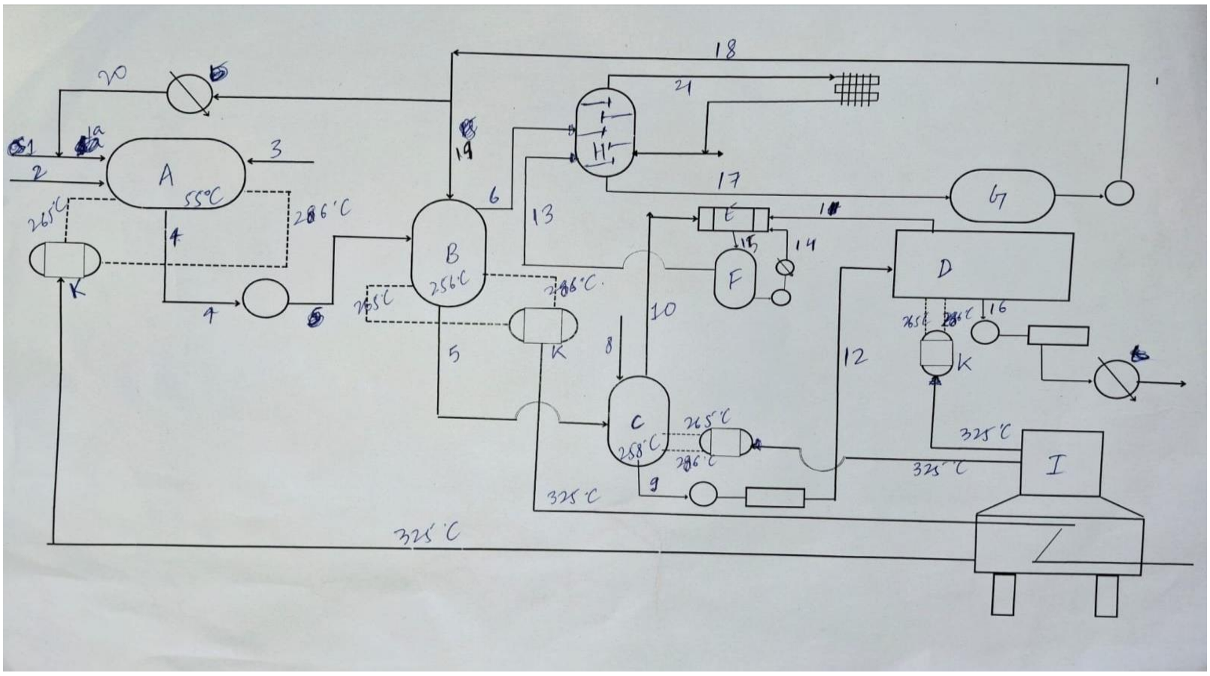
**Applicant:** SynergyX
**Inventors:** Diya Saraf, Sakshi Dargu, Aditya Gupta, Sanskaar Srivastava, Priyanshu Kamde
**Chemical Formula:** $(C_{10}H_8O_4)_n$
**Chemical Name:** Polyethylene terephthalate(PET)
**Process Title:** Production of PET from Pure Terephthalic Acid and Ethylene Glycol
**Catalysts:** Antimony TriAcetate
**Process Description:**

a. Process Flow Diagram:


A
55°C
B
256°C
C
258°C
D
E
F
G
H
I
K
K
K
286°C
265°C
325°C
18
20
21
17
13
10
12
9
16
14
1a
2
3
4
5
6
8
19

A - MIXING VESSEL

B - ESTERIFIER

C - PRE-POLY CONDENSATION TANK

D - DISC RING REACTOR

E - SCRAPPER CONDENSER

F - CONDENSATE COLLECTOR

G - MOTHER VESSEL OF EG

H - DISTILLATION COLUMN

I - FURNACE

K - HEAT EXCHANGERS

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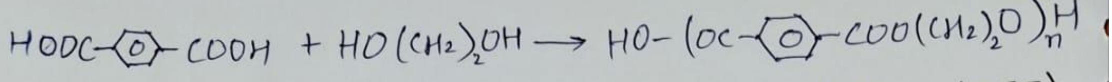
1. Fresh EG
2. Catalyst
3. PTA
4. Paste
5. BHET
6. Waste + Unreacted EG vapors
7. Catalyst
8. Catalyst
9. Small chain PET
10. EG vapors
11. EG vapors
12. small chain PET
13. liquid EG
14. Cold EG
15. Condensed EG
16. Long Chain PET
17. Spent EG
18. Recovered EG
19. Recovered EG
20. Recycled EG
21. Water Vapors.

b. Material Balance:

Main Reaction:-



(TPA) (EG) $+ 2nH_2O$ (PET)

(MM=166.14) (MM= 62.07) ($H_2O$) (MM=192.2)

(MM=18)

- Basis = 100 tonnes PET/day = 4166.6 kg PET/hr
  $= 100 \times 10^3 \times \frac{1}{24}$ kg PET/hr = 4166.6 kg PET/hr
  $= 100 \times 10^3 \times \frac{1}{24} \times \frac{1}{192.2}$ kmol PET/hr = 21.68 kmol/hr

For 90 % overall conversion,

- EG required = $\frac{21.68}{0.9}$ = 24.08 kmol/hr
- TPA required = EG required = 24.08 kmol/hr

Balance across Mixer

- Flowrate of Catalyst (Antimony TriAcetate) is taken to be 18ppm
- Also for the ratio, E/T = 1.12
- Thus flowrate of MEG = (1.12)(24.08 kmol/hr)
  = 26.97 kmol/hr
- Fresh MEG = 24.08 kmol/hr
- MEG recycled = (26.97 − 24.08) kmol/hr
  = 2.89 kmol/hr
  = 2.89 × 62.07 kg/hr = 179.38 kg/hr
- Flowrate of TPA = 24.08 kmol/hr

| | Input | Output |
|---|---|---|
| TPA | 24.08 | |
| MEG | 26.97 | |
| Paste | | |
| Total | 51.05 | 51.05 |

## Balance Across Esterifier :-

$$HOOC-C_6H_4-COOH + 2\,HO(CH_2)_2OH \longrightarrow HO(CH_2)_2COO-C_6H_4-COO-(CH_2)_2OH + 2H_2O$$

(TPA) (MM = 166.14)    (MM = 62.07)    (BHET) (MM = 254.24)    $H_2O$ (MM = 18)

- TPA req for the above reaction is 24.08 kmol/hr
- Thus MEG req = 2(TPA req) = 2(24.08) = 48.16 kmol/h
- MEG from paste of mixer = 26.97 kmol/hr
- Thus MEG obtained from recycle = (48.16 − 26.97)
  = 21.19 kmol/hr

Due to 90 % conversion,

We have unreacted MEG as = (0.1)(48.16)
= 4.816 kmol/hr
= 298.93 kg/hr

∴ Reacted MEG = (0.9)(48.16)
= 43.34 kmol/hr

We have unreacted TPA as = (0.1)(24.08)
= 2.408 kmol/hr

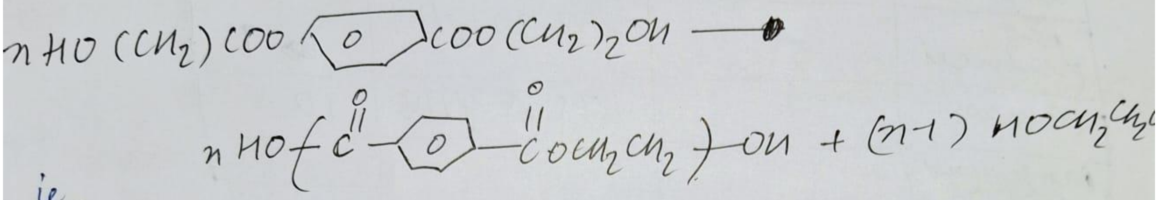
∴ Reacted TPA = (0.9)(24.08)
= 21.672 kmol/hr

Also, BHET [bis(2-hydroxyethyl) terephthalate) produced in above reaction = no. of reacted moles of TPA
= 21.672 kmol/hr

And Water produced = no. of reacted moles of MEG
= 43.34 kmol/hr
= 780.12 kg/hr

| | Input | Output | Stream |
|---|---|---|---|
| recycled MEG | 21.19 | | |
| MEG in | 26.97 | | |
| TPA | 24.08 | | |
| BHET | | 21.67 | |
| EG (un-reacted) | | 4.816 | |
| TPA (un-reacted) | | 2.408 | |
| Water | | 43.34 | |
| Total | 72.24 | 72.234 | |

Balance Across ~~[illegible]~~ Pre-Polycondensation Tank [Unit C]



ie

$n\,BHET \longrightarrow n\,PET + (n-1)\,EG$.

MM: 254.24 192.2 62.07

Moles of BHET available = stream 5

= 21.679 kmol/hr

= 5511.62 kg/hr

$\boxed{\text{conversion} = 92\%}$ [From RnD report]

so, reacted BHET = 92% × [21.678]

= 19.944 kmol/hr

= 5070.56 kg/hr.

⇒ unreacted BHET = (available − reacted BHET)

= (21.678 − 19.944) kmol/hr

= 1.734 kmol/hr

= 440.85 kg/hr

moles of PET produced = moles of BHET reacted

∴ PET produced = 19.944 kmol/hr.

= 3833.24 kg/hr.

moles of MEG vapors = (moles of BHET reacted − 1)

= 18.944 kmol/hr

= 1175.85 kg/hr ;

| | input | output | stream |
|---|---|---|---|
| BHET in | 5517.62 kg/hr | | 5 |
| un-reacted PTA | 400.19 kg/hr | 400.19 kg/hr | 5 |
| BHET unreacted | — | 440.85 kg/hr | 9 |
| PET produced | — | 3833.24 kg/hr | 9 |
| EG vapors | — | 1175.85 kg/hr | 10. |
| ~~By products~~ | | | |

Balance across mother vessel of SEG [unit G].

EGR in stream 17 = EGR in stream 18 = EGR in stream 19 + EGR in stream 20.

= Total EGR in mother vessel.

∵ MEG recycled = 179.38 kg/hr = EGR in stream 20
[From ~~overall~~ balance across mixer]

MEG recycled in stream 19 = 21.19 kmol/hr
= 1315.26 kg/hr
[From balance across esterifier]

∴ Total MEG in stream 17 = 1315.26 + 179.38

= 1494.64 kg/hr.

| | input (kg/hr) | output (kg/hr) | stream |
|---|---|---|---|
| EG | 1494.64 | – | 17 |
| MEG | – | 1315.26 | 19 |
| MEG | – | 179.38 | 20 |

Balance Across Distillation column [unit H]

mass input = mass output

⇒ stream 6 + stream 13 = stream 21 + stream 17

water ~~vapors~~ in = water vapors out

⇒ $H_2O$ vapours in stream 21 = $H_2O$ in input stream 6

∴ stream 21 = 780.12 kg/hr [From balance across esterifier]

Also, ~~EG unreacted in~~

unreacted EG in stream 6 + EG recovered in stream 13 = spent EG in stream 17.

EG recovered = (1494.64 − 298.93) kg/hr
= 1195.71 kg/hr.

| | input | Output | stream |
|---|---|---|---|
| EG (un-reacted) | 298.93 kg/hr | – | 6 |
| water | 780.12 kg/hr | – | 6 |
| EG recovered | 1195.71 kg/hr | – | 13 |
| spent EG | – | 1494.64 kg/hr | 17 |
| water vapors. | – | 780.12 kg/hr | 21 |

Balance Across Disc Ring Reactor (Unit D)

~~unreacted~~ Reaction Yield = 96%.
[From RnD Report] -

~~stream~~

unreacted BHET in stream 9 = unreacted BHET in stream 12

⇒ BHET in stream 12 = 440.85 kg/hr.

BHET that will react = 0.96 X 440.85
= 423.216 kg/hr = 1.6646 kmol/hr

BHET unreacted = 440.85 − 423.21
= 17.64 kg/hr.
= 0.069 kmol/hr

PET formed = ~~320 kg/hr~~ moles of BHET reacted
= 1.6646 kmol/hr
= ~~1.6~~ 319.94 kg/hr

→ small chain PET input = 3833.24 kg/hr
[Stream 9]
= stream 12
= 19.944 kmol/hr

EG vapors = 41.27 kg/hr
= 0.665 kmol/hr
[= (moles of BHET − 1)]

Long chain PET = PET formed + small chain PET input
= 4153.18 kg/hr
= 21.608 kmol/hr.

input = output

PET in + BHET in ~~unreacted~~ = solids + EG vapors + long chain PET

440.85 + 3833.24 = solids + 41.27 + ~~31.608~~ 4153.18

solids = 79.64 kg/hr

| | input (kg/hr) | output (kg/hr) | streams |
|---|---|---|---|
| PET input | 3833.24 | | 12 |
| BHET unreacted | 440.85 | ~~17.64~~ 17.64 | 12 & 16 |
| solids | – | 79.64 | 11 |
| EG vapors | – | 41.27 | 11 |
| Long chain PET | – | 4153.18 | 16 |

Balance across scrapper condenser [Unit E] & distillate collector

Total input of EG = stream 10 + stream 11
= 1217.12 kg/hr.

Let showering cold EG = X kg/hr.
Condensed EG = Y kg/hr
uncondensed vapors out = Z kg/hr

By mass balance, input = output

$1083.028 + X = Y + Z$ —— ①

$Y = X + 1076.48$ —— ②

$\Rightarrow Z = 21.065$ kg/hr

since 40% of the tank is used in showering, rest is sent to distillation column

so,

EG showered = X = 797.394 kg/hr

condensed EG = Y = 1993.48 kg/hr

Scrapper Condenser

| | Input (kg/hr) | Output (kg/hr) | Streams |
|---|---|---|---|
| EG vapors | 41.27 | – | 10 |
| EG vapors | 1175.88 | – | 10 |
| EG showered | 797.394 | – | 14 |
| condensate | – | 1993.48 | 15 |
| Non-condensed | – | 21.065 | |

Condensate collector

| | Input | Output | Streams |
|---|---|---|---|
| Condensate EG | 1993.48 | – | 15 |
| Cold EG | – | 797.394 | 14 |
| Liquid EG | – | ~~1196~~ 1195.71 | 13 |

c. Energy Balance:

## Balance Across Mixer

$T = 328\ K$

$P = 1\ atm$

$(C_p)_{TPA} = 2.82 \times 10^2 \ \frac{kJ}{kmol.K}$

$(C_p)_{MEG} = 1.49 \times 10^2 \ \frac{kJ}{kmol.K}$

$\boxed{\text{Input}} \Rightarrow \quad \Delta T = 25 K$

For TPA, $\dot{Q} = \dot{m} C_p \Delta T = \left(24.08 \frac{kmol}{hr}\right)\left(2.82 \times 10^2 \frac{kJ}{kmol.K}\right) \times (25) K$

$\dot{Q} = 1.69 \times 10^5 \ \frac{kJ}{hr}$

For MEG, $\dot{Q} = \dot{m} C_p \Delta T = \left(26.97 \frac{kmol}{hr}\right)\left(1.49 \times 10^2 \frac{kJ}{kmol.K}\right) \times (25 K)$

$\dot{Q} = 1.00 \times 10^5 \ \frac{kJ}{hr}$

Total $\dot{Q}_{in} = (1.00 \times 10^5 + 1.69 \times 10^5) \frac{kJ}{hr} = \underline{2.69 \times 10^5} \ \frac{kJ}{hr}$

$\boxed{\text{Output}} \Rightarrow \quad \Delta T = 55 K$

For TPA, $\dot{Q} = \left(24.08 \frac{kmol}{hr}\right)\left(2.82 \times 10^2 \frac{kJ}{kmol.K}\right)(55 K)$

$\dot{Q} = 3.74 \times 10^5 \ \frac{kJ}{hr}$

For MEG, $\dot{Q} = \left(26.97 \frac{kmol}{hr}\right)\left(1.59 \times 10^2 \frac{kJ}{kmol.K}\right)(55 K)$

$\dot{Q} = \cancel{2.21}\ \cancel{2.26}\ 2.36 \times 10^5 \ \frac{kJ}{hr} = 2.36 \times 10^5 \ kJ/hr$

Total $\dot{Q}_{out} = \underline{6.10 \times 10^5} \ \frac{kJ}{hr} = (3.74 + 2.36) \times 10^5 \ \frac{kJ}{hr}$

- Net Heat, $\dot{Q}_{net} = \dot{Q}_{in} - \dot{Q}_{out} = (2.69 - 6.10) \times 10^5 \ \frac{kJ}{hr}$

$$\boxed{\dot{Q}_{net} = -3.41 \times 10^5 \ kJ/hr}$$

- Flowrate of Dow Therm required

$T = 286°C = 559\,K \qquad \Delta T = 20\,K$

$C_p = 842.61 \frac{kJ}{kmol.K}$

$$(\dot{m})_{dowtherm} = \frac{Q}{(C_p)_{dowtherm}\,\Delta T} = \frac{3.4 \times 10^5\ kJ/hr}{\left(842.61 \frac{kJ}{kmol\,K}\right)(20\,K)}$$

$$(\dot{m})_{dowtherm} = 20.2\ kmol/hr$$

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Balances Across Esterifier :-

$T = 256°C = 529\,K \qquad \Delta T = 55\,K$ (for MEG & TPA)

$P = 0.14$ bar $\qquad \Delta T = 100\,K$ (for recycled MEG)

$\boxed{\text{Input}} \Longrightarrow \dot{Q} = \dot{m} C_p \Delta T \quad @\ T = 328\,K$

For TPA, $\dot{Q} = \left(24.08 \frac{kmol}{hr}\right)\left(2.82 \times 10^2 \frac{kJ}{kmol.K}\right)(55\,K)$

$\dot{Q} = 3.74 \times 10^5 \frac{kJ}{hr}$

For MEG, $\dot{Q} = \left(26.97 \frac{kmol}{hr}\right)\left(1.59 \times 10^2 \frac{kJ}{kmol.K}\right)(55\,K)$

$\dot{Q} = 2.36 \times 10^5\ kJ/hr$

For Recycled MEG, $\dot{Q} = \left(21.19 \frac{kmol}{hr}\right)\left(1.59 \times 10^2 \frac{kJ}{kmol.K}\right)(100\,K)$

$\dot{Q} = 3.37 \times 10^5\ kJ/hr$

Total $\dot{Q}_{in} = (3.74 + 2.36 + 3.37) \times 10^5\ kJ/hr$

$= 9.47 \times 10^5\ kJ/hr$

$\boxed{\text{Output}} \Longrightarrow \dot{Q} = \dot{m} C_p \Delta T + \dot{m}\lambda \quad @\ T = 529\,K$

$\Delta T = 256\,K$

$(\lambda)$ for EG vap (unreacted) $= 6.56 \times 10^4\ kJ/kmol$

$(\lambda)$ for water vapor $= 4.07 \times 10^4\ kJ/kmol$

For BHET, $\dot{Q} = m C_p \Delta T$

$C_p = 404 \frac{kJ}{kmol\,K}$

$\dot{Q} = \left(21.67 \frac{kmol}{hr}\right)\left(404 \frac{kJ}{kmol\,K}\right)(256\,K)$

$\dot{Q} = 2.24 \times 10^6\ kJ/hr$

For EG vapor (unreacted),

$$\dot{Q} = \left(4.816\ \frac{kmol}{hr}\right)\left(130\ \frac{\cancel{kmol}J}{kmol\,K}\right)(256)K$$

$$+ \left(4.816\ \frac{kmol}{hr}\right)\left(6.56\times10^{4}\ \frac{kJ}{kmol}\right)$$

$$\dot{Q} = (1.6 + 3.16)\times10^{5}\ kJ/hr = 4.76\times10^{5}\ kJ/hr$$

For TPA (unreacted)

$$\dot{Q} = \left(2.408\ \frac{kmol}{hr}\right)\left(350\ \frac{kJ}{kmol\,K}\right)(256K)$$

$$\dot{Q} = 2.16\times10^{5}\ kJ/hr$$

For Water vapor,

$$\dot{Q} = \dot{m}C_p\Delta T + \dot{m}\lambda$$

$$\dot{Q} = \left(43.34\ \cancel{\times10}\ \frac{kmol}{hr}\right)\left(35.7\ \frac{kJ}{kmol\,K}\right)(256\,K)$$

$$+ \left(43.34\ \frac{kmol}{hr}\right)\left(4.07\times10^{4}\ \frac{kJ}{kmol}\right)$$

$$\dot{Q} = (3.96\times10^{5} + 17.6\times10^{5})\ kJ/hr$$

$$\dot{Q} = 2.16\times10^{6}\ kJ/hr$$

Total $Q_{out} = 5.09\times10^{6}$ kJ/hr

Also,

Heat of reaction:-

| | | | |
|---|---|---|---|
| TPA | $-8.16\times10^{5}$ kJ/kmol | BHET | $-10.94\times10^{5}$ kJ/kmol |
| MEG | $-3.85\times10^{5}$ kJ/kmol | Water | $-2.42\times10^{5}$ kJ/kmol |

Total $H_r = -4.16\times10^{6}$ kJ / ~~kmol~~ hr

$$\dot{Q}_{in} + H_r - \dot{Q}_{out} = \dot{Q}_{net}$$

$$\dot{Q}_{net} = (0.947 - 4.16 - 5.09)\times10^{6}\ kJ/hr$$

$$\boxed{\dot{Q}_{net} = -8.3\times10^{6}\ kJ/hr}$$

- Flow rate of Dow Therm required for this heat

$T = 284°C = 557\ K$ $\quad \Delta T = 557 - 529 = 28\ K$

$C_p = 842.61\ kJ/kmol.K$

$$(\dot{m}) = \frac{\dot{Q}}{C_p\ \Delta T} = \frac{+8.27 \times 10^6\ kJ/hr}{(842.61\ \frac{kJ}{kmol.K})(28\ K)}$$

$$\boxed{M = 352.07\ kmol/hr}$$

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Balance Across Pre-Polycondensation Tank :-

$T = 272°C = 545\ K$

$P = 19-20\ bar$

$\boxed{Input} \Longrightarrow$ @ $T = 529\ K$ $\quad \Delta T = 256\ K$

For BHET, $\dot{Q} = (21.67\ \cancel{\times 10}\ \frac{kmol}{hr})(404\ \frac{kJ}{kmol\ K})(256\ K)$

$\dot{Q} = 2.24 \times 10^6\ kJ/hr$

For TPA unreacted, $\dot{Q} = (2.408\ \frac{kmol}{hr})(350\ \frac{kJ}{kmol\ K})(256\ K)$

$\dot{Q} = 2.16 \times 10^5\ kJ/hr$

Total $\dot{Q}_{in} = (2.16 + 22.4) \times 10^5\ kJ/hr$

$\dot{Q}_{in} = 2.46 \times 10^6\ kJ/hr$

$\boxed{Output} \Longrightarrow$ @ $T = 545\ K$ $\quad \Delta T = 272\ K$

For TPA unreacted, $\dot{Q} = (2.408\ \cancel{\times 10}\ \frac{kmol}{hr})(359\ \frac{kJ}{kmol\ K})(272\ K)$

$\dot{Q} = 2.35 \times 10^5\ kJ/hr$

For BHET unreacted, $\dot{Q} = (1.734\ \frac{kmol}{hr})(405\ \frac{kJ}{kmol\ K})(272\ K)$

$\dot{Q} = 1.91 \times 10^5\ kJ/hr$

For PET produced, $\dot{Q} = (19.944\ \frac{kmol}{hr})(5190\ \frac{kJ}{kmol\ K})(272\ K)$

$\dot{Q} = 2.82 \times 10^7\ kJ/hr$

For EG vapors,

$\lambda = 6.56 \times 10^4$ kJ/kmol

$\dot{Q} = \dot{m} C_p \Delta T + \dot{m}\lambda$

$\dot{Q} = \left(18.944 \frac{kmol}{hr}\right)\left(131 \frac{kJ}{kmol\,K}\right)(272\,K) + \left(18.944 \frac{kmol}{hr}\right)\left(6.56 \times 10^4 \frac{kJ}{kmol}\right)$

$\dot{Q} = (6.75 + 12.4) \times 10^5$ kJ/hr

$\dot{Q} = 19.2 \times 10^5$ kJ/hr $= 1.92 \times 10^6$ kJ/hr

Total $\dot{Q}_{out}$ = $\underline{3.05 \times 10^7}$ kJ/hr

Also, Heat of Reaction

| | |
|---|---|
| BHET | $-10.94 \times 10^5$ kJ/kmol |
| PET | $-19.74 \times 10^5$ kJ/kmol |
| MEG | $-3.85 \times 10^5$ kJ/kmol |

$H_r = -248.36 \times 10^5$ kJ/~~kmol~~ hr

- Flow Rate of Dow Therm required for this heat

$T = 284°C = 557$ K

$C_p = 842.61$ kJ/kmol.K

$\Delta T = (557 - 545)$ K $= 12$ K

$\dot{Q}_{net} = \dot{Q}_{in} - \dot{Q}_{out} + H_r$

$= (0.246 - 3.05 - 2.48) \times 10^7$ kJ/hr

$\boxed{\dot{Q}_{net} = -5.29 \times 10^7 \text{ kJ/hr}}$

$(\dot{m})_{dowtherm} = \frac{\dot{Q}}{(C_p)(\Delta T)} = \frac{5.29 \times 10^7 \text{ kJ/hr}}{\left(842.61 \frac{kJ}{kmol\,K}\right)(12\,K)}$

$\boxed{(\dot{m})_{dowtherm} = 5229.56 \text{ kmol/hr}}$

## Balance Across DRR

$T = 548\ K$

$P = 1.5 - 1.2\ mbar$

$\boxed{\text{Input}} \Rightarrow$ @ $T = 545\ K$ $\quad \Delta T = 272\ K$

For BHET unreacted, $\dot{Q} = \dot{m} C_p \Delta T$

$$\dot{Q} = \left(1.734\ \frac{kmol}{hr}\right)\left(405\ \frac{kJ}{kmol\ K}\right)(272\ K)$$

$$\dot{Q} = 1.91 \times 10^5\ kJ/hr$$

For PET, $\dot{Q} = \left(19.944\ \frac{kmol}{hr}\right)\left(5190\ \frac{kJ}{kmol}\right)(272\ K)$

$$\dot{Q} = 2.82 \times 10^7\ kJ/hr$$

Total $\dot{Q}_{in} = \underline{2.83 \times 10^7}\ kJ/hr$

$\boxed{\text{Output}} \Rightarrow$ @ $T = 548\ K$ $\quad \Delta T = 275\ K$

For BHET unreacted, $\dot{Q} = \left(0.0643\ \frac{kmol}{hr}\right)\left(405\ \frac{kJ}{kmol\ K}\right)(275\ K)$

$$\dot{Q} = 7.73 \times 10^3\ kJ/hr$$

For Long Chain PET, $\dot{Q} = \left(21.61\ \frac{kmol}{hr}\right)\left(5160\ \frac{kJ}{kmol\ K}\right)(275\ K)$

$$\dot{Q} = 3.07 \times 10^7$$

For EG vapors, $\lambda = 6.56 \times 10^4\ kJ/kmol$

$$\dot{Q} = \dot{m} C_p \Delta T + \dot{m} \lambda$$

$$\dot{Q} = \left(0.665\ \frac{kmol}{hr}\right)\left(132\ \frac{kJ}{kmol.K}\right)(275\ K) + \left(0.665\ \frac{kmol}{hr}\right)\left(6.56 \times 10^4\ \frac{kJ}{kmol}\right)$$

$$\dot{Q} = 6.78 \times 10^4\ kJ/hr$$

Total $\dot{Q}_{out} = \underline{3.07 \times 10^7}\ kJ/hr$

$$\dot{Q}_{net} = \dot{Q}_{in} - \dot{Q}_{out} = (2.83 - 3.07) \times 10^7\ \frac{kJ}{hr}$$

$$\boxed{\dot{Q}_{net} = 2.39 \times 10^6\ kJ/hr}$$

Flow Rate of Dow Therm required for this heat,

$T = 286\,°C = 559\,K$

$C_p = 842.61 \frac{kJ}{kmol.K}$

$\Delta T = (559 - 548)K$

$\Delta T = 11\,K$

$\Delta T = 11\,K$

$$(\dot{m})_{dowtherm} = \frac{\dot{Q}}{C_p\,\Delta T} = \frac{2.39 \times 10^6\ kJ/hr}{\left(842.61 \frac{kJ}{kmol\,K}\right)(11\,K)}$$

$$\boxed{(\dot{m})_{dowtherm} = 258.17 \frac{kmol}{hr}}$$

## Balance Across Distillation Column

$P = 260$ mbar

$\boxed{\text{Input}} \Longrightarrow$

For EG vapor unreacted, $\dot{Q} = \left(4.82 \frac{kmol}{hr}\right)\left(130 \frac{kJ}{kmol\,K}\right)(256\,K)$

$\left(\lambda = 6.56 \times 10^4 \frac{kJ}{kmol}\right)$ $\quad + \left(4.82 \frac{kmol}{hr}\right)\left(6.56 \times 10^4 \frac{kJ}{kmol}\right)$

$\dot{Q} = (1.6 + 3.16) \times 10^5\ kJ/hr$

$\dot{Q} = 4.76 \times 10^5\ kJ/hr$

For Water vapors, $\lambda = 4.07 \times 10^4\ kJ/kmol$

$\dot{Q} = \dot{m} C_p \Delta T + \dot{m}\lambda$

$\dot{Q} = \left(43.34 \frac{kmol}{hr}\right)\left(35.7 \frac{kJ}{kmol\,K}\right)(256\,K)$

$\quad + \left(43.34 \frac{kmol}{hr}\right)\left(4.07 \times 10^4\ kJ/kmol\right)$

$\dot{Q} = (3.96 + 17.6) \times 10^5\ kJ/hr$

$\dot{Q} = 2.16 \times 10^6\ kJ/hr$

For EG liq recovery, $\dot{Q} = \dot{m} C_p \Delta T$ , $\Delta T = 80\,K$

$\dot{Q} = \left(19.27 \frac{kmol}{hr}\right)\left(183 \frac{kJ}{kmol\,K}\right)(80\,K)$

$\dot{Q} = 2.82 \times 10^5\ kJ/hr$

$\dot{Q}_{in}$ (total) $= \underline{2.92 \times 10^6}\ kJ/hr$

$\boxed{\text{Output}} \Longrightarrow$

For EG liq, $\lambda = 6.56 \times 10^4$ kJ/kmol, $\Delta T = 100$ K

$\dot{Q} = \dot{m} C_p \Delta T + \dot{m}\lambda$

$\dot{Q} = \left(24.08 \frac{kmol}{hr}\right)\left(160 \frac{kJ}{kmol\,K}\right)(100\,K)$

$\cancel{+ \left(24.08 \frac{kmol}{hr}\right)\left(6.56 \times 10^4 \frac{kJ}{kmol\,K}\right)}$

$\dot{Q} = 3.85 \times 10^5$ kJ/hr

For Condensed water, $\Delta T = 40$ K

$\dot{Q} = \left(43.34 \frac{kmol}{hr}\right)\left(65 \frac{kJ}{kmol\,K}\right)(40\,K)$

$\dot{Q} = 1.13 \times 10^5$ kJ/hr

total $\dot{Q}_{out} = (1.13 + 3.85) 10^5$ kJ/hr

$\dot{Q}_{out} = \underline{4.98 \times 10^5 \text{ kJ/hr}}$

$\dot{Q}_{net}$ (Net Heat) $= \dot{Q}_{in} - \dot{Q}_{out}$

$\dot{Q}_{net} = (2.92 \times 10^6 - 4.98 \times 10^5)$ kJ/hr

$\boxed{\dot{Q}_{net} = 2.42 \times 10^6 \text{ kJ/hr}}$

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## Balance Across Scrapper Condenser

$\boxed{\text{Input}} \Longrightarrow$

For EG vapors, $\lambda = 6.56 \times 10^4$ kJ/kmol, $\Delta T = 275$ K

$\dot{Q} = \dot{m} C_p \Delta T + \dot{m}\lambda$

$\dot{Q} = \left(0.665 \frac{kmol}{hr}\right)\left(132 \frac{kJ}{kmol\,K}\right)(275\,K)$

$+ \left(0.665 \frac{kmol}{hr}\right)(6.56 \times 10^4 \text{ kJ/kmol})$

$\dot{Q} = (2.42 + 4.36) 10^4$ kJ/hr $= 6.78 \times 10^4$ kJ/hr

Also for EG vapors,

$$\dot{Q} = \left(18.95\ \frac{kmol}{hr}\right)\left(132\ \frac{kJ}{kmol\,K}\right)(275\,K) + \left(18.95\ \frac{kmol}{hr}\right)\left(6.56\times10^{4}\ \frac{kJ}{kmol}\right)$$

$$\dot{Q} = (6.88 + 12.4)\times10^{5}\ kJ/hr$$

$$\dot{Q} = 1.93\times10^{6}\ kJ/hr$$

For EG showered, $\dot{Q} = \dot{m} C_p \Delta T$

$$\dot{Q} = \left(12.85\ \frac{kmol}{hr}\right)\left(154\ \frac{kJ}{kmol\,K}\right)(40\,K)$$

$$\dot{Q} = 7.9\times10^{4}\ kJ/hr$$

Total $\dot{Q}_{in} = (1.93 + 0.079 + 0.068)\times10^{6}\ kJ/hr$

$$\dot{Q}_{in} = 2.07\times10^{6}\ kJ/hr$$

$\boxed{\text{Output}} \Longrightarrow$

For Condensed EG, $\dot{Q} = \dot{m} C_p \Delta T$, $\Delta T = 80\,K$

$$\dot{Q} = \left(32.12\ \frac{kmol}{hr}\right)\left(157\ \frac{kJ}{kmol\,K}\right)(80\,K)$$

$$\dot{Q} = 4.03\times10^{5}\ kJ/hr$$

Total $\dot{Q}_{out} = 4.03\times10^{5}\ kJ/hr$

Net Heat, $\dot{Q}_{net} = \dot{Q}_{in} - \dot{Q}_{out}$

$$\dot{Q}_{net} = (2.07 - 0.403)\times10^{6}\ kJ/hr$$

$$\boxed{\dot{Q}_{net} = 1.67\times10^{6}\ kJ/hr}$$

**Contributions of each Author:**

a. Process Flow Diagram: Diya Saraf, Sanskaar Srivastava
b. Material Balance: Sakshi Dargu ,Aditya Gupta, Priyanshu Kamde
c. Energy Balance: Sakshi Dargu, Diya Saraf

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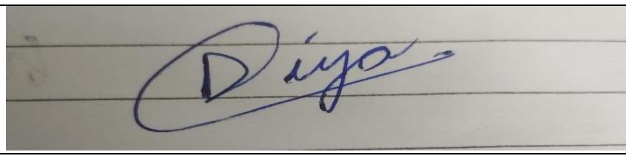
| Diya Saraf | 220383 |  |
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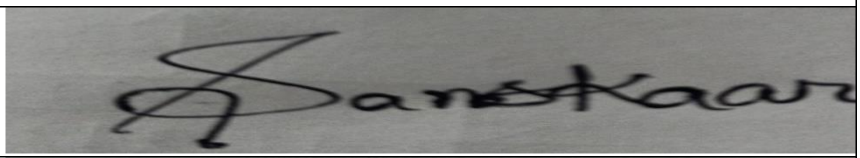
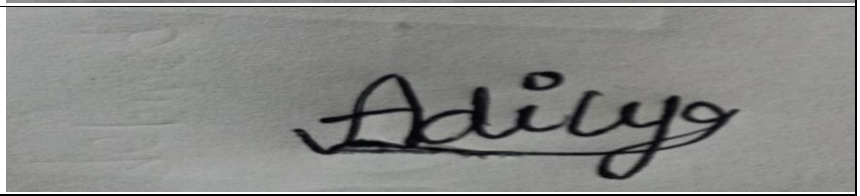
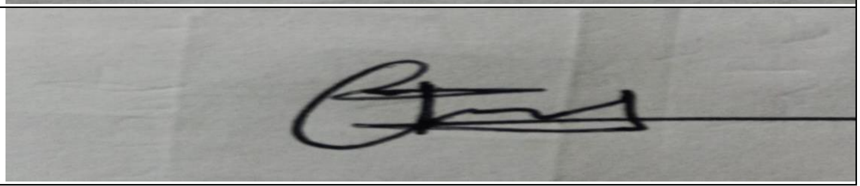
| Sanskaar Srivastava | 220967 |  |
| Aditya Gupta | 220066 |  |
| Priyanshu Kamde | 220494 |  |