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CH18B020

CH4010 ASSIGNMENT-2

(1)

H1 : $180^\circ \xrightarrow{F_{cp} = 2.1} 40^\circ$

H2 : $180^\circ \xrightarrow{F_{cp} = 4} 40^\circ$

C1 : $180^\circ \xleftarrow{F_{cp} = 3} 60^\circ$

C2 : $130^\circ \xleftarrow{F_{cp} = 2.6} 30^\circ$

given Roll

$\Rightarrow (\Delta T)_{min} = 9^\circ C$

In the earlier SAT / assignment, the pinch was found to be at $T_{hot\ pinch} = 150^\circ C$

$T_{cold\ pinch} = 141^\circ C$

Also, $Q_h = 54$ kW, $Q_c = 168$ kW

Spaghetti Design

$F_{cp} = 2.1$: $180^\circ \rightarrow 150^\circ$ [H1]

$F_{cp} = 3$: $180^\circ \leftarrow 141^\circ$ [C1]

From the composite curve plot, the first segment of interest is $T_{h,entry} = 180^\circ$, $T_{h,exit} = 150^\circ$.

$3(T_{exit} - 141) = 2.1(180 - 150)$ [energy balance]

$\Rightarrow T_{c,exit} = 162^\circ$

H1: $180^\circ \xrightarrow{F_{cp} = 2.1} 150^\circ$

C1: $162^\circ \xleftarrow{F_{cp} = 3} 141^\circ$

$$LMTD = \frac{(180-162) - (150-141)}{\ln\left(\frac{180-162}{150-141}\right)}$$

$= 12.98425$

$U = 0.001\ MW/m^2\,°C = 1\ kW/m^2\,°C$

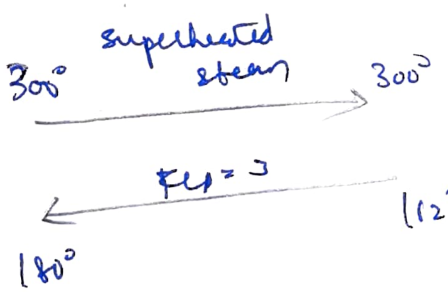
$Q = 2.1 \times 30 = \underline{63\ kW}$

$\therefore\ A_1 = \underline{4.852}\ m^2 \quad \left(\because A = \dfrac{Q}{U \times LMTD}\right)$

Now, just the cold stream remains, for which we can use a heater

$Q = 3(180 - 162) = \underline{54\ kW}$

– matches with Q_{hmin} calculated in PTA

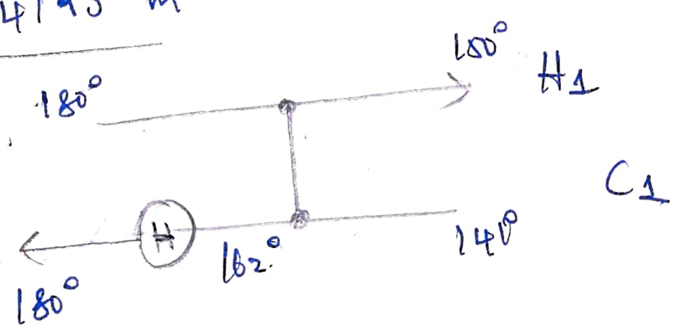


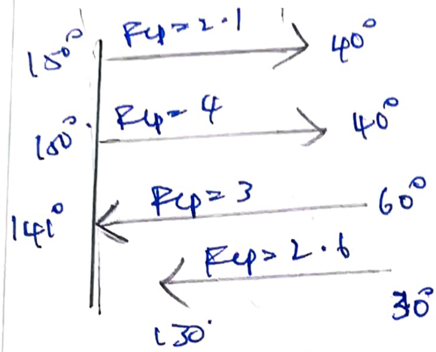
$$LMTD = \frac{(\Delta T)_1 - (\Delta T)_2}{\ln\left(\dfrac{(\Delta T)_1}{(\Delta T)_2}\right)}$$

$= 128.79°$

$$A_2 = \frac{54}{1 \times 128.79} \quad \left(\frac{Q}{U \times LMTD}\right)$$

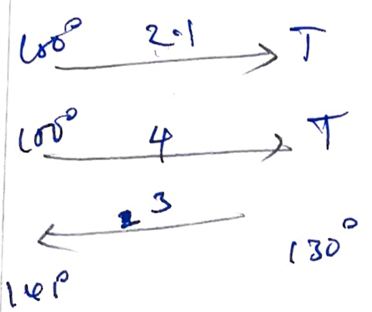
$= \underline{0.4193\ m^2}$





We can use the composite curve to divide the segments

segment ⓐ : Tcold goes from ~~[illegible]~~ 130° to 141°



energy balance :

$6.1(-T_h - 100) = 3(141-130)$

$\Rightarrow T_h = \underline{144.859°C}$

Need to split the cold stream so that both hot streams can be cooled.

$x(141-130) = 2.1(150-T)$

$\Rightarrow x = \underline{1.033}$ (for match with H1)

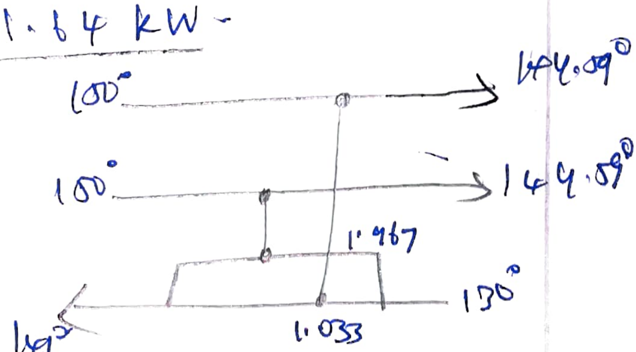
~~[illegible]~~ $\Rightarrow Q_{a1} = 1.033(11) = \underline{11.361 \text{ kW}}$

$3-x = 1.967$ goes with H2 then, (overall ΔH match so no need to check this)

$Q_{a2} = 1.967(141-130) = \underline{21.64 \text{ kW}}$

$$LMTD = \frac{(\Delta T)_1 - (\Delta T)_2}{\ln\left(\frac{(\Delta T)_1}{(\Delta T)_2}\right)}$$

(same for both) $= 11.571°$



A_{a1} (match with H_1) $= 0.9819\ m^2$

A_{a2} (match with H_2) $= 1.8702\ m^2$

Next, segment ①: Till $T_C = 60°$

$144.59° \xrightarrow{2.1} T_h$

$144.59° \xrightarrow{4} T_h$

$130° \xleftarrow{3} 60°$

$130° \xleftarrow{2.6} 60°$

overall balance

$(6.1)(144.59 - T) = 5.6(70)$

$\Rightarrow T_h = 80.328°$

Match C_1 with H_2 (split H_2 to x & $4-x$)

$x(144.59 - 80.327) = 3(130-60)$

$\Rightarrow x = 3.2678$

$Q_{b1} = 3(70) = 210\ kW$. C_1 done!

Match remainder of $H_2 = 4 - 3.2678$
$= 0.7321\ W/°C$

with C_2 (split C_2 into y & $2.6 - y$)

$y(130-60) = 0.7321(144.59 - 80.327)$

$\Rightarrow y = 0.6721$; $Q_{b2} = 0.7321(144.59 - 80.327) = 47.05\ kW$. H_2 done!

Match remainder of C_2 with H_1

$\rightarrow 2.6 - 0.6721 = 1.9279$

$$Q_{b3} = 0.\cancel{x}224(2.6 - 0.6721)(70)$$

$$= (2.1)(144.59 - 80.327)$$

$$\simeq \underline{139.951 \text{ kW}}$$ C2 & H1 done!

LMTD

(Same for all 3 hex)

$$= \frac{(144.59 - \cancel{80.327}^{130}) - (80.328 - 60)}{\ln\left(\frac{144.59 - 130}{80.328 - 60}\right)}$$

$$\simeq \underline{17.3007\,^\circ C}$$

$$A = \frac{Q}{U \times LMTD}$$

$$A_{b1} = \underline{12.138 \text{ m}^2}, \quad A_{b2} = \underline{2.719 \text{ m}^2}$$

$$A_{b3} = \underline{8.0893 \text{ m}^2}$$

Segment ⓒ : Till T cold = 30°

$80.328 \xrightarrow{Fcp = 2.1} T_{h,exit}$ $\qquad 2.1(80.328 - T) = (2.6)(60 - 30)$

$80.328 \xrightarrow{Fcp = 4} T_{h,exit}$

$60^\circ \xleftarrow{Fcp = 2.6} 30^\circ$

$\Rightarrow T_{h,exit} = \underline{67.541\,^\circ}$

Split C2 & match with H1

& match remaining with H2

$$Q\ x(30) = 2.1(80.328 - 67.541)$$

$$\Rightarrow x = 0.8951 \text{ kW/}^\circ C$$

H1 ~~ticked~~ off done!

Remaining $2.6 - 0.895 = 1.705$

will take off the complete H2

$Q_{C1} = 0.895(60-30) = \underline{26.85\ kW}$

$Q_{C2} = 1.705(60-30) = \underline{51.15\ kW}$

LMTD = $28.06°C$

$A_{c1} = \underline{0.957\ m^2}$ & $A_{c2} = \underline{1.823\ m^2}$

Just the 2 hot streams remain, use ~~cold~~ coolers to both.

H1 : $67.54 \xrightarrow{C} 40°$ F_{cp} 2.1

H2 : $67.54 \xrightarrow{C} 40$ 4

water in cooler : $30° \leftarrow 15°$

$Q_{cooler\ 1} = (67.54-40)(2.1) = 57.834$

$Q_{cooler\ 2} = (67.54-40)(4) = 110.16$

$Q_{cooling\ utility} =$ 168 kW (as calculated in earlier SAT / Assgn)

$$LMTD = \frac{(67.54 - 30) - (40 - 15)}{\log\left(\frac{(67.54 - 30)}{(40 - 25)}\right)}$$

$$= \underline{30.846^\circ}$$

$A_{cooler-1} = \underline{1.8768 \ m^2}$

$A_{cooler-2} = \underline{3.5712 \ m^2}$

total Area of heat exchangers $= 0.419 + 4.882 + 1.87 + 0.982 + 12.138 + 2.719 + 8.089 + 0.957 + 1.828 + 1.877 + 3.571$

$$\Rightarrow \boxed{A_{total} = 38.879 \ m^2}$$

Total no of heat exchangers = 8 + 1 heater + 2 coolers

$$= \boxed{11}$$

$$\text{capital cost} = 11 \times \left(40000 + \frac{500 \times 38.879}{11}\right)$$

$$= ₹ 459439.56$$

$$= \boxed{₹ 4.594 \times 10^5}$$

Utility cost = Ƶ $120 \times 54 + 10 \times (57.89 + 110.16)$

$= \boxed{Ƶ\ 8160}$

Total cost = $0.25 \times$ capital cost + ~~tot~~ Utility cost

$= \boxed{Ƶ\ 123020.43} = \boxed{Ƶ\ 1.23 \times 10^5}$

comparing with HW1 targets

	~~Sl~~ HW1 Target	Spaghetti
Area	$39.01\ m^2$	$38.879\ m^2$
capital cost	Ƶ 259503.7	Ƶ 459439.56
utility cost	Ƶ 8160/year	Ƶ 8160 ~~854~~/year
Total cost	Ƶ 73036/year	Ƶ 123020.43/year

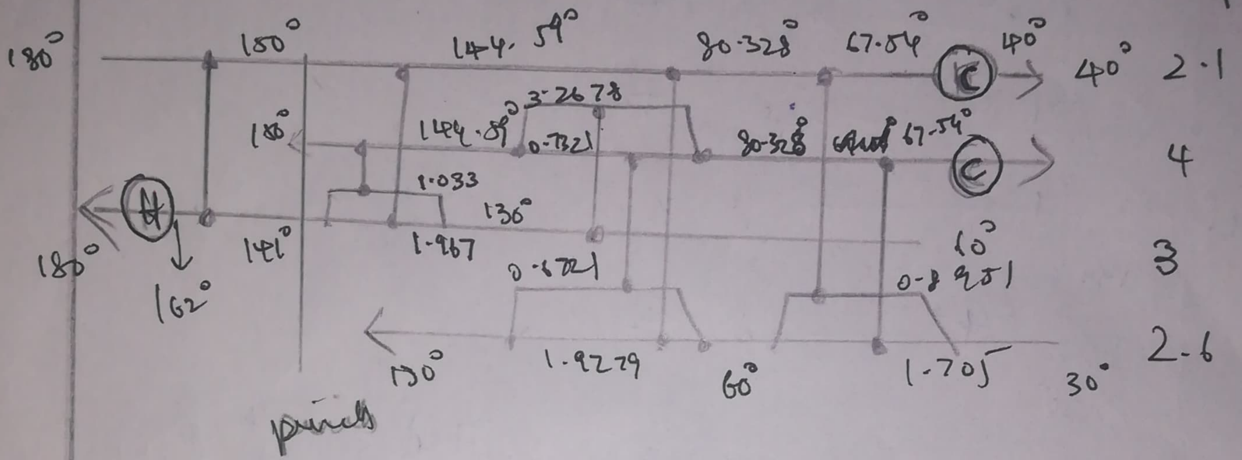
Utility costs same! → max heat recovered in Spaghetti

As expected Spaghetti design costs more because it has more capital cost - due to number of heat exchangers (11) way above minimum (6).

However, total area is slightly lesser, probably because of more exchangers used (more coolers particularly)

$$\left(\frac{\text{cost}}{\text{Area}}\right)_{\text{spaghetti}} = ₹\ 3164.177$$

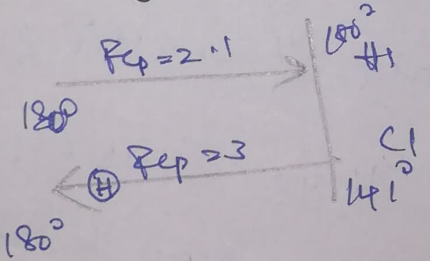
$$\left(\frac{\text{cost}}{\text{Area}}\right)_{\text{target}} = ₹\ 1872.238$$



[Spaghetti design HEN]

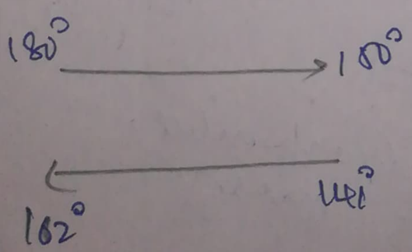
2nd part : MER using PDM rules

Above pinch :



Tick off H1.

$$(T_{c1\,exit} - 141)3 = 2.1(180-150)$$
$$\Rightarrow T_{c1\,exit} = \underline{162°}$$



Same as in spaghetti design

LMTD = $\underline{12.984°}$

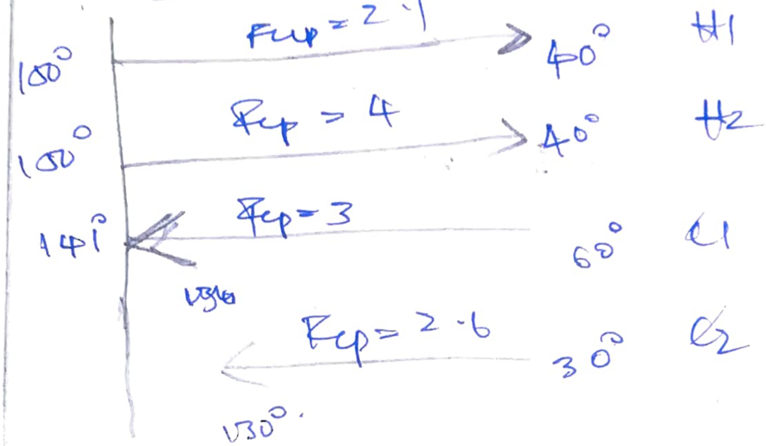
$\underline{Q = 63\text{ kW}}$ $A_1 = \underline{4.852\text{ m}^2}$

Heater value will also be same as Spaghetti design.

⇒ $Q_H = 54$, $A_2 = 0.4192\ m^2$, LMTD = 128.79

C_1 ticked off.

Below pinch.



We notice that $(Fcp)_{H1} \leq (Fcp)_{C2}$ & $(Fcp)_{C1}$ & since we are below pinch, chances are that (ΔT) will fall below pinch if we try to use tick off heuristic. & In fact, they actually do. Since $(Fcp)_{C1} \geq (Fcp)_{C2}$, it is enough if we show intersection for C_2 & H_1. Tick of H_1: $\{T_{c\,entry} + (130)\} 2.6 = 38\ \} \ 2.1(180-40)$

⇒ $T_{c\,entry} = 41.154° > T_{inlet}$!

match can't be allowed (infeasible match)

To ensure feasible matches, we will resort to splitting streams.

Split C_2 into 2 parts: C_{21} (flow rate : $FC_p = x$)

and C_{22} ($FC_p = 2.6 - x$)

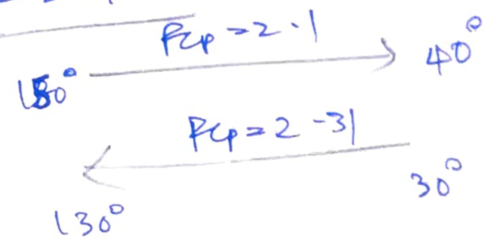
Use C_{21} to tick off H_1 & itself

i.e. $(x)(130-30) = 2.1(180-40)$

$\Rightarrow x = 2.31$ & $Q = 231$ kW ; LMTD $= 14.427$ °C

$\therefore$ Area$_3$ = 16.012 m^2

So split of C_2 (C_{21}) & H_1 are now ticked off.



We now have $N_c = 2$ (C_{22}, C_1)

$N_H = 1$ (H_2)

Split H_2 so that $N_h = 2$ & we can make feasible matches.

conditions for split (we have 3 'variables' : x, $T_{H21,exit}$, $T_{H22,exit}$)

(i) ensure both streams leave at same temp after being cooled.

(ii) Ensure C_{22} as well as C_1 is ticked off.

Let the common temp be T_{exit} ((i) satisfied)

(ii) : $\begin{cases} x(180 - T_{exit}) = 243 \longrightarrow C_1 \quad (1) \\ \& \\ (4-x)(150 - t_{exit}) = (2.6 - 2.31)(100) \end{cases}$

$= (0.29)(100)$ $\rightarrow$ balance for C_{22}

$= 29. \quad (2)$

$\frac{(1)}{(2)} \Rightarrow \frac{x}{4-x} = \frac{243}{29}$

$\Rightarrow x \approx 3.5735$ & $T_{exit} = 81.999^\circ C$

The 2 exchangers :

with C1

$180 \xrightarrow{F c_p = 3.5735} 81.999$ H_{21}

$141 \xleftarrow{F c_p = 3} 60$

$Q = 243$ kW ;

LMTD = $14.547^\circ C$; $A_4 = 16.708\ m^2$

with C_{22}

$180 \xrightarrow{F c_p = 0.4265} 81.998$ H_{22}

$130 \xleftarrow{F c_p = 0.29} 30$

$Q = 29$ kW

LMTD = $33.489^\circ C$;

$A_5 = 0.866\ m^2$

Since T_{exit} is same for both H_{21} we mix them back at $T = 81.999^\circ C$

Cooler :

$\xrightarrow{H_2,\ F c_p = 4}$

$81.999^\circ \quad 40^\circ$

$30^\circ \longleftarrow 15^\circ$

$Q_c = 4(81.999 - 40)$

≈ 168 kW

LMTD = ~~38.458~~ $90.94^\circ C$

$A_6 = 1.85\ m^2$

Total Area = $A_1 + A_2 + A_3 + A_4 + A_5 + A_6$

$= 0.42 + 4.85 + 16.01 + 16.71 + 0.87 + 1.85 \; m^2$

$= \boxed{40.704 \; m^2}$

total no of exchangers $= \boxed{6}$

Capital cost $= 6 \times \left(40000 + 500 \times \dfrac{40.704}{6}\right)$

$= ₹\, 260352.1 = \boxed{₹\, 2.603 \times 10^5}$

Utility cost $= 120 \times 54 + 10 \times 168$

$= \boxed{₹\, 8160} \; / \text{year}$

total cost $= 260352.1 \times 0.25 + 8160$

$= \boxed{₹\, 73248 \; / \text{year}}$

	HW 1 targets	MER - PDM
Area target	$39.01 \; m^2$	$40.704 \; m^2$
Capital cost	₹ 259803.7	₹ 260352.1
Utility cost	₹ 8160 / year	₹ 8160 / year
total cost	₹ 73036 / year	₹ 73248 / year
No of heat exchangers	6	6

MER using PDM rules comes & very close to the set targets

Maybe the area is slightly higher because of the splitting we did. ~~Splitting lowers Q ...~~ hence

$$\left(\frac{\text{total cost}}{\text{total area}}\right)_{\text{target}} = ₹\ 1822.238\ /\text{year}/m^2 \qquad \left(\frac{\text{cost}}{\text{area}}\right)_{\text{MER}} = ₹\ 1299.56\ /\text{year}/m^2$$