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CH18B020

CH4010 Assignment-1: Targetting

Given stream data:

Stream No.	Type	Heat Capacity* Flow Rate kW / K	Supply Temperature °C	Target Temperature °C
1	Hot	2.1	180	40
2	Hot	4	150	40
3	Cold	3	60	180
4	Cold	2.6	30	130

Since $(\Delta T)_{min}$ = 9 degrees C (even roll number), we can shift the hot stream below by 9/2 = 4.5 degrees and the cold stream above by 4.5 degrees. This results in:

Modified stream data:

Stream No.	Type	Heat Capacity* Flow Rate kW / K	Supply Temperature °C	Target Temperature °C
1	Hot	2.1	175.5	35.5
2	Hot	4	145.5	35.5
3	Cold	3	64.5	184.5
4	Cold	2.6	34.5	134.5

Part-1: Pinch-point, Q_C, Q_H and composite curves

Using the problem table algorithm, one can arrive at the following table:

	2.1	4	3	2.6	Σ ($FC_{p,\,hot}$) (in kW/C)	Σ($FC_{p,\,cold}$) (in kW/C)	ΔT (in C)	ΔH (in kW)	$q_{transfer}$ (in kW)
184.5	0	0	1	0	0	3	9	27	0
175.5	1	0	1	0	2.1	3	30	27	-27
145.5	1	1	1	0	6.1	3	11	-34.1	-54
134.5	1	1	1	1	6.1	5.6	70	-35	-19.9
64.5	1	1	0	1	6.1	2.6	29	-101.5	15.1

35.5	0	0	0	1	0	2.6	1	2.6	116.6
34.5	0	0	0	0	0	0			114

We can see the lowest $q_{transfer}$ is -54 kW. So if we provide a heating of 54 kW, all heat transfers will be non-negative (and hence heat won't flow from lower temperature to higher temperature).

	2.1	4	3	2.6	Σ ($FC_{p,\ hot}$) (in kW/C)	Σ($FC_{p,\ cold}$) (in kW/C)	ΔT (in C)	ΔH (in kW)	$q_{transfer}$ (in kW)
184.5	0	0	1	0	0	3	9	27	54
175.5	1	0	1	0	2.1	3	30	27	27
145.5	1	1	1	0	6.1	3	11	-34.1	0
134.5	1	1	1	1	6.1	5.6	70	-35	34.1
64.5	1	1	0	1	6.1	2.6	29	-101.5	69.1
35.5	0	0	0	1	0	2.6	1	2.6	170.6
34.5	0	0	0	0	0	0			168

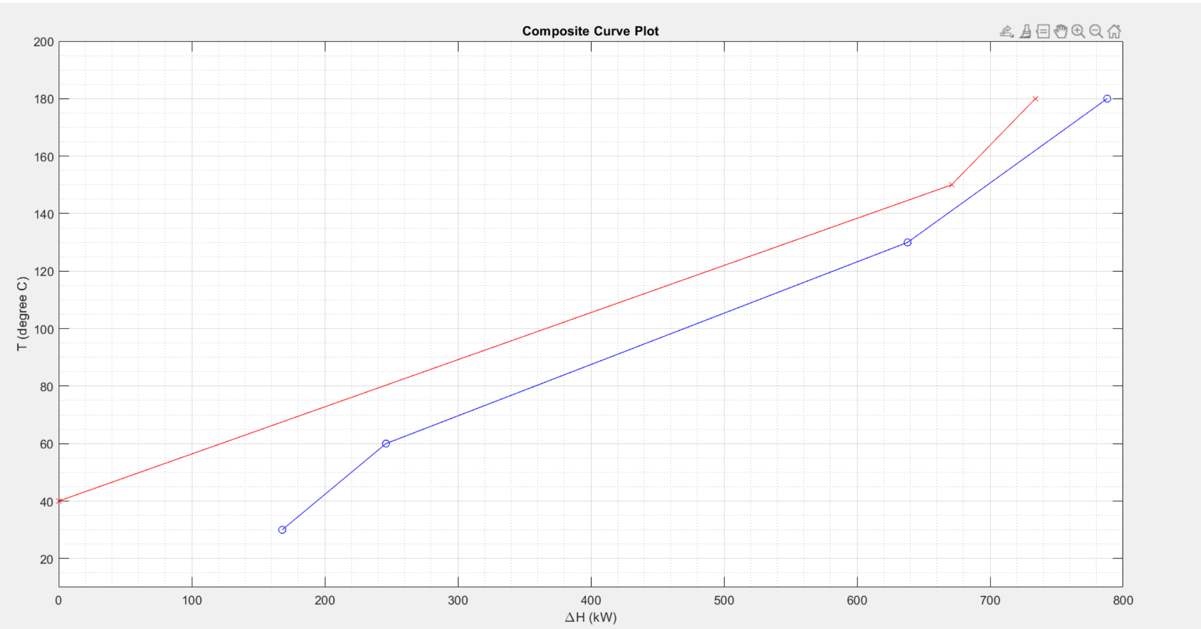
Hence from the above Problem Table we obtain the following:

Pinch point: i) cold stream pinch = 145.5°C – 4.5°C = **141°C**

ii) hot stream pinch = 145.5°C + 4.5°C = **150°C**

Heating utility required, $\mathbf{Q_h}$ = **54 kW**

Cooling utility required, $\mathbf{Q_c}$ = **168 kW**



Plot 1a): Composite curves. Red: hot curve; blue: cold curve

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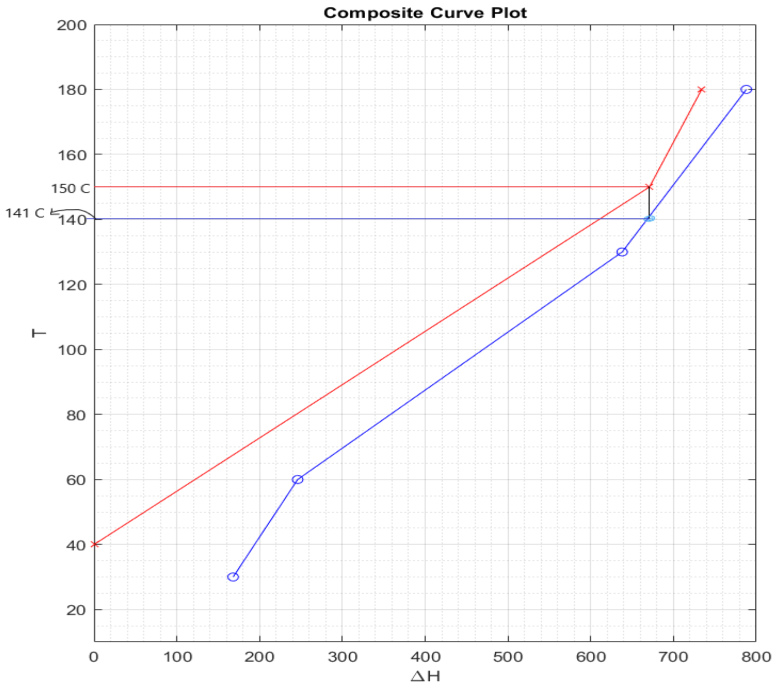
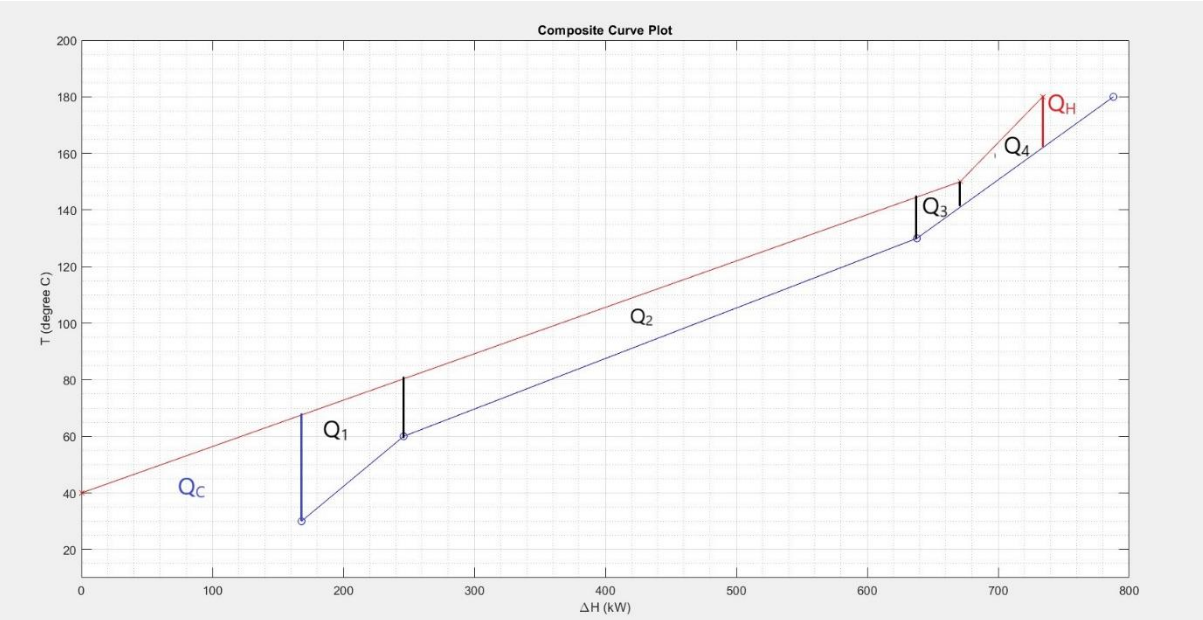


Plot 1b): Composite curves with the pinch point marked. Red: hot curve; blue: cold curve

Part-2: Area Targetting



Plot 2: Showing different parts of the system where heat exchangers have to be used.

2. AREA TARGETTING contd.

First, let's start from finding out area requirement of cooler.

Assume that the average heat transfer coefficient, $U = 0.001\ MW/Km^2$
$= 1\ kW/m^2$

$$Q_c = A\,U\,LMTD$$

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

part - 1: Given that the cooling water heats up from a temperature of 15°C to 30°; $T_{hot,entry} = T_{hot,out} + \frac{Q_c}{F_{cp}} = 40 + \frac{168}{6.1} = 67.54$

T = 67.541° → 40 Hot stream ($H_1 + H_2$) ($F_{cp} = 2.1 + 4 = 6.1$ kW/K)
6.1 kW/K

30° ← 15° Water

$$A_1 = \frac{Q_c}{10^3 \times 0.001 \times LMTD}$$

$$LMTD = \frac{(67.541 - 30) - (40 - 15)}{\ln\left(\frac{67.541 - 30}{40 - 15}\right)}$$

$$\Rightarrow LMTD = 30.8468°$$

$$\therefore A_1 = \frac{168}{0.001 \times 10^3 \times 30.8468} = \boxed{5.446\ m^2}$$

Part - 2: → from previous step

T = 80.3279°C → 67.541°C; 6.1 kW/K; $F_{cp} = 6.1$ kW/K

From heat balance

60°C ← 30°C; 2.6 kW/K; $F_{cp} = 2.6$ kW/K (C_1)

From graph

Heat balance.

$$(T - 67.541)6.1 = (60 - 30)(2.6)$$

$$\Rightarrow T = 80.3279°C$$

$Q_1 = 2.6\,(60-30) = \underline{78\ kW}$

$$LMTD = \frac{(80.328-60)-(67.541-30)}{\ln\left(\frac{80.328-60}{67.541-30}\right)}$$

$$= \underline{28.06\,^\circ C}$$

$$A_2 = \frac{78}{0.001\times10^3 \times 28.06} = \boxed{2.78\ m^2}$$

Part - 3

$T = 144.589^\circ$ $\longrightarrow$ 80.3271°

$F_{cp} = 6.1\ kW/K$

130° $\longleftarrow$ 60°

$F_{cp} = 5.6\ kW/K$

$Q_2 = 5.6\,(130-60)$

$= \underline{392\ kW}$

Heat balance :

$6.1\,(T - 80.3271) = 392$

$\Rightarrow T = 144.589^\circ C$

$$LMTD = \frac{(144.59-130)-(80.3271-60)}{\ln\left(\frac{144.59-130}{80.3271-60}\right)}$$

$$= \underline{17.3\,^\circ C}$$

$$A_3 = \frac{Q_2}{U\times LMTD} = \frac{392}{0.001\times10^3\times17.3} = \boxed{22.658\ m^2}$$

part-4

150° → 144.59°, $FCp = 6.1$ kW/K

$T = 141°$ ← 130°, $FCp = \cancel{2.6}\ 3$ kW/K

$$Q_3 = \cancel{2.6}\ 6.1(150-144.59) = 33 \text{ kW}$$

Heat Balance,

$$\cancel{2.6}\ 3(T-130) = 6.1(150-144.59)$$

$$\Rightarrow T = 141°C$$

$$LMTD = \frac{(150-141)-(144.59-130)}{\ln\left(\frac{150-141}{144.59-130}\right)} = 11.571°$$

$$A_4 = \frac{33}{0.001\times10^3 \times 11.571°} = \boxed{2.852 \text{ m}^2}$$

part-5

150° → 180°, $FCp = 2.1$ kW/K

$T = 162°$ ← 141°, $FCp = \cancel{2.6}\ 3$ kW/K

$$Q_4 = 2.1(180-150) = 63 \text{ kW}$$

Heat balance,

$$(\cancel{2.6}\ 3)(T-141) = 2.1(180-150)$$

$$\Rightarrow T = 162°$$

$$LMTD = \frac{(180-141)-(162-150)}{\ln\left(\frac{180-141}{162-150}\right)} = 12.984°C$$

$$A_5 = \frac{63}{1\times 12.984} = \boxed{4.852 \text{ m}^2}$$

part - 6

We ~~can~~ are ~~assume~~ given that the ~~the~~ heating utility is steam and that it ~~vers~~ condenses at 300°C (only latent heat)

$\dot{Q}_h$ = 54 kW ; cold stream heated from 162° - 180°

$$LMTD = \frac{(180-300) - (162-300)}{\ln\left(\frac{300-180}{300-162}\right)} = \underline{128.79°}$$

$$\therefore A_6 = \frac{54}{128.79} = 0.4193$$

$$\approx \boxed{0.42 \text{ m}^2}$$

$$\text{Total Area} = \sum_{k=1}^{6} A_k$$

$$= 5.454 \quad 2.78 + 22.66 + 2.85 + 4.85 + 0.42$$

$$= 39.0073 \text{ m}^2$$

Area target $= \boxed{39.01 \text{ m}^2}$

3) Above pinch, S = 1 hot + 1 cold + 1 utility = 3.

∴ No of hexchangers = ~~3~~ S - 1

= 2 exchangers

Below pinch,

no of streams, S = 2 hot + 2 cold + 1 utility ~~of 4~~

= ~~4~~ 5 streams

No of exchangers = ~~S~~ $- 1 = 5 - 1$

= 4 exchangers

~~total minimum num~~

Minimum number of heat exchangers = 2 above + 4 below

⇒ Min no. of units = $\boxed{6}$ heat exchangers

4. Cost Target

Steam cost = ₹ $12000 \times Q_h = 120000 \times 54 \times 10^{-3}$

= 6480 rupees/year

Water cost = $10000 \times Q_c = 10^4 \times 168 \times 10^{-3}$

= 1680 rupees/year.

Capital cost = $6 \times \left(40000 + 500 \frac{\text{target area}}{6}\right)$

$= 6 \times \left(40000 + 800 \times \frac{39.0073}{6}\right)$

= ₹ 259503.7

Annualization factor = 0.25

Total cost = Annualisation factor × Capital cost

+ Utility costs

(steam heating + cooling costs)

$$= 0.25 \times (259803.7) + 1680 + 6480$$

$$= \boxed{₹\ 73035.917\ /\text{year}}$$

$$= \boxed{₹\ 73{,}036.\ /\text{year}}$$

Table of Contents


```
clear; close all;
```

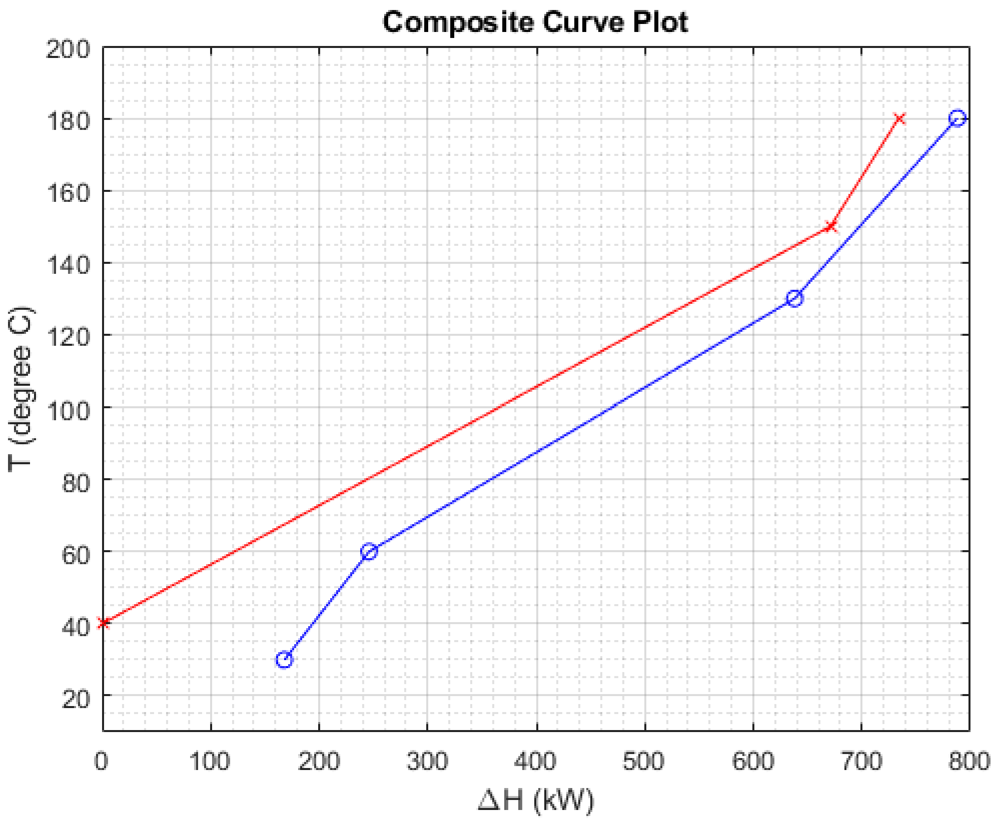
Initialise values

```
Tpinch_hot = 150;
FCphot = [6.1,2.1];
hot_slopes = 1./FCphot ;
ThotChange = [40,150,180];
FCpCold = [2.6,5.6,3];
cold_slopes = 1./FCpCold;
TcoldChange = [30,60,130,180];
Qc = 168;
Qh = 54;
```

Plot the graphs

```
x1 = 0;
xhot = x1;
yhot = [];
for i = 1:length(ThotChange)-1
    m = hot_slopes(i);
    y1 = ThotChange(i);
    yhot = [yhot y1];
    y2 = ThotChange(i+1);
    x2 = (y2-y1)/m + x1;
    plot([x1 x2],[y1 y2],'r',[x1 x2],[y1 y2],'rx')
    hold on;
    x1 = x2;
    xhot = [xhot x2];
end
yhot = [yhot y2];
grid on;
grid minor;
x1 = Qc;
xcold = [x1];
ycold = [];
for i = 1:length(TcoldChange)-1
    m = cold_slopes(i);
    y1 = TcoldChange(i);
    ycold = [ycold y1];
    y2 = TcoldChange(i+1);
```

```
    x2 = (y2-y1)/m + x1;
    plot([x1 x2],[y1 y2],'b',[x1 x2],[y1 y2],'bo')
    hold on;
    x1 = x2;
    xcold = [xcold x2];
end
ycold = [ycold y2];
title("Composite Curve Plot");
xlabel("\DeltaH (kW)");
ylabel("T (degree C)");
%legend("hot stream","","cold stream","");
ylim([10,200]);
%hold off;
```



Calculating Qs

```
X = [xhot xcold];
chngs = length(X);
X = sort(X);
Q = zeros(chngs-1,1);
LMTDs = Q;
Thexit = ThotChange(2);
Tcentry = TcoldChange(1);
U = 0.001;
Thentry = 40;
Tcexit = 30;
```

```
lmtd = @(Th1,Th2,Tc1,Tc2)(((Th2-Tc1) - (Th1-Tc2))/log((Th2-Tc1)/(Th1-
Tc2)));
Ths = [];
Tcs = [];
for i = 1:chngs-1
    Q(i) = X(i+1)-X(i);
    if i ~= 1 && i~= chngs-1
        Thexit = interp1(xhot,yhot,X(i));
        Thentry = interp1(xhot,yhot,X(i+1));
        Tcentry = interp1(xcold,ycold,X(i));
        Tcexit = interp1(xcold,ycold,X(i+1));
        LMTDs(i) = lmtd(Thentry,Thexit,Tcentry,Tcexit);
        disp(LMTDs(i));
        % Areas(i) = Q(i)/(LMTDs(i)*U);
        Ths = [Ths Thexit];
        Tcs = [Tcs Tcentry];
    end

    Thexit = Thentry;
    Tcentry = Tcexit;
end
LMTDs(1) = lmtd(Ths(1),ThotChange(1),15,30);
LMTDs(chngs-1)=  lmtd(300,300,Tcexit,TcoldChange(4));

Areas = Q./(LMTDs*U)/10^3; % since Q is in kW; converting to MW

Area_target = sum(Areas);
```

```
   28.0600

   17.3007

   11.5709

   12.9843
```

Costs

```
n_hex = length(Areas);
Capital = n_hex*(40000 + 500*Area_target/n_hex);
Steam = Qh*120000/10^3;% Qh is in kW; converting to MW
Water = Qc*10000/10^3; % Qc is in kW; converting to MW
Annul = 0.25;
cost_target = Capital*Annul + Steam + Water;
```

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