<u>TUTORIAL-04: SHELL TARGETING</u>

Based on **Lecture-15: Shell Targeting -1st Part**

Problem 1: Compute the number of shells targeted for the stream data shown in Table 1.

Given: Hot utility temperature range: 400 to 399°C

Cold utility temperature range: 10 to 15°C

ΔT_{min} = 10°C

Table 1: Stream data for Problem 1

Stream	Supply temperature (^{0}C)	Target temperature (^{0}C)	Heat capacity flow rate (kW ^{0}C^{-1})
HOT (H1)	290	70	28
HOT (H2)	190	30	40
COLD (C1)	50	190	38
COLD (C2)	150	290	60

Solution 1: The amount of hot and cold utilities and the pinch temperature are required to target number of shells. These values are computed using Problem Table Algorithm as described in Problem 1 of Tutorial-02 and shown below:

Minimum hot utility: 5080 kW

Minimum cold utility: 3920 kW

Pinch temperature: 155°C

Hot pinch temperature: 160°C

Cold pinch temperature: 150°C

To compute the data for balanced hot composite curve (BHCC), temperatures and CP values of hot streams (H1, H2), shown in Table 1, and Hot utility (HU) are considered. The detailed computation for BHCC is shown in Table 2. Similarly, data of balanced cold composite curve (BCCC) is computed and presented in Table 3.

Table 2: Data for BHCC

Temperature (°C)	CP=40	Cum CP (kW $^0C^{-1}$)	Q_h = ΔT*cum CP (kW)	Cum Q_h (kW)
30	CP=28	0	0	0
70		40	1600	1600
190		68	8160	9760
290	H2 CP=5080	28	2800	12560
399	H1	0	0	12560
400		5080	5080	17640

HU

Table 3: Data for BCCC

Temperature (°C)	CU	Cum CP (kW $^0C^{-1}$)	Q_c = ΔT*cum CP (kW)	Cum Q_c (kW)
10		0	0	0
15	C1	784	3920	3920
50	CP=784 C2	0	0	3920
150		38	3800	7720
190		98	3920	11640
290	CP=38	60	6000	17640

CP=60

Data of BHCC and BCCC are plotted in Figure 1 using Cum Q_h and Cum Q_c of Table 2 and 3, respectively. Further, cumulative enthalpies at different temperature intervals along with known interval temperatures of BHCC and BCCC are presented in Table 4. In this table the cumulative enthalpies are also shown where unknown temperatures of BHCC and BCCC are available.

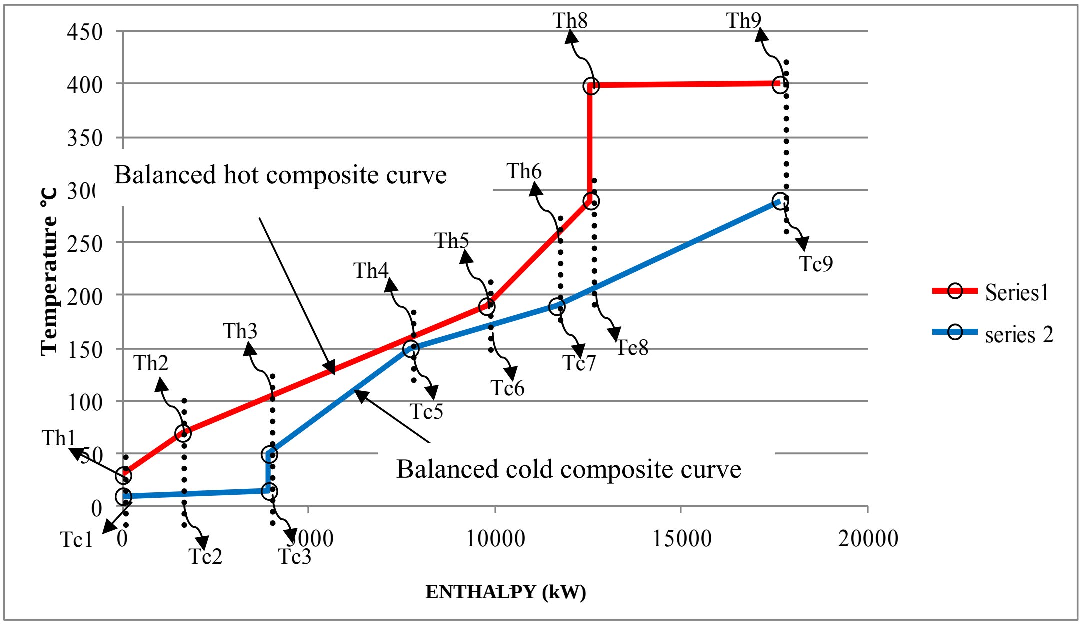

Figure 1: Balanced hot and cold composite curves

Table 4: Calculation of unknown temperatures of BHCC and BCCC

Enthalpy interval no	Cum enthalpy (kW)	Th_i (°C)	BHCC temperature	Tc_i (°C)	BCCC temperature	Cum CP (kW/°C)
	0	30	Th_1	10	Tc_1	0
1	1600	70	Th_2	Unknown	Tc_2	40
2	3920	Unknown	Th_3	15	Tc_3	784
3	3920	Unknown	Th_4	50	Tc_4	0
4	7720	Unknown	Th_5	150	Tc_5	38
5	9760	190	Th_6	Unknown	Tc_6	68
6	11640	Unknown	Th_7	190	Tc_7	98
7	12560	290	Th_8	Unknown	Tc_8	28
8	12560	399	Th_9	Unknown	Tc_9	0
9	17640	400	Th_{10}	290	Tc_{10}	60

Now, the unknown temperatures of BHCC and BCCC in each enthalpy interval are computed as described for Problem 1 of Tutorial-03 and shown below:

$Th_3 = 104.12°C$

$Th_4 = 104.12°C$

$Th_5 = 160°C$

$Th_7 = 257.14°C$

$Tc_2 = 12°C$

$Tc_6 = 170.82$

$Tc_8 = 205.33°C$

$Tc_9 = 205.33°C$

The values of all temperatures of BHCC and BCCC are shown in Table 5. Further, calculation of number of shells is carried out, which requires following equations:

$$P = \left(\frac{T_1 - T_2}{T_1 - t_1}\right) \quad (1)$$

$$R = \left(\frac{t_2 - t_1}{T_1 - T_2}\right) \quad (2)$$

$$P_{12} = X_P * P_{MAX} \quad (3)$$

$$P_{MAX} = \left[\frac{2}{(R+1)+(R^2+1)^{1/2}}\right] \quad (4)$$

if R = 1 :

$$S = \frac{\left[{P}/{(1-P)}\right]}{{P_{12}}/{(1-P_{12})}} \quad (5)$$

Else –

$$S = \frac{\ln\left[\frac{(1-RP)}{(1-P)}\right]}{\ln\left[\frac{(1-RP_{12})}{(1-P_{12})}\right]} \quad (6)$$

$$No\ of\ shell = S * (N-1) \quad (7)$$

Where, N is the number of streams

Calculation of the number of shells for first enthalpy interval is carried out as:

Eq. 1 is used to calculate P where T_1, T_2 and t_1 are considered as 70, 30 and 10, respectively. These values are taken from Table 5 for interval no. 1.

$$P = \frac{(70 - 30)}{(70 - 10)} = 0.667$$

Value of R is computed using Eq. 2 where T_1, $T_{2,}$ $t_{1,}$ and t_2 are considered as 70, 30, 10 and 12, respectively, from interval no. 1 as shown in Table 5.

$$R = \frac{(12 - 10)}{70 - 30)} = 0.05$$

Eq. 4 is used to calculate $P_{max,}$ where R = 0.05

$$P_{max} = \frac{2}{(0.05 + 1) + (0.05^2 + 1)^{1/2}} = 0.9750$$

P_{12} is predicted using Eq. 3 where X_P is considered as 0.9.

P_{12} = 0.9*0.9750 = 0.8775

As R ≠ 1, Eq. 6 is used to calculate S, where R and P are taken as 0.05 and 0.667, respectively. Thus,

$$S = \frac{ln\left[\frac{(1-0.05*0.667)}{(1-0.667)}\right]}{ln\left[\frac{(1-0.05*0.8775)}{1-0.8775}\right]} = 0.5186$$

N is the number of streams lying in the corresponding enthalpy interval. For interval no. 1, N is 2 as shown in Table 5. Thus, the number of shells for this interval is computed as

$No\ of\ shell = S * (N - 1)$ = 0.5186 (2-1) = 0.5186

The overall calculation for the shells is presented in Table 5.

Table 5: Calculation of the number of shells

Enthalpy interval no.	Enthalpy (kW)	T_h (°C)	T_c (°C)	P	R	P_{12}	S	N	S(N-1)
0	0	30	10	-	-	-	-	-	-
1	1600	70	12	0.667	0.05	0.8775	0.5186	2	0.5186
2	3920	104.12	15	0.37	0.0879	0.86	0.2273	3	0.4546
3	3920	104.12	50	0	-	-	-	-	-
4	7720	160	150	0.508	1.7895	0.3719	2.679	3	5.358
5	9760	190	170.82	0.75	0.694	0.6183	1.6178	4	4.8534
6	11640	257.14	190	0.778	0.2857	0.7739	1.0136	3	2.0272
7	12560	290	205.33	0.3286	0.4665	0.70	0.2869	2	0.2869
8	12560	399	205.33	0.5628	-	-	-	-	-
9	17640	400	290	5.14e-03	84.67	0.01056	0.2533	2	0.2533

As hot and cold pinch temperatures are 160°C and 150°C, So

No. of shells below the pinch is ≈ 7 (0.5186+0.4546+5.358=6.3312) (from interval 0 to 4)

No. of shells above the pinch is ≈ 8 (4.8534+2.0272+0.2869+0.2533=7.4208) (from interval 5 to 9)

Thus, the total no. of shells = No. of shells above the pinch+ No. of shells below the pinch

= 8 + 7 = 15

Problem 2: Compute the number of shells required for the given data in Table 6. For this problem the value of ΔT_{min} is 10°C.

Table 6: Stream data for Problem 2

Streams	Supply temperature (°C)	Target temperature (°C)	Heat capacity kW °C^{-1}
HOT (H1)	170	65	25
HOT (H2)	230	50	35
COLD (C1)	35	225	32
COLD (C2)	125	305	22
COLD UTILITY(CU)	30	40	
HOT UTILITY (HU)	325	324	

Solution 2: The amount of hot and cold utilities and the pinch temperature are required to target number of shells, which are computed using Problem Table Algorithm as described in Problem 1 of Tutorial-03 and shown below:

Amount of hot utility : 3170 kW

Amount of cold utility : 2055 kW

Pinch temperature: 165°C

Hot pinch temperature : 170°C

Cold pinch temperature : 160°C

CP of hot utility : 3170/(325-324) = 3170 kW.°C^{-1}

CP of cold utility : 2055/(40-30) = 205.5 kW.°C^{-1}

The computation for BHCC and BCCC are shown in Table 7 and 8, respectively.

Table 7: Data for BHCC

Temperature (°C)		Cum CP (kW.°C^{-1})	Q_h = cum CP*ΔT (kW)	Cum Q_h (kW)
	35			
50	25	0	0	0
65		35	525	525
170		60	6300	6825
230	H1 3170	35	2100	8925
324	H2	0	0	8925
325		3170	3170	12095
	HU			

Table 8: Data for BCCC

Temperature (°C)		Cum CP (kW.°C^{-1})	Q_C= cum CP* ΔT (kW)	Cum Q_C (kW)
	CU			
30	C1	0	0	0
35		205.5	1027.5	1027.5
40	C2	237.5	1187.5	2215
125	205.5	32	2720	4935
225		54	5400	10335
305	32	22	1760	12095
	22			

Data of BHCC and BCCC are plotted in Figure 2 using Cum Q_h and Cum Q_c of Table 7 and 8, respectively. Further, cumulative enthalpies at different temperature intervals along with known interval temperatures of BHCC and BCCC are presented in Table 9. The unknown temperatures in each enthalpy interval of Table 9 are computed as described for Problem 1 of Tutorial-03. The values of all temperatures of BHCC and BCCC are shown in Table 10.

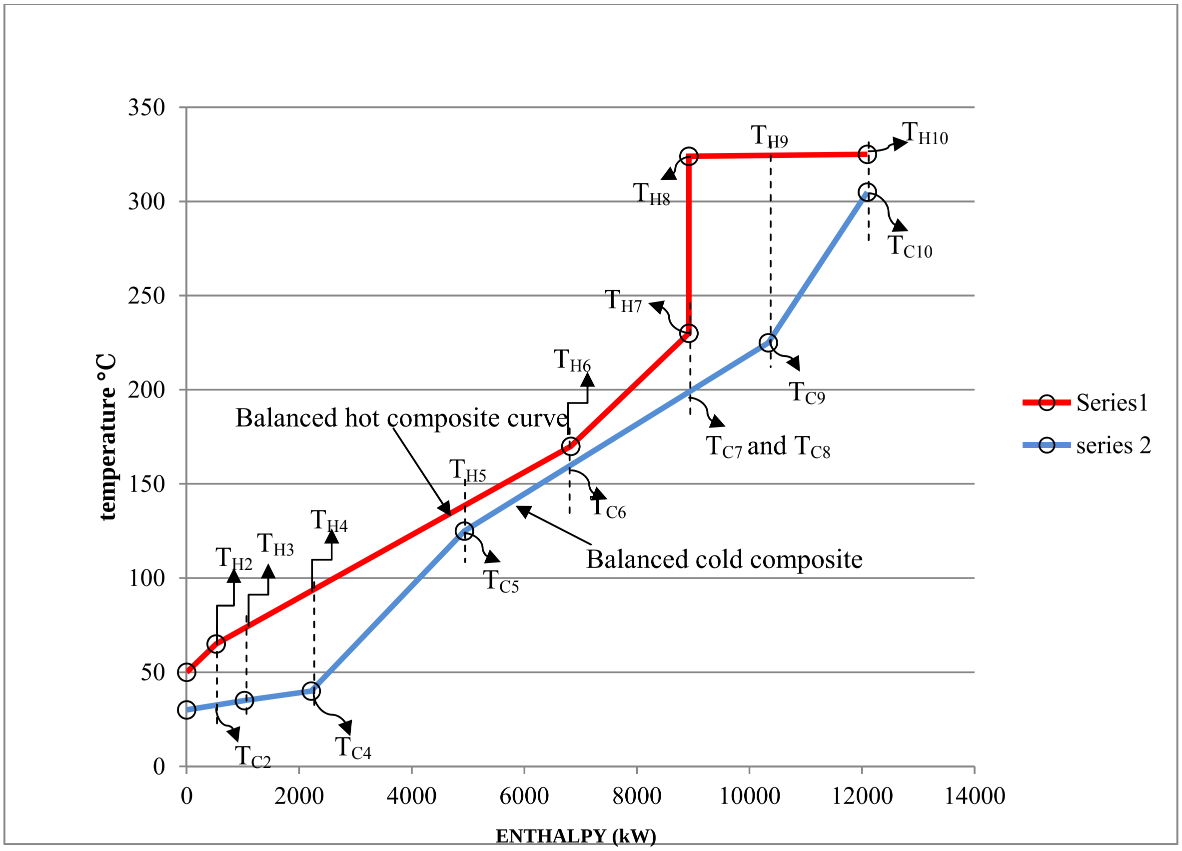

Figure 2: Graphical representation of balanced hot and cold composite curve

Table 9: Calculation of unknown temperatures of balanced hot and cold composite curve

Enthalpy interval number	Cum enthalpy (kW)	T_{HI} (°C)	BHCC temperature	T_{CI} (°C)	BCCC temperature	Cum CP (kW/°C)
0	0	50	T_{H1}	30	T_{C1}	0
1	525	65	T_{H2}	Unknown	T_{C2}	35
2	1027.5	Unknown	T_{H3}	35	T_{C3}	205.5
3	2215	Unknown	T_{H4}	40	T_{C4}	237.5
4	4935	Unknown	T_{H5}	125	T_{C5}	32
5	6825	170	T_{H6}	Unknown	T_{C6}	60
6	8925	230	T_{H7}	Unknown	T_{C7}	35
7	8925	324	T_{H8}	Unknown	T_{C8}	0

8	10335	Unknown	T_{H9}	225	T_{C9}	54
9	12095	325	T_{H10}	305	T_{C10}	3170

Further, calculation of number of shell is carried out using Eq. 1 to 7 as described for Problem 1. The overall calculation for shell targeting is presented in Table 10.

Table 10: Computation of number of shells

Enthalpy interval no.	Enthalpy (kW)	T_H (°C)	T_C (°C)	P	R	P_{12}	S	N_I	$S(N_I - 1)$
0	0	50	30	-	-	-	-	-	-
1	525	65	32.55	0.428	0.17	0.824	0.3045	2	0.3045
2	1027.5	73.375	35	0.205	0.2925	0.77	0.1375	3	0.275
3	2215	93.167	40	0.3403	0.2526	0.788	0.2453	4	0.7359
4	4935	138.5	125	0.46	1.875	0.36	2.0187	3	4.0374
5	6825	170	160	0.7	1.11	0.499	2.556	4	7.668
6	8925	230	198.89	0.857	0.648	0.6339	2.3838	3	4.7676
7	8925	324	198.89	0.7513	-	-	-	-	-
8	10335	324.45	225	3.58e-03	58.022	0.0154	0.1031	3	0.2062
9	12095	325	305	5.5e-03	145.45	6.166e-03	0.7079	2	0.7079

As the hot pinch temperature is 170°C and the cold pinch temperature is 160°C, so

No. of shells below the pinch ≈ 13(0.3045+0.275+0.7359+4.0374+7.668 = 13.208) (from interval 0 to 5)

No. of shells above the pinch ≈ 6 (4.7676+0.2062+0.7079 = 5.6817) (from interval 6 to 9)

So, the total no. of shells are = No of shells above the pinch+ No of shells below the pinch

= 13 + 6 = 19