TUTORIAL-03: AREA TARGETING

Based on

Lecture-17: **AREA TARGETING -1st Part (Unequal film heat transfer coefficient)**
Lecture-18: **AREA TARGETING -2nd Part (Equal stream heat transfer coefficient)**

Problem 1: Compute area targeting for stream data shown in Table 1 where two hot streams exchange heat against a single cold stream using ΔT_{min} as 10°C. The overall heat transfer coefficient U is constant and equal to 0.123 $kW.m^{-2}K^{-1}$ for all exchangers.

Table 1: Stream data for problem 1

stream	Supply temperature Ts(˚C)	Target temperature Tt(˚C)	Heat capacity flow rate, CP($kW.^oC^{-1}$)
HOT (H1)	180	140	1.4
HOT (H2)	150	90	2.5
COLD (C1)	70	150	4

Solution 1: To calculate the area target for the given stream data in Table 1, first the amount of hot and cold utility and the pinch temperature should be known. For this purpose all steps used for Problem 1 of Tutorial-02 should be followed. The shifted temperatures and problem table cascade for the present problem are shown in Table 2 and Figure 1, respectively.

Table 2: Shifted temperature data for the stream data of Table 1

Stream	Supply temperature Ts(˚C)	Target temperature Tt(˚C)	Shifted supply temperature Ts(˚C)	Shifted target temperatures Tt(˚C)
HOT (H1)	180	140	175	135
HOT (H2)	150	90	145	85
COLD (C1)	70	150	75	155

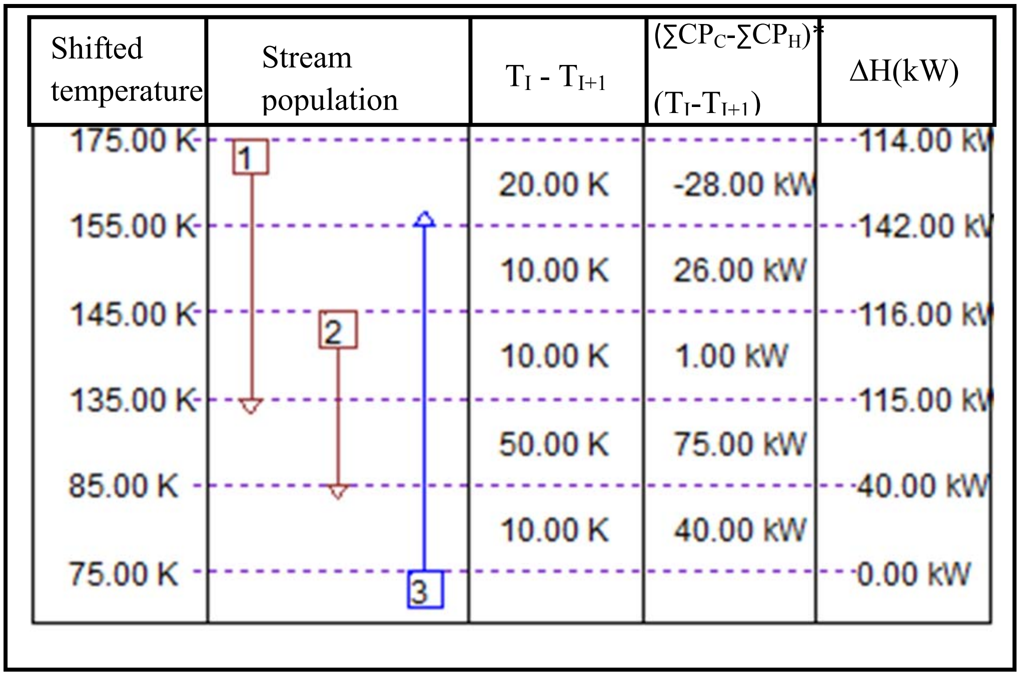


Figure 1: Problem table analysis for the determination of the amount of hot and cold utility

From the problem table analysis it is clear that-

Hot utility : 114 kW

Cold utility : 0 kW

Pinch temperature : 75°C

Hot pinch temperature : 80°C

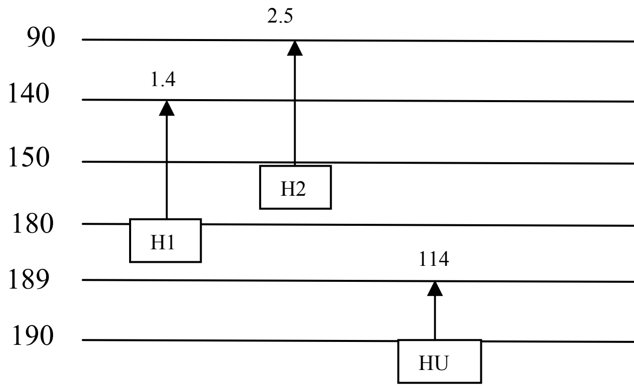
Cold pinch temperature : 70°C

As there is no requirement of cold utility the present problem is a threshold problem.

Let the temperatures of hot utility is from 190˚C to 189˚C. Thus, CP of hot utility is found as 114kW/˚C.

For data of balanced hot composite curve (BHCC) temperatures and CP values of hot streams (H1, H2) and hot utility (HU) are considered. The detailed computation for BHCC is shown in Table 3.

Table 3: Table for BHCC data



$\sum CP_{,hb}$ (kW.°C^{-1})	$Q_{hb}=\Delta T*\sum CP_{,hb}$ (kW)	Cum Q_{hb} (kW)
0	0	0
2.5	125	125
3.9	39	164
1.4	42	206
0	0	206
114	114	320

Similarly, data of balanced cold composite curve (BCCC) is computed and shown in Table 4.

Table 4: Table for BCCC data curve

Temperature (°C)	$\sum CP_{hb}$ (kW.°C^{-1})	$Q_{hb}=\Delta T*\sum CP_{hb}$ (kW)	Cum Q_{hb} (kW)
70	0	0	0
150	4	320	320

Necessary data for plotting BHCC and BCCC are extracted from Table 3 and 4, respectively, and shown in Table 5 and 6. Using these data BHCC and BCCC and plotted in Figure 2. From this figure it can be seen that what temperatures of BHCC are unknown corresponds to the known data of BCCC and vice versa.

Table 5: Data for plotting the BHCC

Thb (^oC)	Cum Qhb (kW)
90	0
140	125
150	164
180	206
189	206
190	320

Table 6: Data for plotting the BCCC

Tcb (^oC)	Cum Qcb (kW)
70	0
150	320

Cumulative enthalpies at different temperature intervals along with known interval temperatures of BHCC and BCCC are presented in Table 7. In this table the cumulative enthalpies where temperatures of BCCC are unknown are also shown.

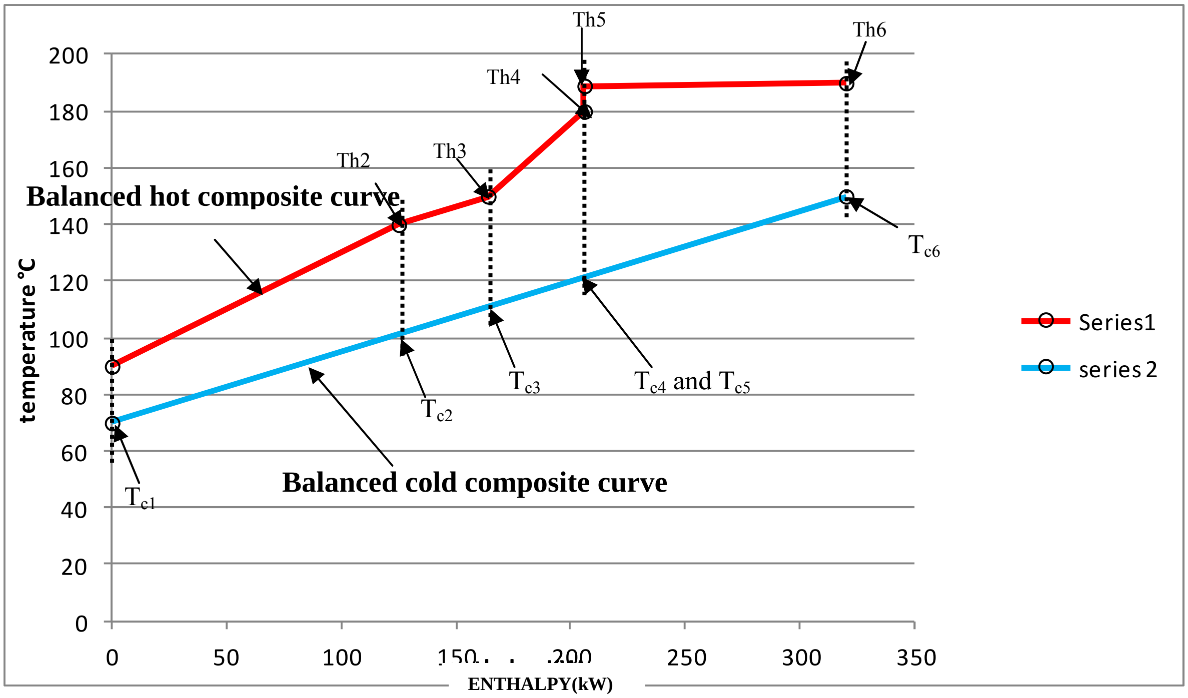


Figure 2: Balanced hot and cold composite curve

Table 7: Calculation of unknown temperatures of BHCC and BCCC

Enthalpy interval No.	Cumulative enthalpy,kW CumQ	T_{hi} (^oC)	BHCC Temp.	T_{ci} (^oC)	BCCC Temp.	ΣCP kW/°C
	0	90	Th1	70	Tc1	0
1	125	140	Th2	unknown	Tc2	2.5
2	164	150	Th3	unknown	Tc3	3.9
3	206	180	Th4	unknown	Tc4	1.4
4	206	189	Th5	unknown	Tc5	0
5	320	190	Th6	150	Tc6	4

To calculate the unknown temperatures in each enthalpy interval following equation is used:

$$T_{c2} = T_{cb\ row\ r} - (CumQ_{cb,\ row\ r} - CumQ) / \Sigma CP_{cb\ row\ r}$$

Where,

$T_{cb\ row\ r}$: Temperature for cold balanced curve in row r (for which temperature is known)

$CumQ_{cb,\ row\ r}$: Cum Q for cold balanced curve in row r

CumQ: Cum Q for the cold balanced curve for which the temperature is to be calculated

$\Sigma CP_{,\ cb\ row\ r}$: ΣCP for the cold balanced curve in row r(for which the temperature is known)

T_{c2} is computed using $T_{cb\ row\ r}$, $CumQ_{cb,\ row\ r}$, CumQ and $\Sigma CP_{cb,\ row\ r}$ as 150, 320, 125 and 4, respectively, from Table 7. Thus,

Tc2 = 150-((320-125)/(4)) = 101.25˚C

Similarly,

Tc3 = 150-((320-164)/(4)) = 111˚C

Tc4 = 150-((320-206)/(4)) = 121.5˚C

Tc5 = 150-((320-206)/(4)) = 121.5˚C

Cumulative enthalpies at different temperature intervals along with known interval temperatures of BHCC and BCCC are shown in Table 8.

As overall heat transfer coefficient, U, is given the area for the given stream data can be calculated as:

$$\Delta Q = U * A * \Delta T_{lm}$$

$$A = \frac{\Delta Q}{U * \Delta T_{lm}}$$

Where,

ΔQ is the cumulative enthalpy for the different interval (kW)

ΔT_{lm} is the log mean temperature difference between the hot and cold stream (^{o}C)

ΔT_{lm} and the area for the different enthalpy intervals can be calculated as -

For interval No.1 -

ΔT_{lm1} =(90-70)-(140-101.25)/ln(20/38.75) = 28.349°C

$$A_1 = \frac{\Delta Q_1}{U * \Delta T_{lm1}} = \frac{(125-0)}{(0.123*28.349)} = 35.975 m^2$$

For interval No.2-

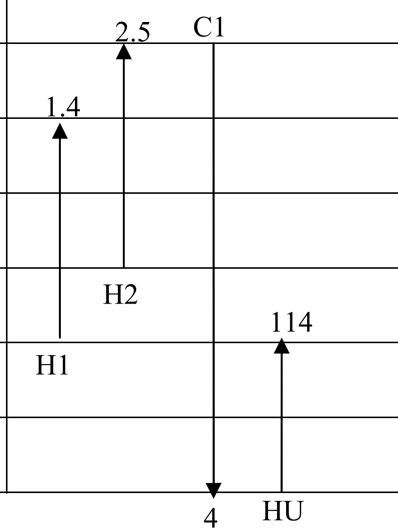
ΔT_{lm2} =(140-101.25)-(150-111)/ln(38.75/39) = 38.875°C

$$A_2 = \frac{\Delta Q_2}{U * \Delta T_{lm2}} = \frac{(164-125)}{(0.123 * 38.875)} = 8.1562 m^2$$

The calculation of area for each enthalpy interval is shown in Table 8 which gives total heat transfer area as **68.866 m²**.

Table 8: Calculation of area target for the given stream network

interval	Cum Qi (kW)		Thi (°C)	Tci (°C)	ΔT_{lm} (°C)	$A = \frac{\Delta Q}{U * \Delta T_{lm}}$ (m^2)
0	0		90	70	0	0
1	125		140	101.25	28.349	35.975
2	164		150	111	38.875	8.1562
3	206		180	121.5	48.093	7.10006
4	206		189	121.5	62.8927	0
5	320		190	150	52.556	17.63497



Problem 2: For a process the stream data together with utility data and heat transfer coefficients are shown in Table 9, where ΔT_{min} is selected as 10 °C. Steam from 250°C to 249°C is to be used as hot utility, however, cold water at 25 °C and returning to the cooling tower at 35 °C is to be used as cold utility. Target the heat exchange area for this process.

Table 9: The stream and utility data for the process

Stream	Supply temperature T_s(°C)	Target temperature T_T(°C)	ΔH (MW)	Heating capacity flow rate, CP ($MW.^oC^{-1}$)	Film heat transfer coefficient, h ($MW.m^{-2}.^oC^{-1}$)
Cold (C1)	25	185	32.0	0.25	0.0008
Hot (H1)	260	50	-31.5	0.16	0.0009
Cold (C2)	145	235	27.0	0.32	0.0009
Hot (H2)	190	70	-30.0	0.26	0.0010
Steam (HU)	250	249			0.0040
Cold water (CU)	25	35			0.0010

Solution 2: To calculate area target for the given stream data in Table 9 the amount of hot and cold utility is computed using Problem Table Algorithm (PTA) as carried out for Problem 1. From PTA following results are found:

Amount of hot utility: 12.9MW

Amount of cold utility: 8.90MW

Pinch point: 150°C

Hot pinch: 155°C

Cold pinch: 145°C

CP of hot and cold utility are computed as 12.9 MW/˚C and 0.89 MW/˚C, respectively.

For data of BHCC, hot streams (H1, H2) and hot utility (HU) temperatures as well as CP values are considered. The detailed computation for BHCC is shown in Table 10. Similarly, data of BCCC is computed and presented in Table 11.

Table 10: Table for BHCC data

Temperature		CUM CP ($MW.^oC^{-1}$)	Qh=ΔT*ΣCP (MW)	CUM Qh (MW)
	0.16			
50	0.26	0	0	0
70		0.16	3.2	3.2
190	12.9	0.42	50.4	53.6
249	H2	0.16	9.44	63.04
250		13.06	13.06	76.1
260	HU	0.16	1.6	77.7
	H1			

Table 11: Table for BCCC data

temperature		CUM CP ($MW.^oC^{-1}$)	Qc= ΔT*ΣCP (MW)	CUM Qc (MW)
	C1 CU			
25		0	0	0
35	C2	1.14	11.4	11.4
145	0.89	0.25	27.5	38.9
185		0.57	22.8	61.7
235	0.25	0.32	16	77.7
	0.32			

Data of BHCC and BCCC are plotted in Figure 3 using CumQh and CumQc of Table 10 and 11, respectively. Figure 3 clearly indicates that what temperatures of BCCC are unknown for known temperatures of BHCC and vice versa. Cumulative enthalpies at different temperature intervals along with known interval temperatures of BHCC and BCCC are presented in Table 12. In this table the cumulative enthalpies are also shown where unknown temperatures of BHCC and BCCC are available.

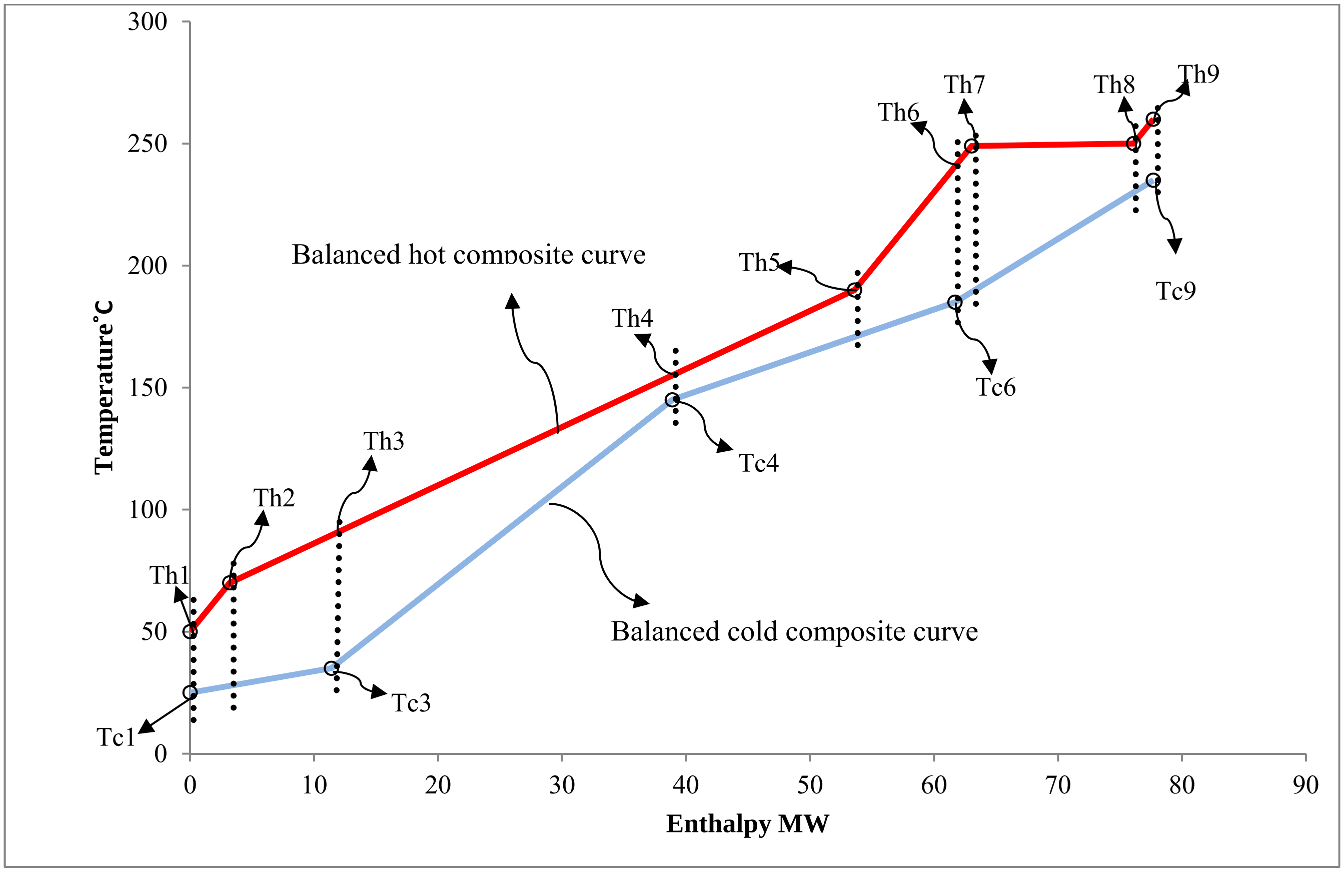


Figure 3: Graphical representation of balanced hot and cold composite curve

Table 12: Calculation of unknown temperatures of balanced hot and cold composite curve

Enthalpy interval No.	Cumulative enthalpy, CumQ, MW	T_{hi} (°C)	BHCC Temp	T_{Ci} (°C)	BCCC Temp	ΣCP MW/°C
	0	50	Th1	25	Tc1	0
1	3.2	70	Th2	unknown	Tc2	0.16
2	11.4	unknown	Th3	35	Tc3	1.14
3	38.9	unknown	Th4	145	Tc4	0.25
4	53.6	190	Th5	unknown	Tc5	0.42
5	61.7	unknown	Th6	185	Tc6	0.57
6	63.04	249	Th7	unknown	Tc7	0.16
7	76.1	250	Th8	unknown	Tc8	13.06
8	77.7	260	Th9	235	Tc9	0.32

The next step is to calculate the unknown temperatures in each enthalpy interval as carried out for Problem 1.

The unknown temperatures of BHCC can be computed as shown below:

Th3 = 190-((53.6-11.4)/(0.42)) = 89.52˚C

Th4 = 190-((53.6-38.9)/(0.42)) = 155˚C

Th6 = 249-((63.04-61.7)/(0.16)) = 240.6˚C

The unknown temperatures of BCCC are predicted as:

Tc2 = 35-((11.4-3.2)/(1.14)) = 27.8˚C

Tc5 = 185-((61.7-53.6)/(0.57)) = 170.79˚C

Tc7 = 235-((77.7-63.04)/(0.32)) = 189.18˚C

Tc8 = 235-((77.7-76.1)/(0.32)) = 230˚C

Cumulative enthalpies at different temperature intervals along with known interval temperatures of BHCC and BCCC are shown in Table 13.

Computation of $\Sigma(CP/h)_h$ and $\Sigma(CP/h)_c$ in each interval is carried out as shown below:

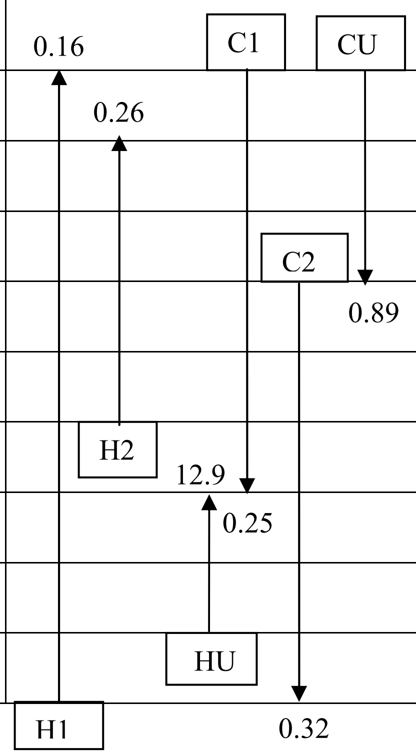
For interval no. 1
$\Sigma(CP/h)_h = (0.16/0.0009) = 177.78$
$\Sigma (CP/h)_c = (0.25/ 0.0008) + (0.89/0.001) = 1202.5$

For interval no. 2

$\Sigma(CP/h)_h = (0.16/ 0.0009) + (0.26/0.001) = 437.78$

$\Sigma (CP/h)_c = (0.25 / 0.0008) + (0.89/0.001) = 1202.5$

Table 13: Cumulative enthalpies at different temperature intervals along with known interval temperatures of BHCC and BCCC



Interval	Cum Qi(MW)	Thi (°C)	Tci (°C)	Σ(CP/h)h (m^2)	Σ(CP/h)c (m^2)
0	0	50	25	0	0
1	3.2	70	27.8	177.78	1202.5
2	11.4	89.52	35	437.78	1202.5
3	38.9	155	145	437.78	312.5
4	53.6	190	170.79	437.78	668.056
5	61.7	240.6	185	177.78	668.056
6	63.04	249	189.18	177.78	355.56
7	76.1	250	230	3402.78	355.56
8	77.7	260	235	177.78	355.56

$\sum(Q / h)$, LMTD and area (A) for different enthalpy intervals are computed as:

For interval No.1 -

$\sum (Q / h)_1 = (70\text{-}50)*177.78+(27.8 - 25)*1202.5 = 6922.6$

$LMTD_1 =(50\text{-}25)\text{-}(70\text{-}27.8)/\ln(25/42.2) = 32.85$

$A_1 = \sum (Q / h)_1 / LMTD_1 = 6922.6/32.85 = 210.73\ m^2$

For interval No.2 -

$\sum (Q / h)_2 = (89.52 - 70)*437.78 + (35 – 27.8)*1202.5 = 17203.46$

$LMTD_2 =(70-27.8)-(89.52-35)/\ln(42.2/54.52) = 48.097$

$A_2 = \sum (Q / h)_2 / LMTD_2 = 357.68 \text{ m}^2$

The values of $\Sigma(CP/h)_h$, $\Sigma (CP/h)_c$, $\sum(Q / h)_I$, LMTD and A for each interval are shown in Table 14, which gives total heat transfer area as **6520.636 m^2**.

Table 14: Computation of Thi, Tci, $\Sigma(CP/h)_{h,}$ $\Sigma(CP/h)_{c,}$ $\sum(Q / h)_I$, $(LMTD)_i$ and A_i

Interval	Thi (ºC)	Tci (ºC)	$\Sigma(CP/h)_h$ (m^2)	$\Sigma(CP/h)_c$ (m^2)	$\Sigma(Q/h)_i$ (m^2.ºC)	(LMTD)i (ºC)	A (m^2)
0	50	25	0	0	0	0	0
1	70	27.8	177.78	1202.5	6922.6	32.85	210.73
2	89.52	35	437.78	1202.5	17203.46	48.097	357.68
3	155	145	437.78	312.5	63040.83	26.25	2401.55
4	190	170.79	437.78	668.056	32551.46	14.107	2307.47
5	240.6	185	177.78	668.056	18488.74	34.24	539.974
6	249	189.18	177.78	355.56	2979.59	57.68	51.657
7	250	230	3402.78	355.56	17916.74	36.35	492.895
8	260	235	177.78	355.56	3555.6	22.407	158.68