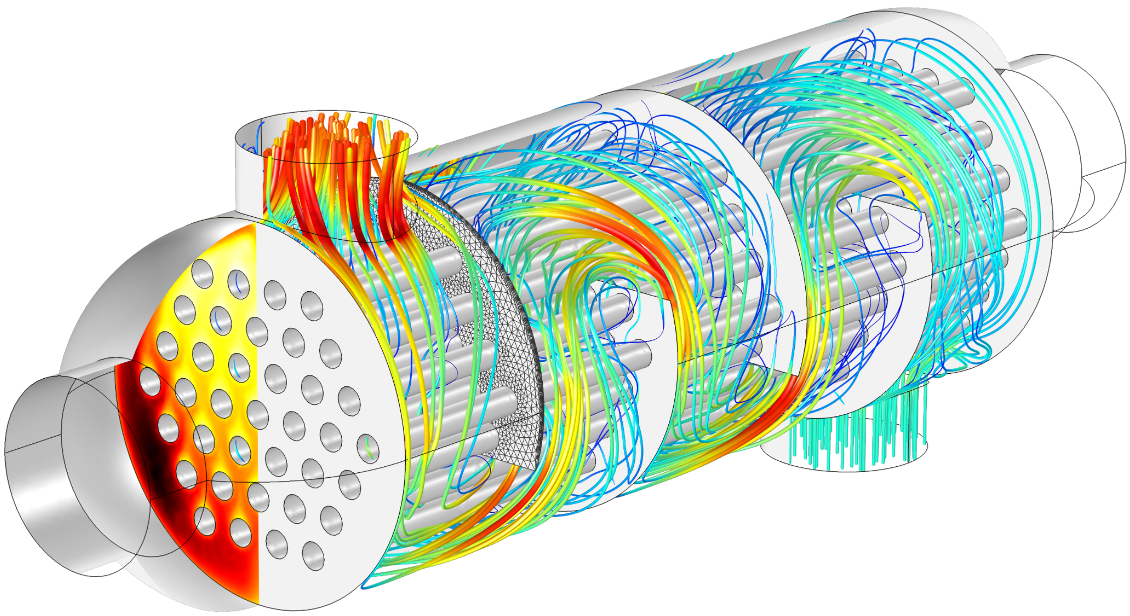
Heat Exchanger Network



Group - 29
S.S.S.Vardhan
19CH30018

Heat Exchanger Network

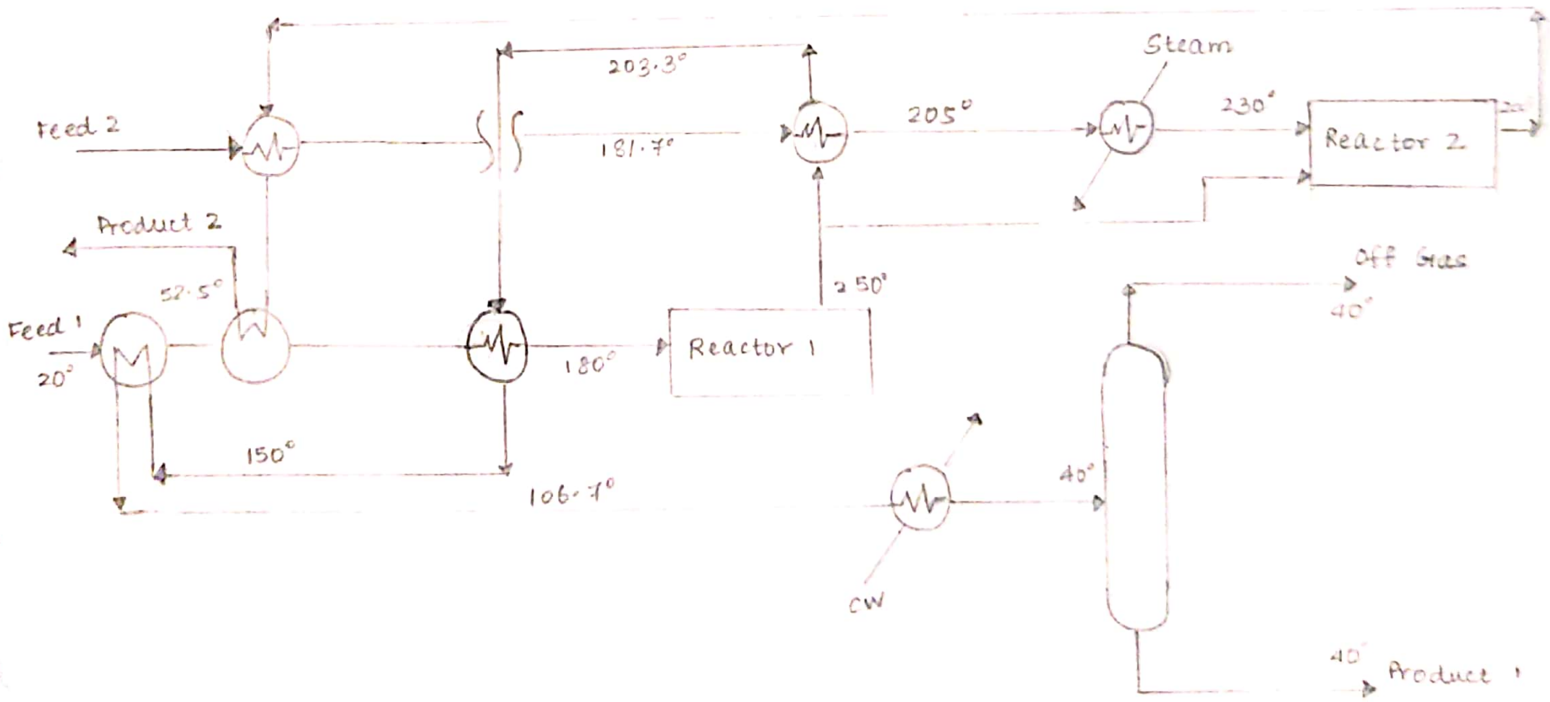
Stream	Type	Supply Temp. (T_s)	Target Temp. (T_t)	ΔH (MW)	Cp (MW °c^{-1})
Reactor 1 (Feed)	Cold	20°c	180°c	33.7	0.211
Reactor 1 (Product)	Hot	250°c	40°c	-31.7	0.151
Reactor 2 (Feed)	Cold	140°c	230°c	28.7	0.319
Reactor 2 (Product)	Hot	200°c	80°c	-34.7	0.289

For heating feed 2 from 140°c to 230°c, ΔH = 28.7 MW °c^{-1}

For heating feed 1 from 20°c to 180°c, ΔH = 33.7 MW °c^{-1}

For cooling reactor 2 outlet stream from 200°c to 80°c, ΔH = -34.7 MW °c^{-1}

For cooling reactor 2 outlet stream from 250°c to 40°c, ΔH = -31.7 MW °c^{-1}



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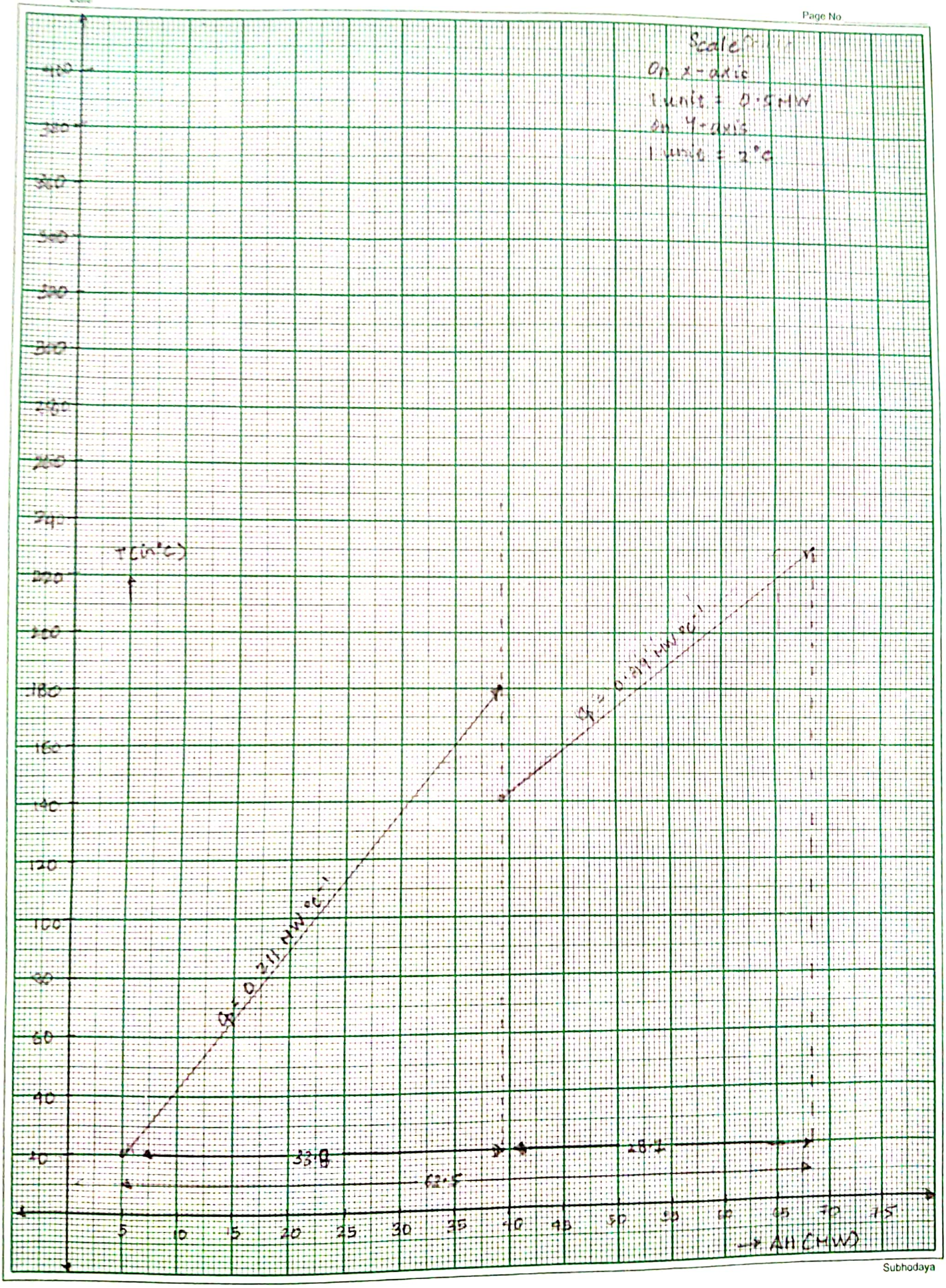

Subhodaya

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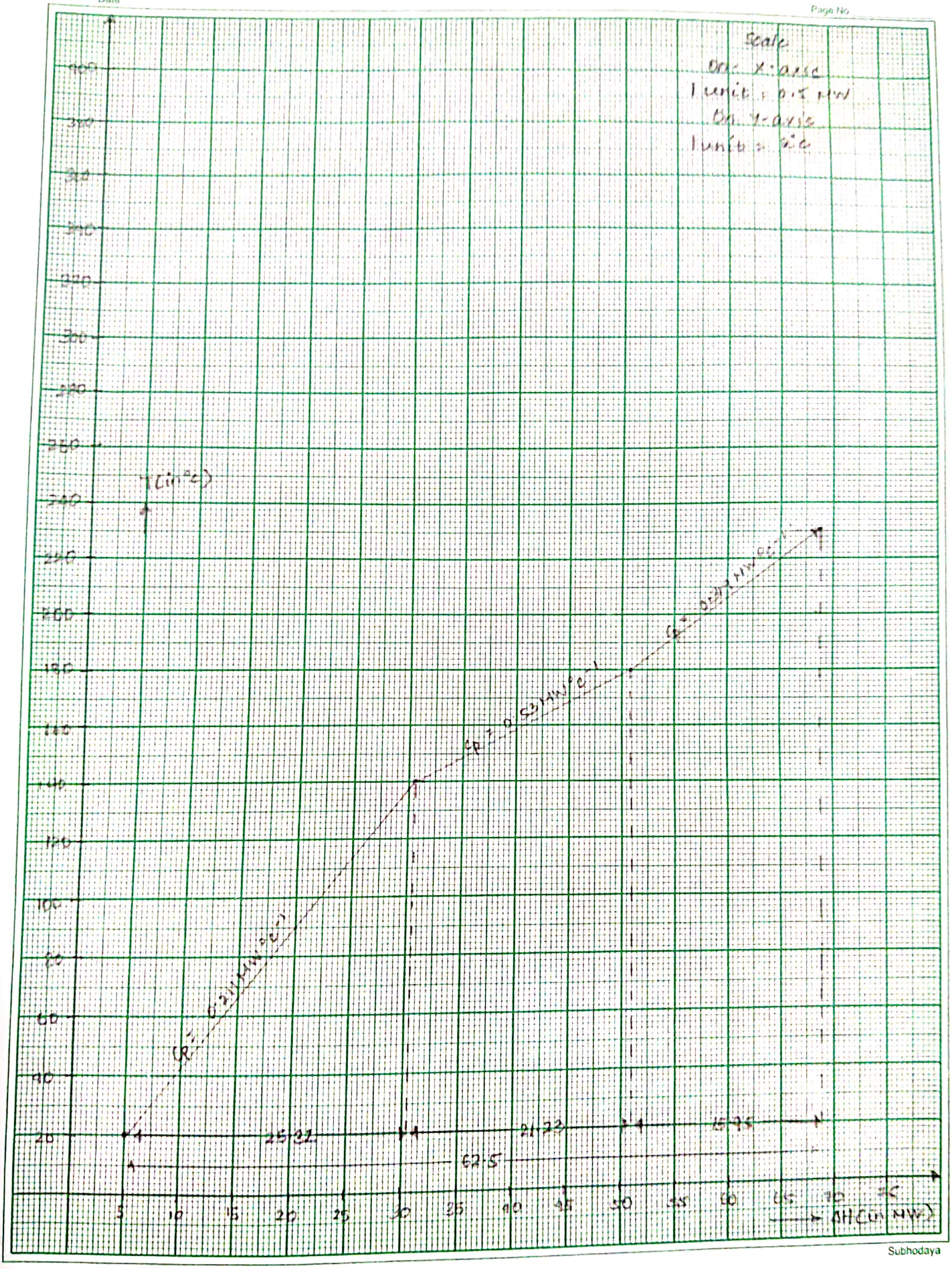

Subhodaya

25.32
21.2

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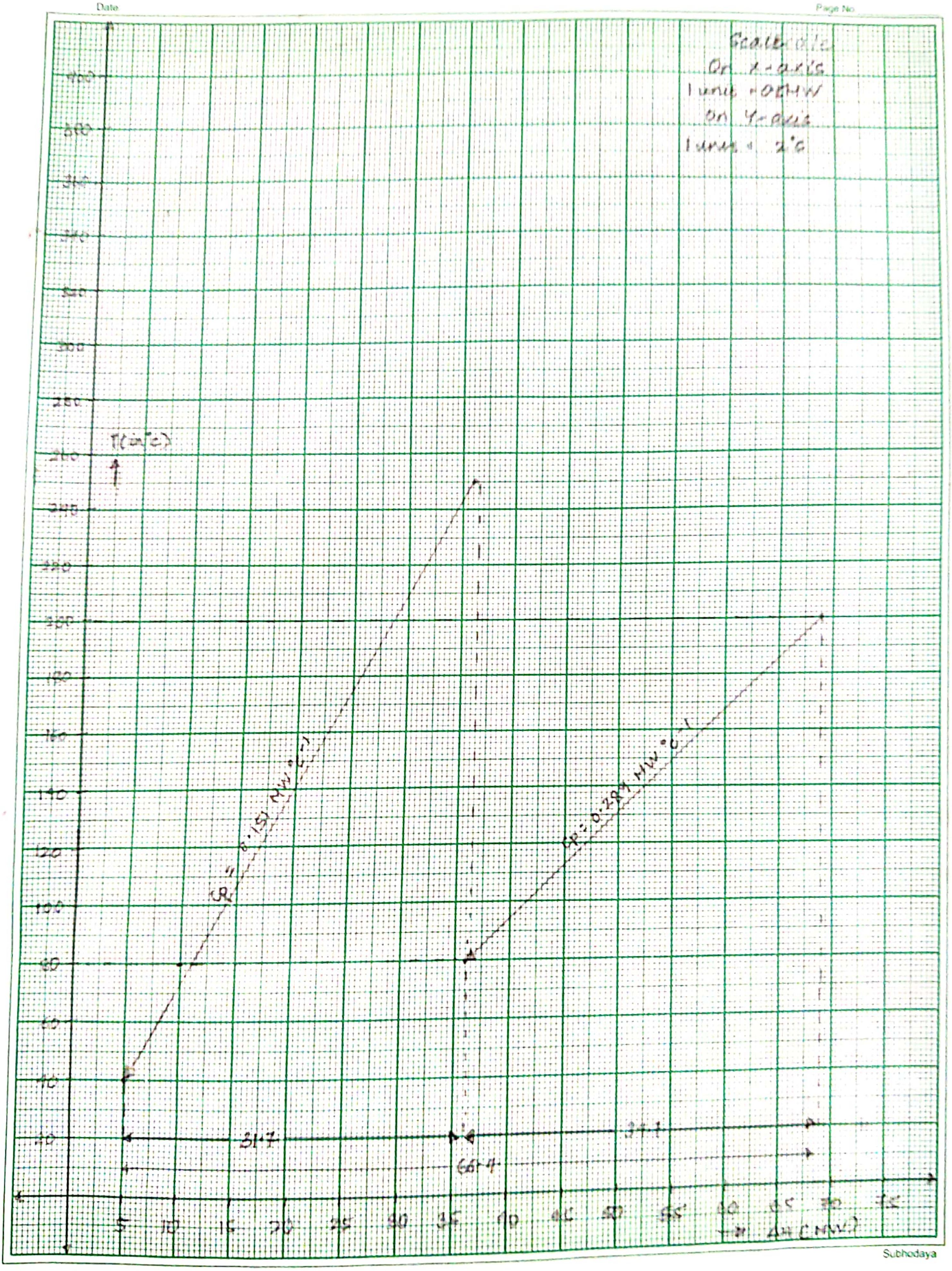

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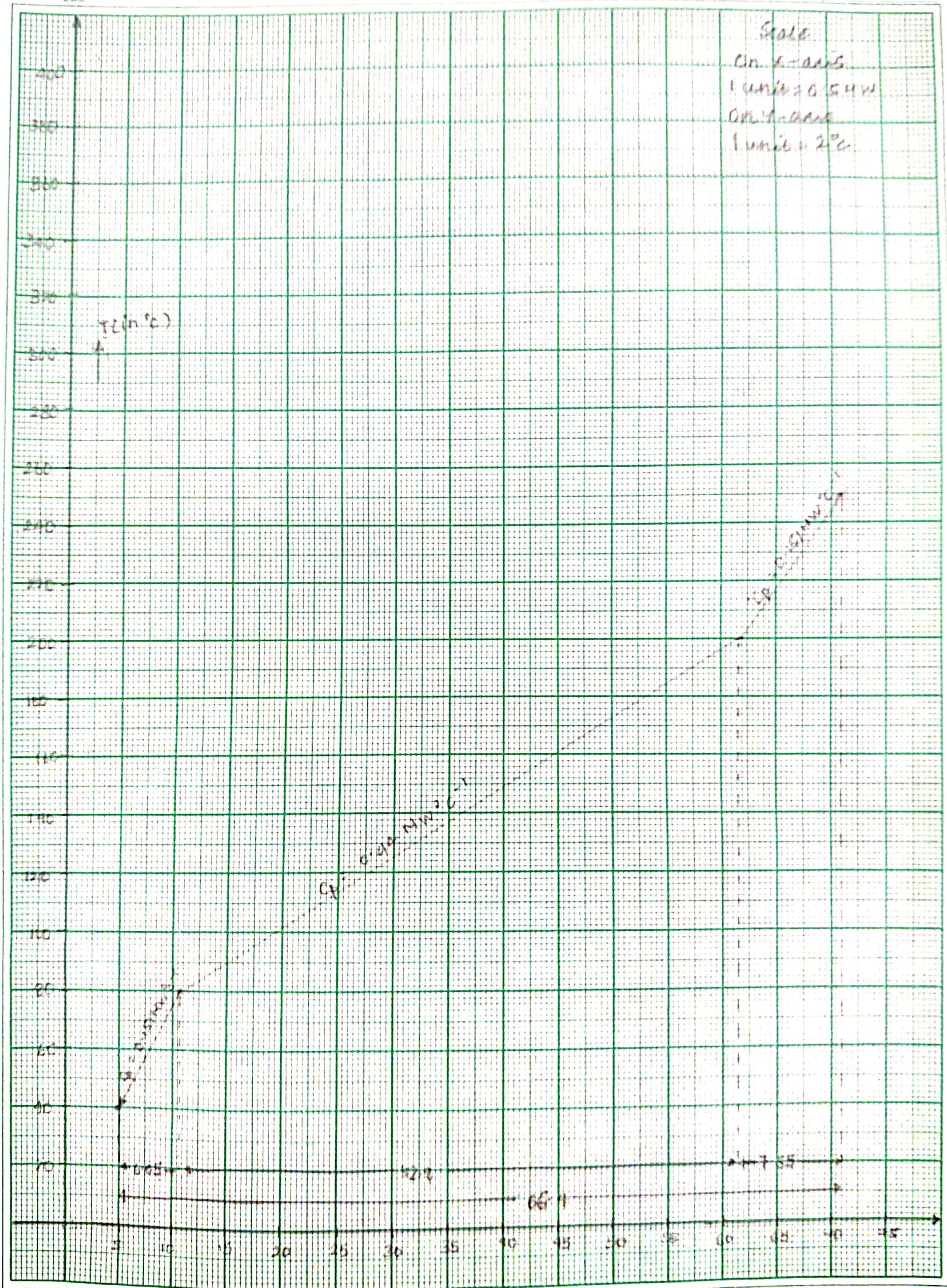

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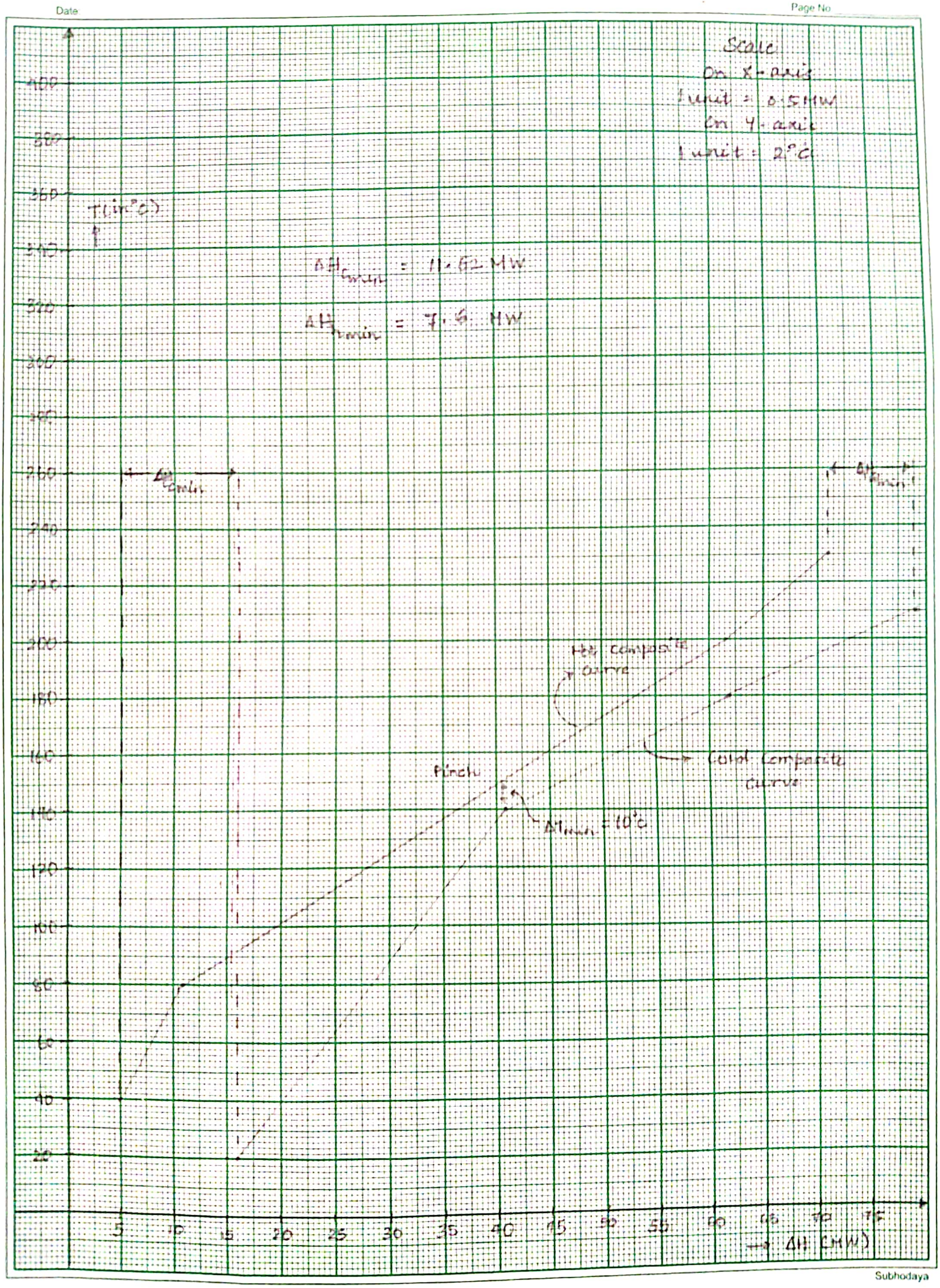

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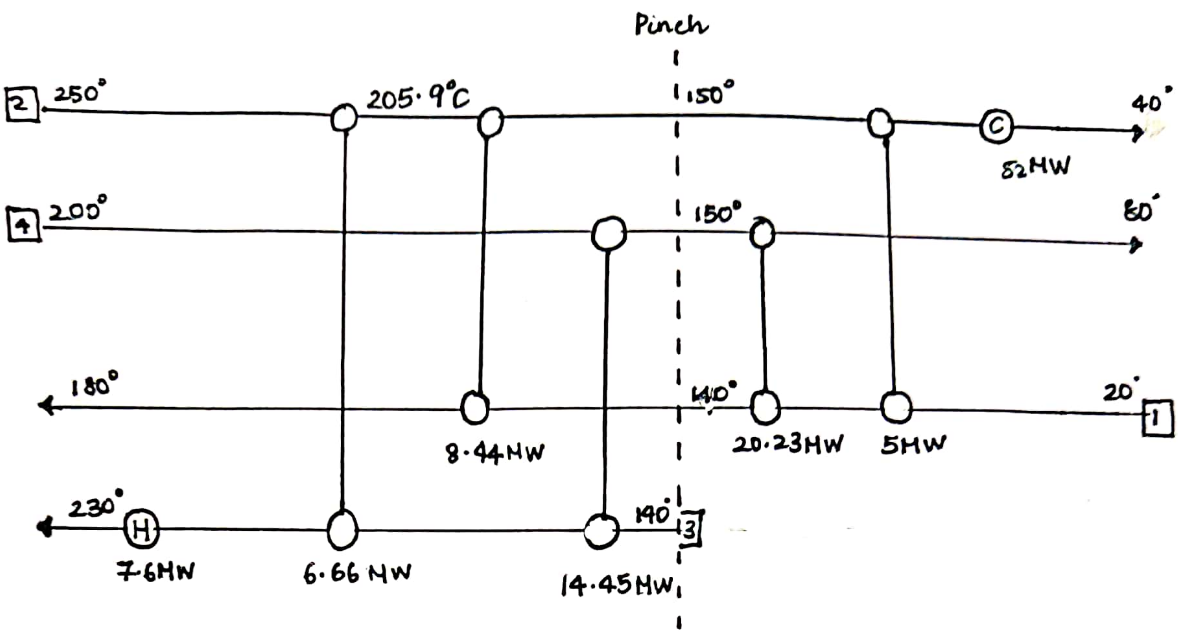
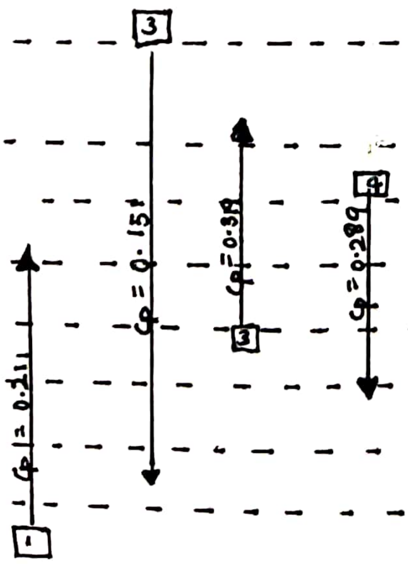


Shifting the curve by $\Delta T_{min}/2$ (5°C)

Stream	Type	T_S	T_T	T_S^*	T_T^*
1	Cold	20	180	25	185
2	Hot	250	40	245	35
3	Cold	140	230	145	235
4	Hot	200	80	195	75

All the temperatures are in °C

Interval Temp.	Stream Population	$\Delta T_{interval}$ (°C)	$\Sigma Cp_C - \Sigma Cp_H$ (MW °C^{-1})	ΔH (MW)	surplus/ Deficit
245					
		10	-0.151	-1.51	Surplus
235					
		40	0.168	6.72	Deficit
195					
		10	-0.121	-1.21	Surplus
185					
		40	0.09	3.6	Deficit
145					
		70	-0.229	-16.03	Surplus
75					
		40	0.06	2.4	Deficit
35					
		10	0.211	2.11	Deficit
25					



Hot Utility

245°C ↓ 0 MW

ΔH = -1.51

235°C ↓ 1.51 MW

ΔH = 6.72

195°C ↓ -5.21 MW

ΔH = -1.21

185°C ↓ -4 MW

ΔH = 3.6

145°C ↓ -7.6 MW

ΔH = -16

75°C ↓ 8.4 MW

ΔH = 2.4

35°C ↓ 6 MW

ΔH = 2.11

25°C ↓ 3.89 MW

Cold Utility

Hot Utility

245°C ↓ 7.6 MW

ΔH = -1.51

235°C ↓ 9.11 MW

ΔH = 6.72

195°C ↓ 2.39 MW

ΔH = -1.21

185°C ↓ 3.6 MW

ΔH = 3.6

145°C ↓ 0 MW

ΔH = -16.03

75°C ↓ 16.03 MW

ΔH = 2.4

35°C ↓ 13.63 MW

ΔH = 2.11

25°C ↓ 11.52 MW

Cold Utility

Stream	Supply Temp (°c)	Target Temp (°c)	ΔH (MW)	Cp (MW °c^{-1})	Film heat transfer co-eff (MW m^{-2} K^{-1})
Reactor 1 feed	20	180	33.7	0.211	0.0006
Reactor 1 pdt.	250	40	-31.7	0.151	0.0010
Reactor 2 feed	140	230	28.7	0.319	0.0008
Reactor 2 pdt.	200	80	28.7	0.289	0.0008
Stream	240	239	7.6	7.6	0.0030
Cooling water	20	30	11.52	1.152	0.0010

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Balanced Hot Composite Data

Temperature	Stream	Population	$\Delta T_{int.}$	ΣC_p	ΔH	$\Sigma \Delta H$
40						
			40	0.151	6.04	6.04
80						
			120	0.44	52.8	58.84
200						
			39	0.151	5.89	64.73
239						
			1	7.751	7.75	72.48
240						
			10	0.151	1.51	74
250						

Balanced Cold Composite Data

Temperature	Stream	Population	ΔT_{int}	ΣC_p	ΔH	$\Sigma \Delta H$
20						
			10	1.363	13.63	13.63
30						
			110	0.211	23.21	36.84
140						
			40	0.53	21.2	58.04
180						
			50	0.319	15.95	74
230						

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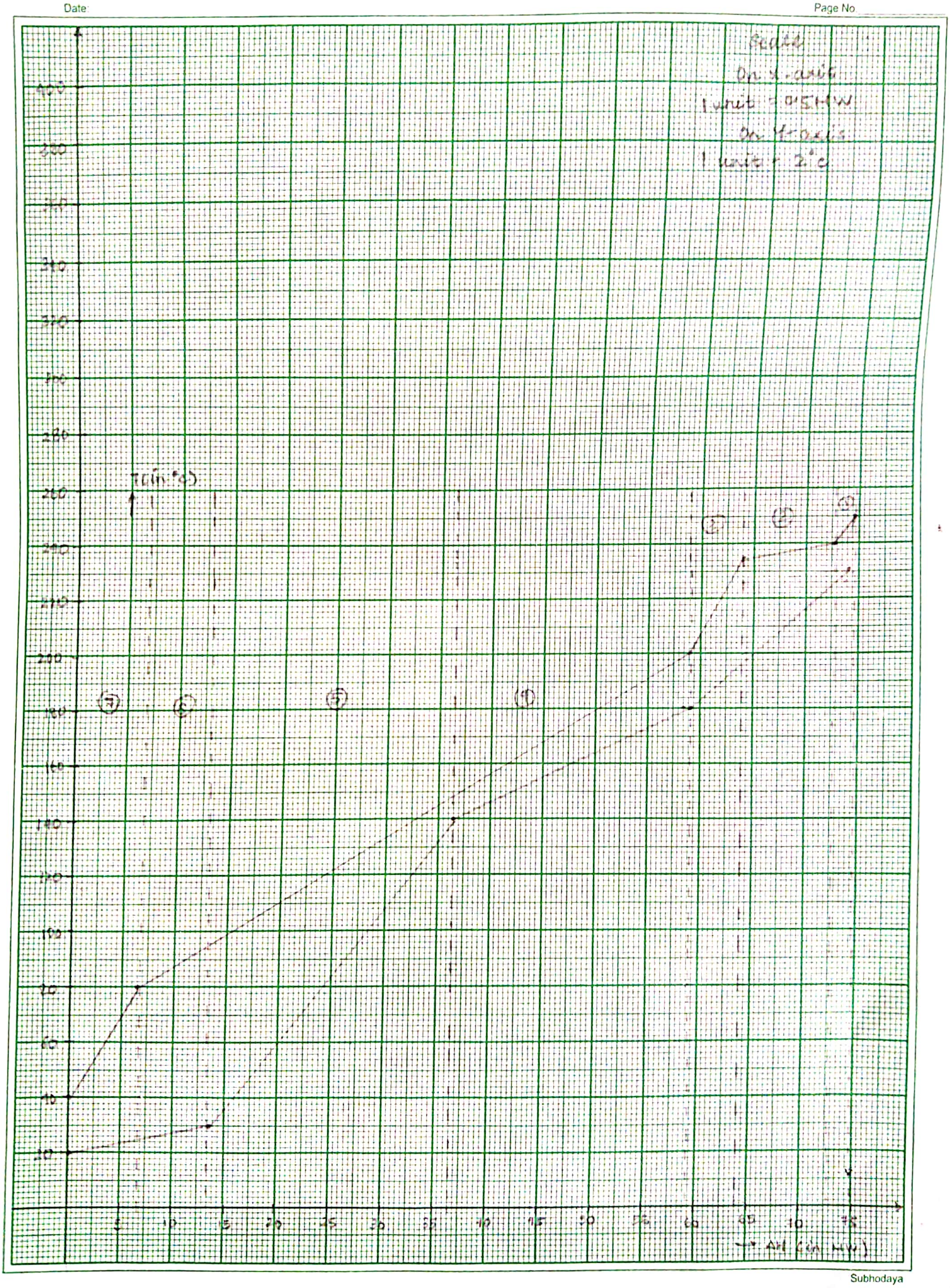

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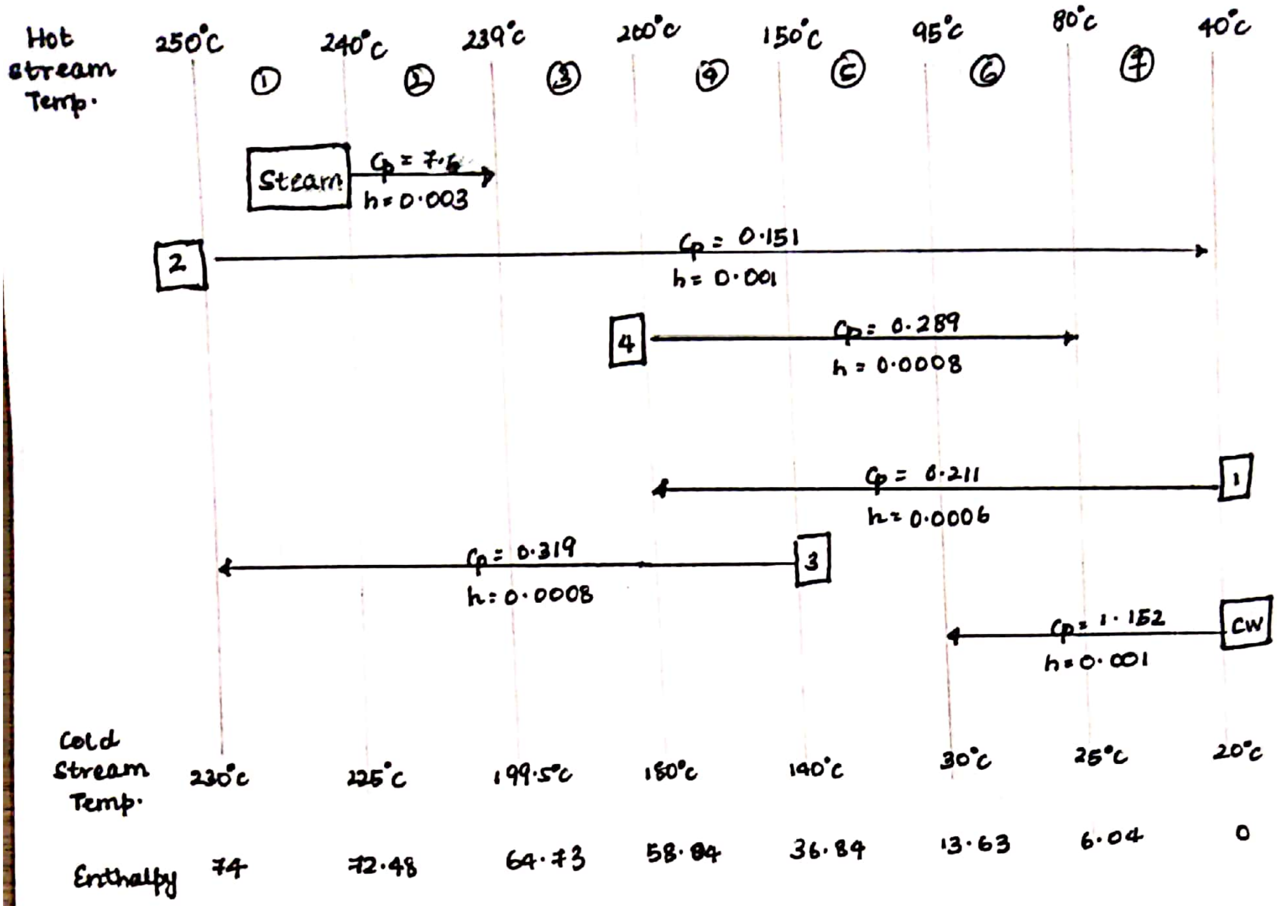

Enthalpy Interval	ΔT_{LMTD}	$\Sigma(q_i/h_i)_h$ (Hot streams)	$\Sigma(q_i/h_i)_c$ (Cold streams)	A_k
1	17.38	1510	1993.75	201.80
2	25.30	2684.83	10168.125	508.00
3	28.65	5889	7775.625	476.95
4	14.43	25612.5	30016.67	3855.11
5	29.38	28173.75	38683.33	2275.5
6	59.86	2561.25	7518.33	168.39
7	34.60	6040	7518.33	391.86

$\Sigma A_k = 7877.509$

$$\text{Area} = \frac{1}{\Delta T_{LMTD}} \left(\sum_h q/h + \sum_c q/h \right)$$

Price of steam = Rs 1.58 / kg

Price of cooling water = Rs 11.1 / 1000 kg

Steam (MJ/kg) = 2.26

water (MJ/kg) = 4.187×10^{-2}

Assuming that there are total 300 working days and 10hrs use of heat exchanger network per day

Total running time = $300 \times 10 \times 3600 = 1.08 \times 10^{7}$ sec

Steam utility = Steam Price / steam Energy * Running Time

= Rs 7550442.48 /MW/year

water utility = water Price / water Energy * Running Time

= Rs 2863147.84 /MW year

Steam utility price = 7500442.48 * 7.6 = Rs 57003362.85 /year

water utility price = 2863147.84 * 11.52 = Rs 32983462.66 /year

Annulaized Capital Cost

a = 3012799.99 , b = 37660 , c = 1

Number of units = (Streams above pinch + Streams below pinch - 2)

= 5+4-2 = 7

Raw cost = $N\left(a + b(\text{area}/N)^{c}\right)$

= 7 (3012799.99 + 37660 (7877.51 / 7))

= Rs 317756626.6 /year

Interest (i) = 10% Time period (n) = 5 years

Annunity factor = $1-(1+i)^{-n}/I$ = 3.791

Cost = Raw cost * Annunity factor

= Rs 1204615371 /year

Total Cost = Rs 1294602197 / year

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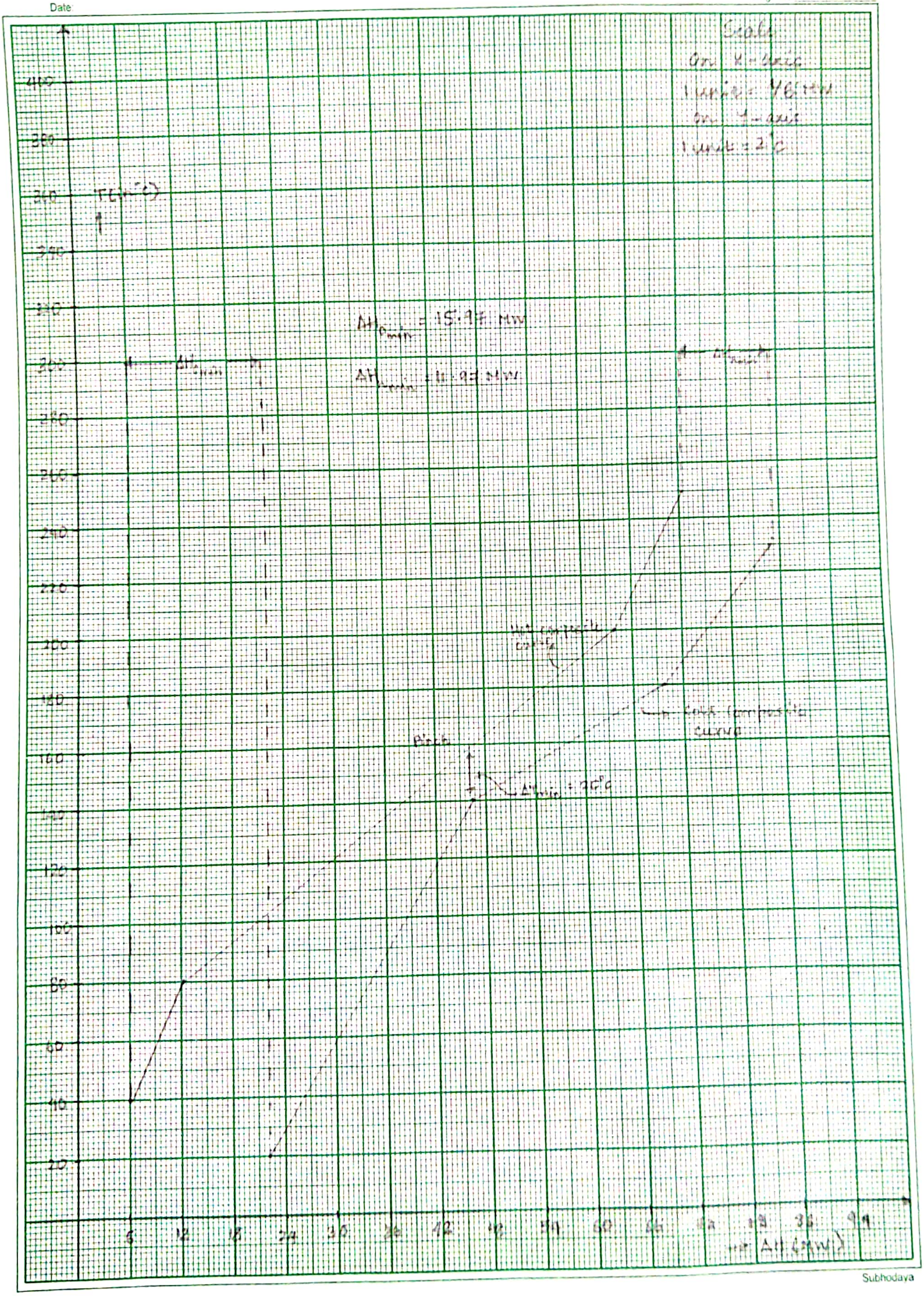

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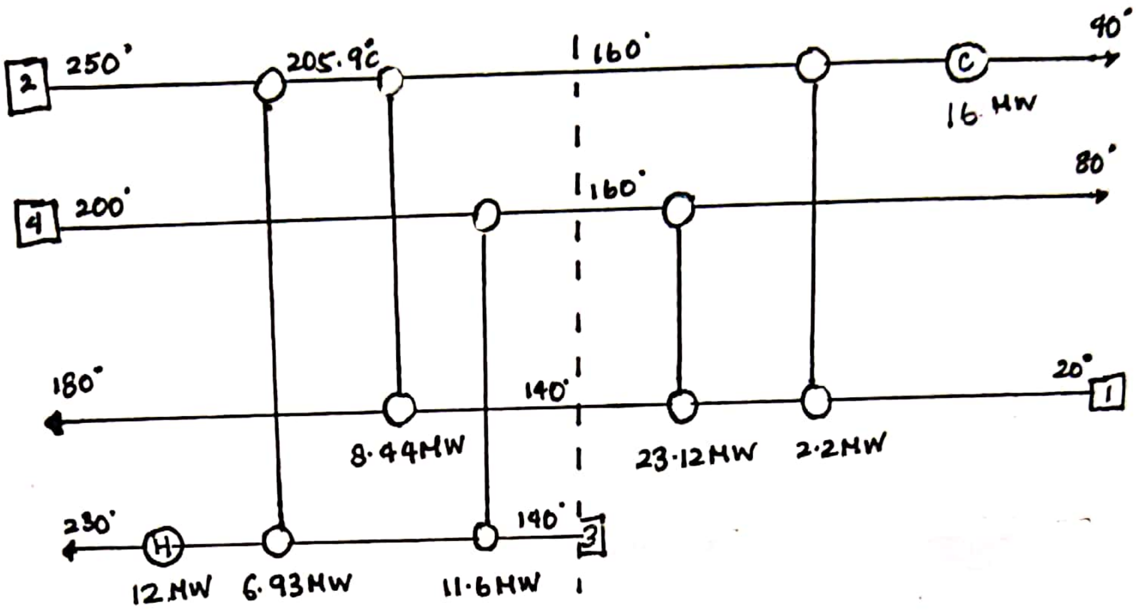
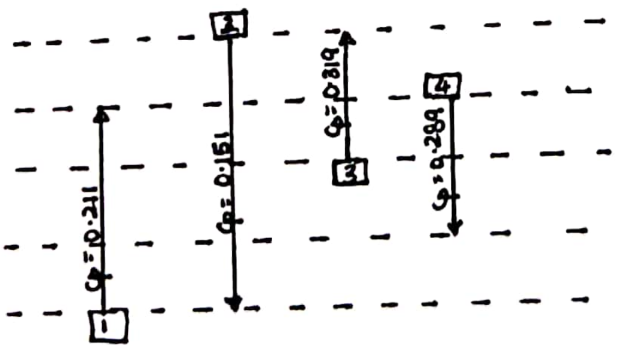


Shifting the curve by $\Delta T_{min}/2$ ($10^\circ C$)

Stream	Type	T_S	T_T	T_S^*	T_T^*
1	Cold	20	180	30	190
2	Hot	250	40	240	30
3	Cold	140	230	150	240
4	Hot	200	80	190	70

All the temperatures are in °c

Interval Temp	Stream Population	$\Delta T_{interval}$	ΣCp	ΔH	Surplus/ Deficit
240					
		50	0.168	8.4	Deficit
190					
		40	0.09	3.6	Deficit
150					
		80	-0.229	-18.32	Surplus
70					
		40	0.06	2.4	Deficit
30					



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Hot Utility

↓ 0 MW

$\Delta H = +8.4$

↓ -8.4 MW

$\Delta H = 3.6$

↓ -12 MW

$\Delta H = -18.32$

↓ 6.32 MW

$\Delta H = 2.4$

↓ 3.92 MW

Cold Utility

Hot Utility

↓ 12 MW

$\Delta H = 8.4$

↓ 3.6 MW

$\Delta H = 3.6$

↓ 0 MW

$\Delta H = -18.32$

↓ 18.32 MW

$\Delta H = 2.4$

↓ 16 MW

Cold Utility

Stream	Supply Temp (°C)	Target Temp (°C)	ΔH (MW)	Cp (MW °C^{-1})	Film heat transfer co-eff (MW m^{-2} °C^{-1})
Reactor 1 feed	20	180	33.7	0.211	0.0006
Reactor 1 pdt.	250	40	-31.7	0.151	0.0010
Reactor 2 feed	140	230	28.7	0.319	0.0008
Reactor 2 pdt.	200	80	-34.7	0.289	0.0008
Steam	240	239	12	12	0.0030
Cooling water	20	30	16	1.6	0.0010

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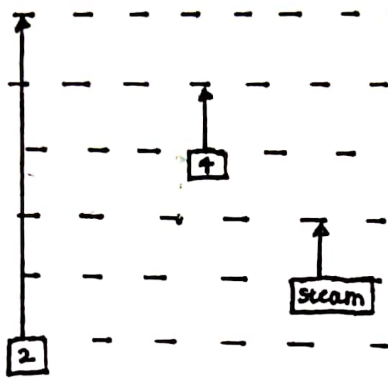
Balanced Hot Composite Data

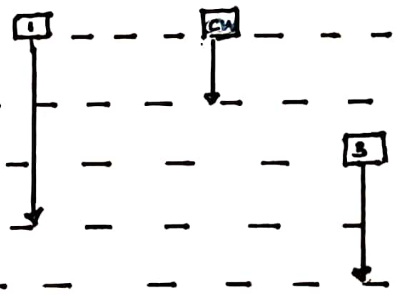
Stream Population



Temperature	ΔT_{int}	ΣCp	ΔH	$\Sigma \Delta H$
40				
	40	0·151	6·04	6·04
80				
	120	0·44	52·8	58·84
200				
	39	0·151	5·89	64·73
239				
	1	12·151	12·151	76·88
240				
	10	0·151	1·51	78·4
250				

Balanced Cold Composite Data

Stream Population



Temperature	ΔT_{int}	ΣCp	ΔH	$\Sigma \Delta H$
20				
	10	1·811	18·11	18·11
30				
	110	0·211	21·10	39·21
140				
	40	0·53	21·2	60·41
180				
	50	0·319	15·95	78·4
230				

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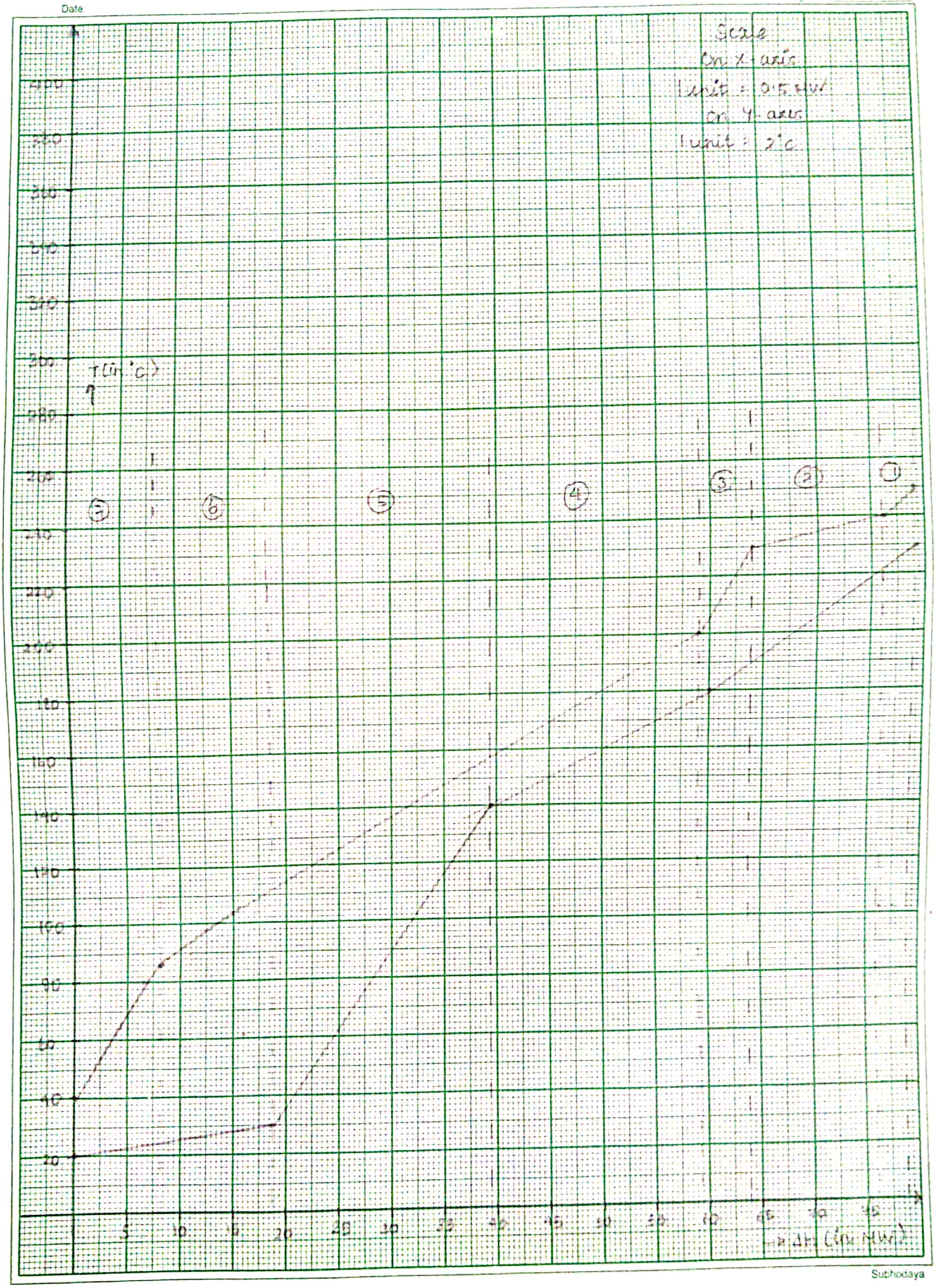
Date



Subhodaya

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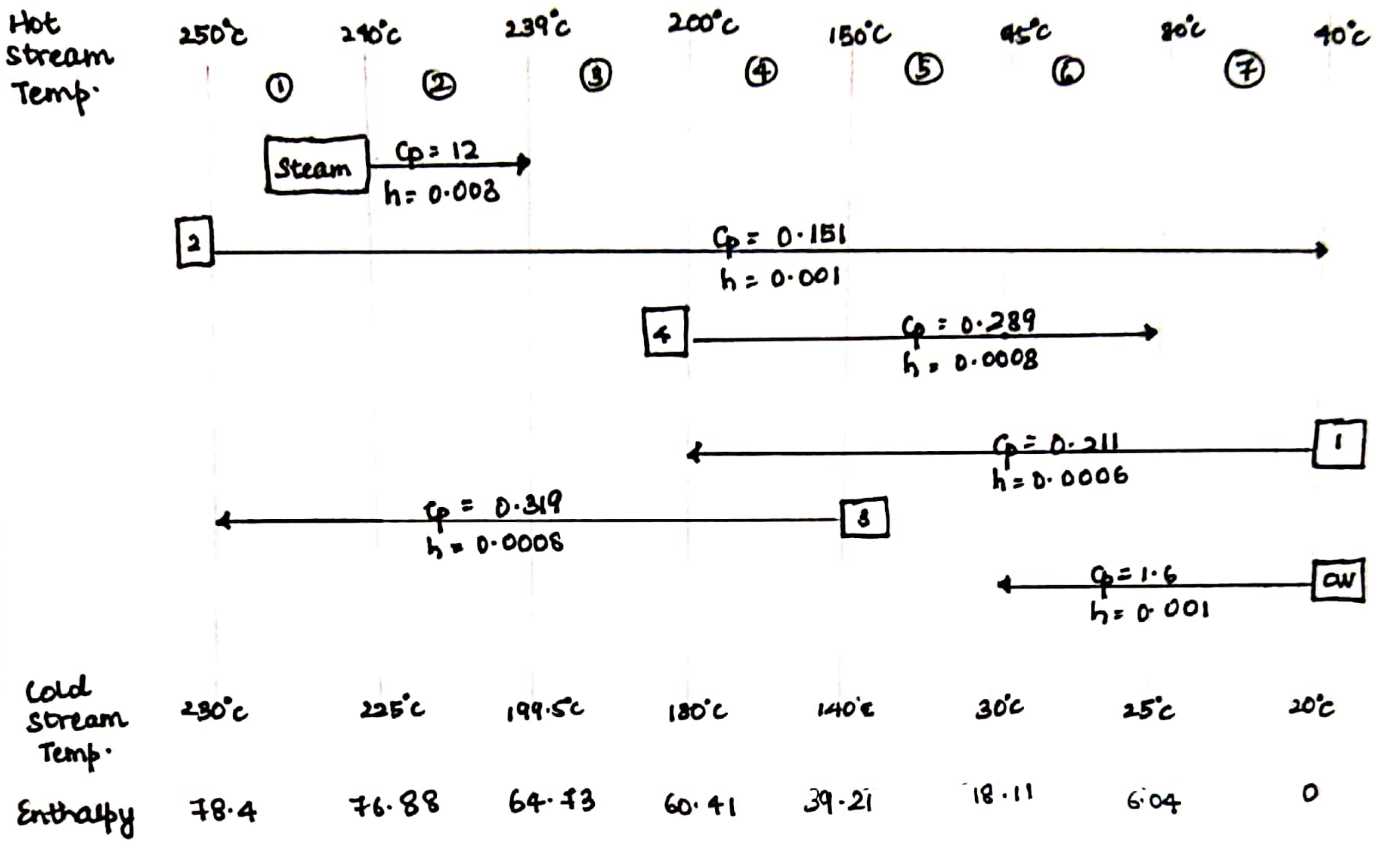

Enthalpy Interval	ΔT_{LMTD}	$\Sigma (q_i/h_i)_h$ (Hot streams)	$\Sigma (q_i/h_i)_c$ (Cold streams)	A_k
1	17.38	1510	1993.75	201.60
2	25.30	4151	10168.125	565.97
3	28.65	5889	7775.625	476.95
4	14.43	25612.5	30016.67	3855.11
5	29.38	28173.75	38683.33	2275.60
6	59.86	2561.25	9758.33	205.81
7	34.60	6040	9758.33	456.60

$\Sigma A_k = 8037.64$

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Price of steam = Rs 1.53 / kg

Price of cooling water = Rs 11.1 / 1000 kg

Steam (MJ/kg) = 2.26

water (MJ/kg) = 4.187×10^{-2}

Assuming that there are total 300 working days and 10 hrs of use of heat exchanger network per day.

Total running time = $300 \times 10 \times 3600 = 1.08 \times 10^7$ sec

Steam Utility = Steam Price / Steam Energy * Running Time

= Rs 7550442.48 / MW year

water Utility = Water Price / water Energy * Running Time

= Rs 2863147.84 / MW year

Steam Utility price = 7550442.48×12 = Rs 90605309.76 / year

Water utility price = 2863147.84×16 = Rs 45810365.48 / year

Annualized Capital Cost

a = 3012799.99, b = 37660, c = 1

Number of unit = (Streams above pinch + streams below pinch − 2)

= 5 + 4 − 2 = 7

Raw cost = $N(a + b(\text{area}/N)^c)$

= 7 (3012799.99 + 37660 (5571.19 / 7))

= Rs 230900615.3 / year

Interest (i) = 10%   Time period (n) = 5 years

Annunity factor = $1 - (1+i)^{-n} / I$ = 3.791

Cost = Raw cost * Annunity factor

= 230900615.3×3.791 = Rs 875344232.7 / year

Total Cost = Rs 1011759908

∴ The cost when $\Delta T_{min} = 10°C$ is more compared to when $\Delta T_{min} = 20°C$

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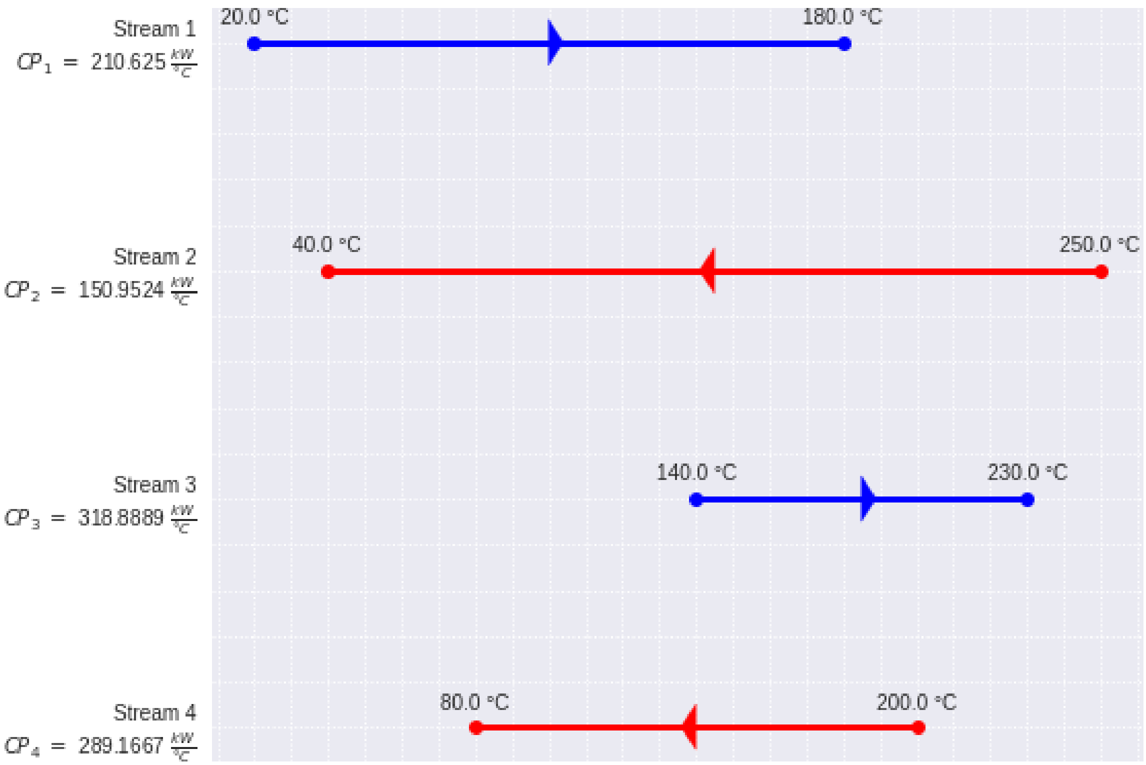
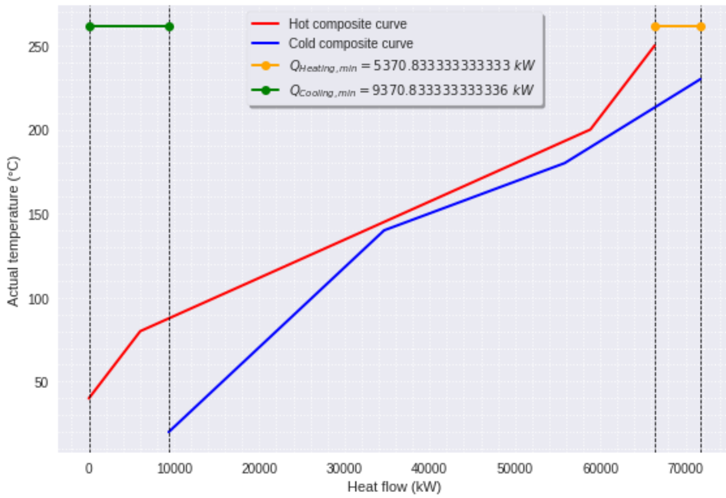
Stream Information	Supply Temperture (°C)	Target Temperature (°C)	Heat Load (MW)
Stream 1	20	180	33.7
Stream 2	250	40	-31.7
Stream 3	140	230	28.7
Stream 4	200	80	-34.7

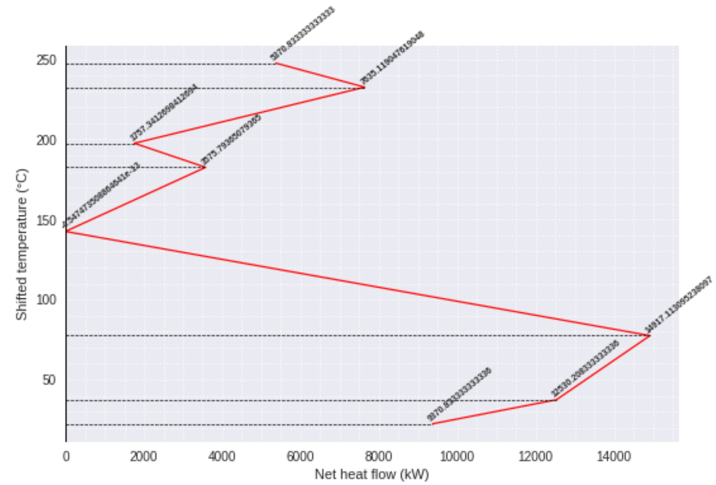


For $\Delta T_{min} = 5^0C$

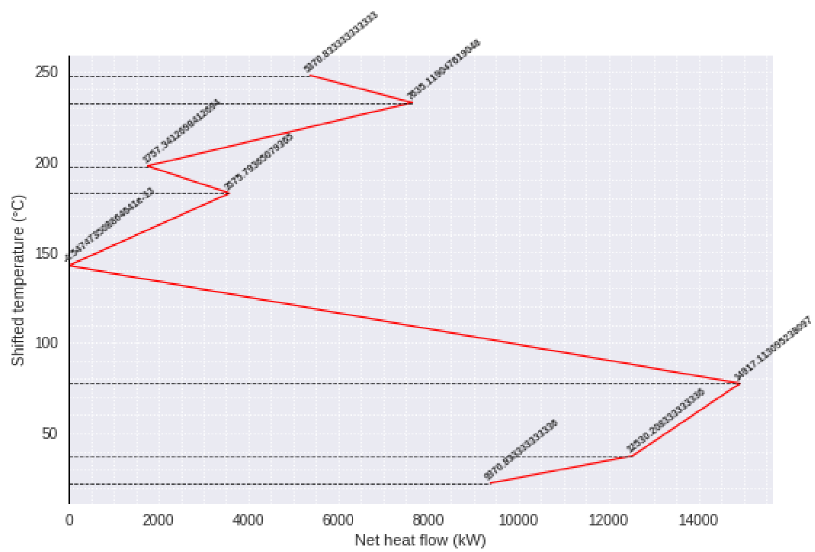
Composite Curve



Grand Composite Curve

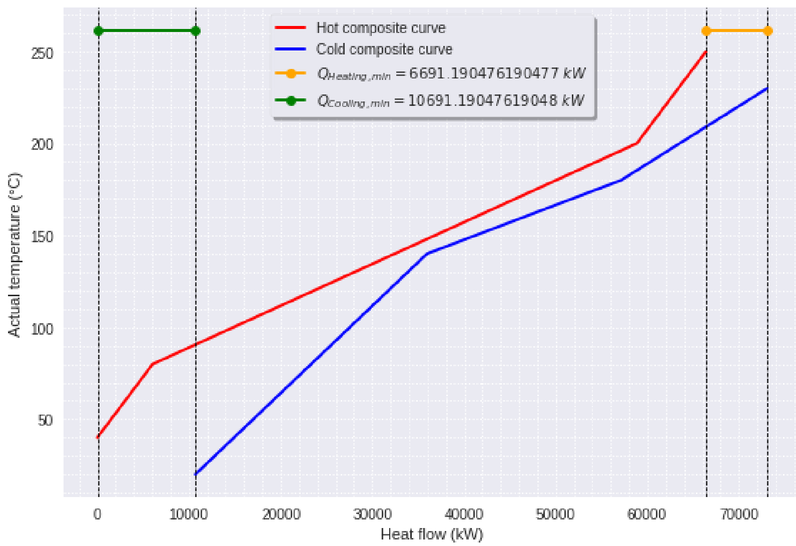


Intervals

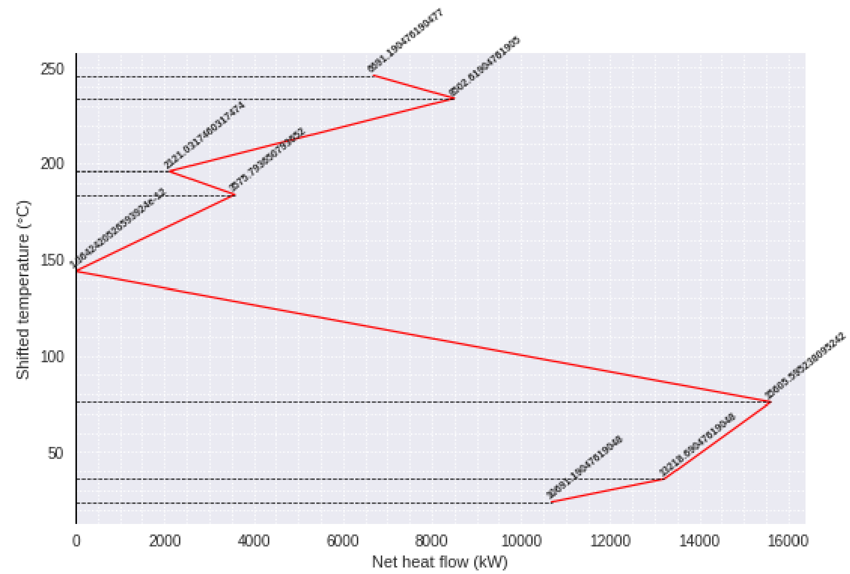


For $\Delta T_{min} = 8^0C$

Composite Curve



Grand Composite Curve



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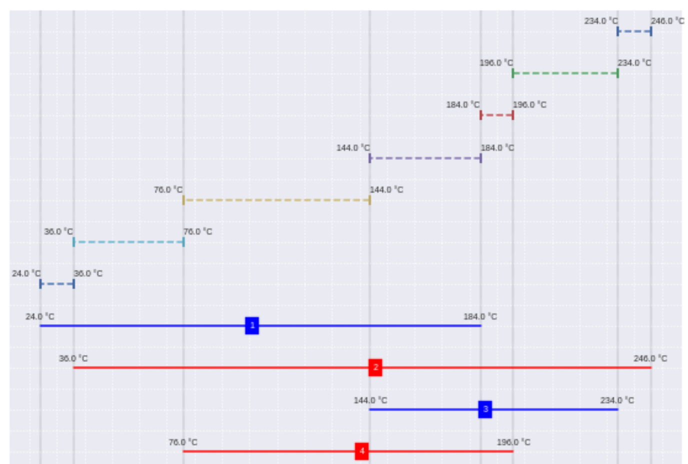
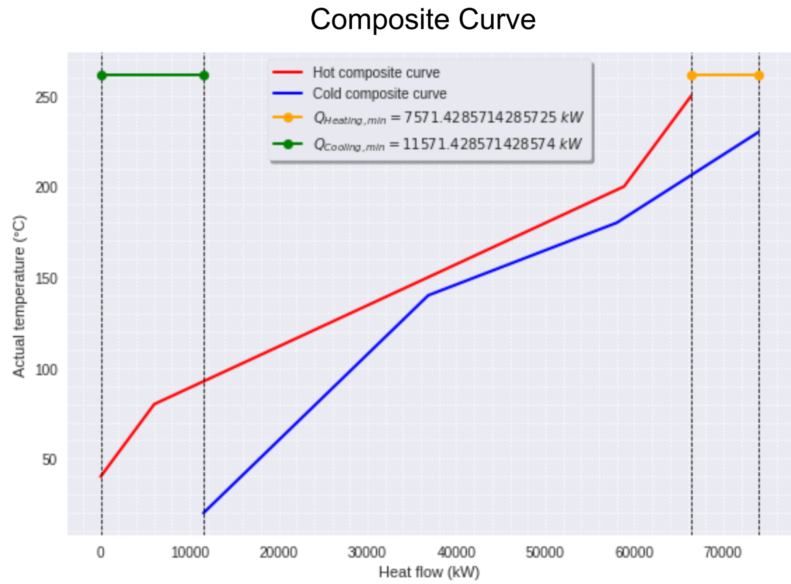
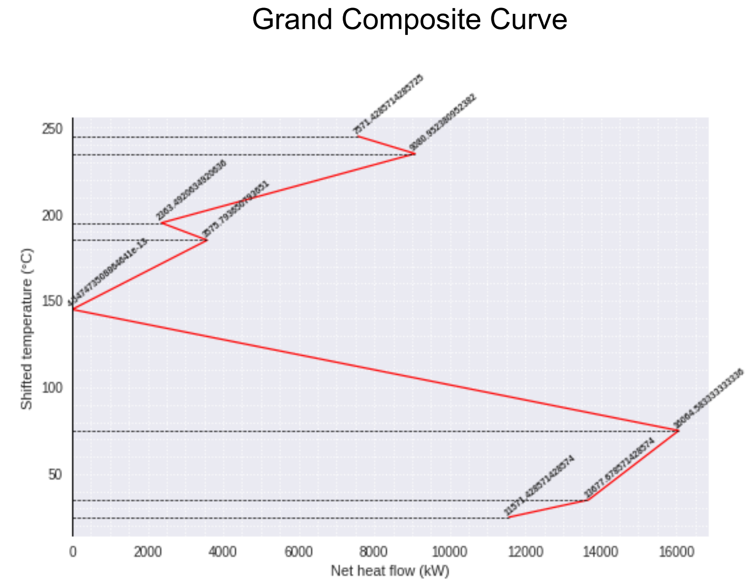
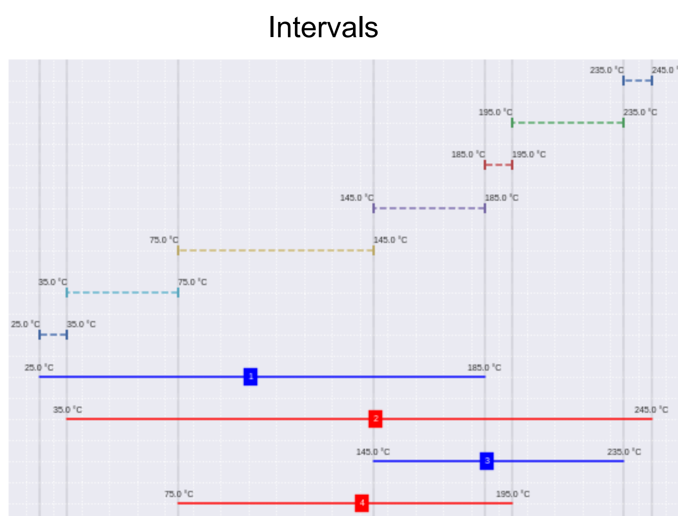


For $\Delta T_{min} = 10^0C$

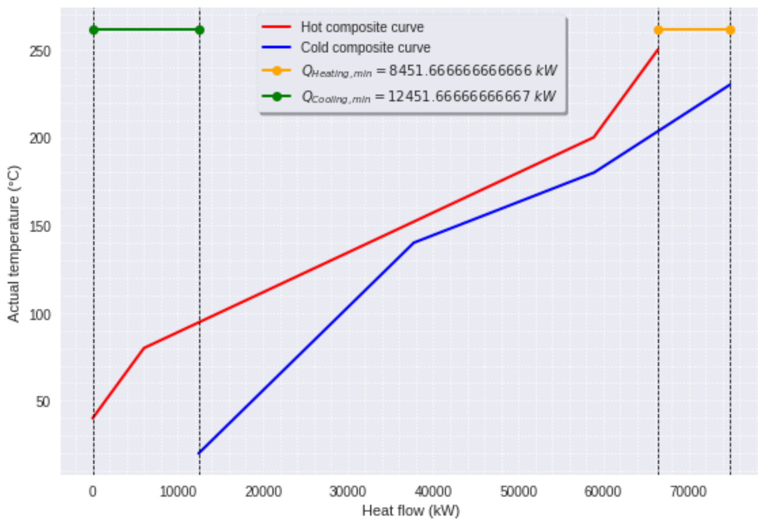




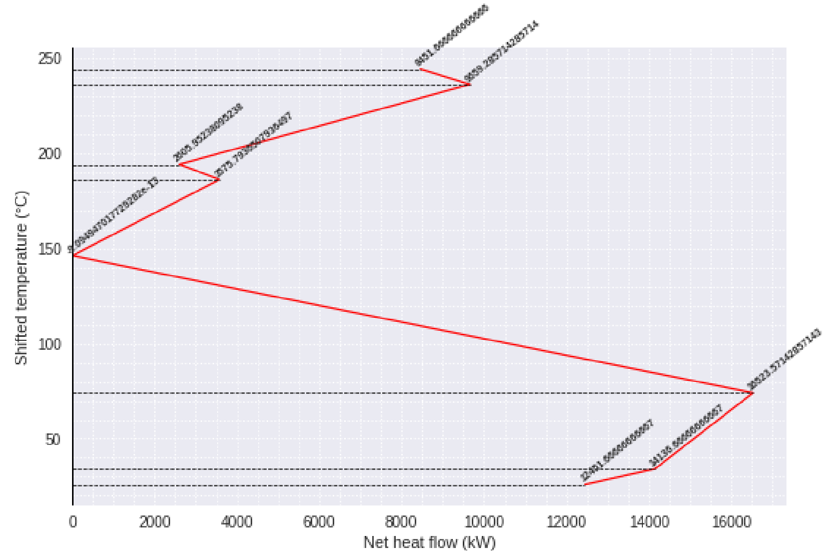


For ΔT_{min} = 12^0C

Composite Curve



Grand Composite Curve



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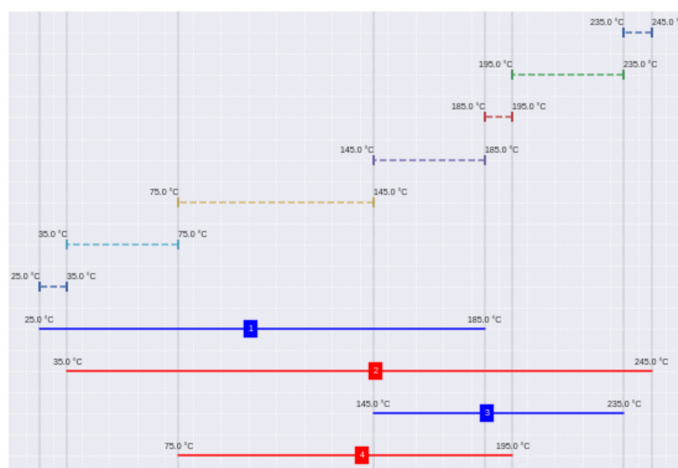
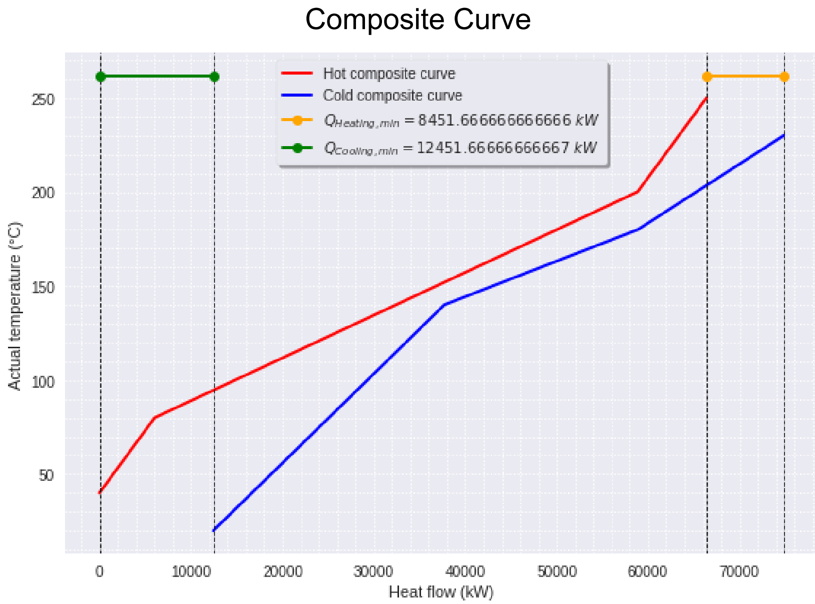
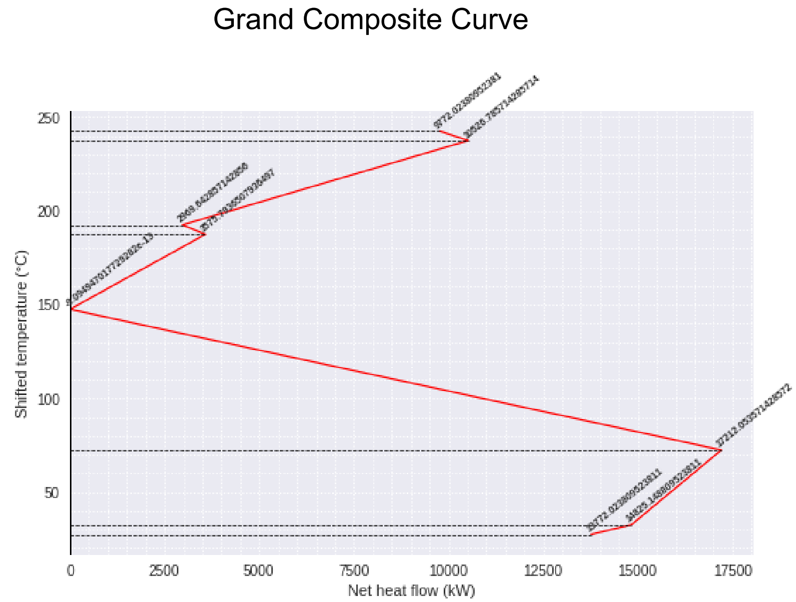
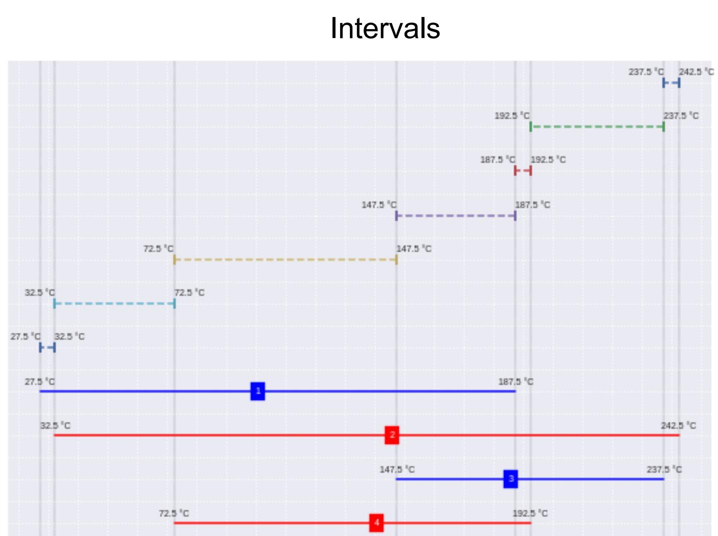


For $\Delta T_{min} = 15^0C$

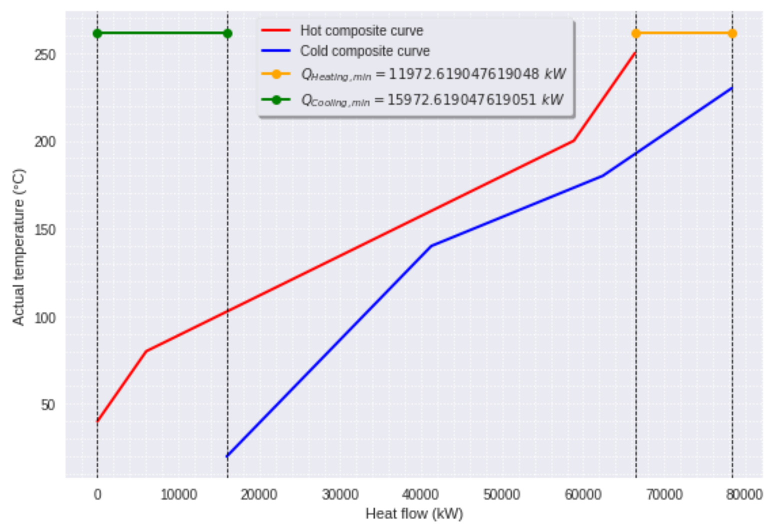




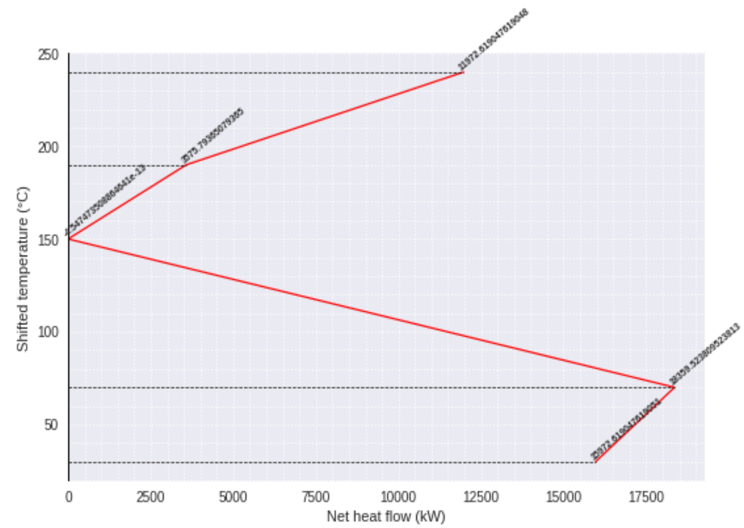


For ΔT_{min} = 20^0C

Composite Curve



Grand Composite Curve



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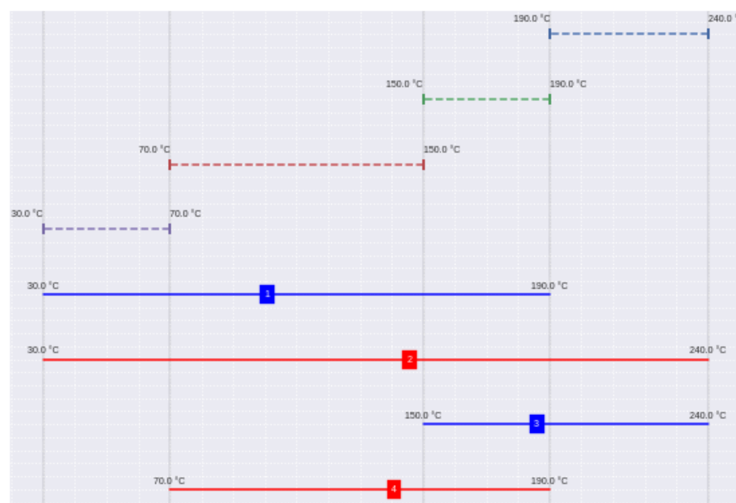

	ΔT_{min} = 10^0C	ΔT_{min} = 20^0C
Hot Utility target	7.6	12
Cold Utility target	11.52	16
Area Target	7877.51	8037.64
Amount for Steam Utility	7550442.48	90605309.76
Amount for Water Utility	2863147.84	4581036548
Annuity Cost	1204615371	875344232.7
Total Cost	1294602197	1011759908

Discussion

As we can see that the hot and cold utility requirement are less for ΔT_{min}= 10°C as compared to ΔT_{min}= 20°C this is because the overlap of the cold and hot composite curve is more for ΔT_{min}= 10°C on temperature vs ΔH plot as shown earlier. So we can conclude that as Tmin increases, effective heat transfer through the heat exchanger decreases, hot and cold utility requirements increases.

As we can see that the area required for constructing the heat exchanger is less for ΔT_{min}= 20°C as compared to ΔT_{min}= 10°C this is because the fact that area required is inversely proportional to the temperature difference in a given heat exchanger.

Out of the two choices of ΔT_{min}= 10°C and ΔT_{min}= 20°C, we would prefer ΔT_{min}= 20°C because the total annualized cost is less for ΔT_{min}= 20°C and for the effective heat transfer through the heat exchanger the hot stream should be hotter by at least 10 degrees than the cold stream and for our choice it is valid.

Resources

1) Process Heat Transfer Principles and Applications by Robert. W. Sarat
2) Process Heat Transfer by D.Q.Kern
3) Equipment Sizing and Capital Cost Estimation by Warren D. Seider, University of Pennsylvania
4) Chemical Technology An Indian Journal Vol. 11 Issue 2 (2016)
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