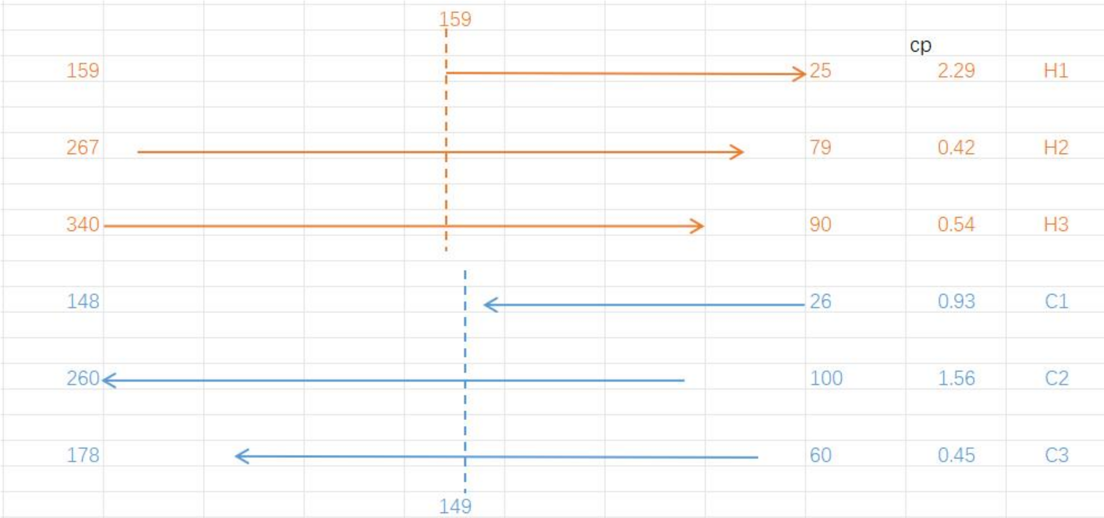
	H1	H2	H3		C1	C2	C3
Fcp[kW/C]	2.29	0.42	0.54	Fcp[kW/C]	0.93	1.56	0.45
Tin[C]	159	267	340	Tin[C]	26	100	60
Tout[C]	25	79	90	Tout[C]	148	260	178

Use The Pinch Design Method to obtain a Heat Exchanger Network and relax the network to obtain one less exchanger.

Use the HRAT obtained using Supertargetingin Homework #2.

From HW2, **the optimal HRAT is 10 C**.

0)draw the streams together with hot or cold pinch.



a)above the pinch. **The rules: cpH<=cpC; NH<=NC**

Let's split C2 into 2 parts.

As the $\Delta Q_{C2} = 173.16\ \mathrm{kW}$, greater than the sum of ΔQ_{H3} and ΔQ_{H2}, 143.1 kW, so just let one of the split be able satisfy the work requirement of the matched cold as well as hot streams.

Meanwhile the two split streams must obey the cp inequations.

After trial and error, we finally split C2 into cp=0.88 matched with H3 and cp=0.68 matched with H2.

Now the result is that, the work of H2, H3 and the split stream matched with H3 are satisfied.

The rest streams to be satisfied by heating utlity are calculated below:

cp=0.68 matched with H2: from ($149 + \frac{45.36}{0.68} = 215.76$) C to 260 C.

C3: from 149 C to 178 C.

The steps that **failed** to get a feasible solution:

H3 - C2 with H2 - C3

$\Delta Q_{H3} = 0.54 \times (340 - 159) = 97.74\ \mathrm{kW}$

$\Delta Q_{C2} = 1.56 \times (260 - 149) = 173.16\ \mathrm{kW}$

$\Delta Q_{H3} < \Delta Q_{C2}$ -> H3's work is satisfied.

The rest for C2's work is from ($149 + \frac{97.74}{1.56} = 211.65$) C to 260 C.

$\Delta Q_{H2} = 0.42 \times (267 - 159) = 45.36\ \mathrm{kW}$

$\Delta Q_{C3} = 0.45 \times (178 - 149) = 13.05\ \mathrm{kW}$

$\Delta Q_{H2} > \Delta Q_{C3}$ -> C3's work is satisfied.

The rest for H2's work is from ($159 + \frac{13.05}{0.42} = 190.07$) C to 267 C.

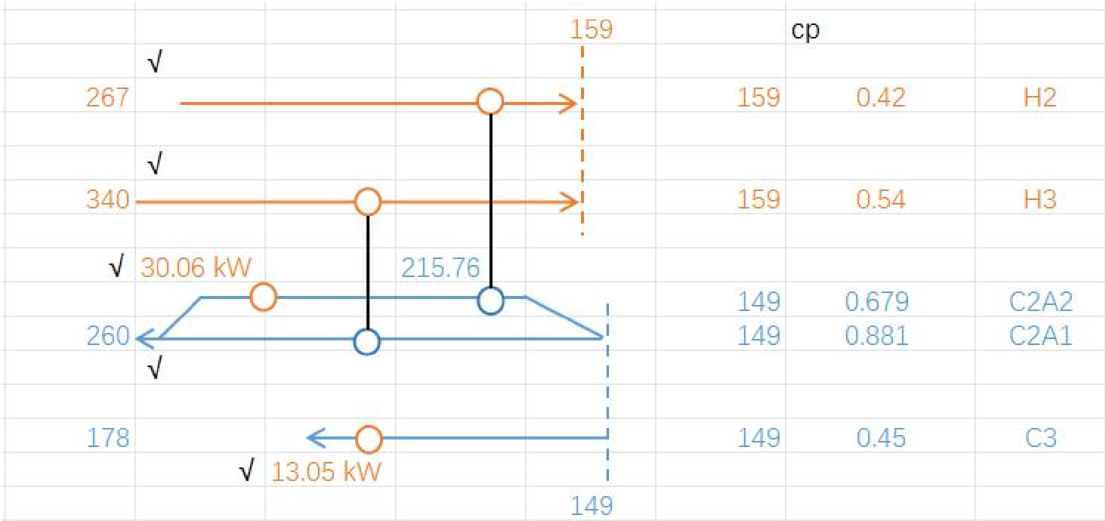
Now let's get the rest H2 and C2 matched.

And we found that the updated starting T of C2 is 211.65 C, which is even larger than the updated starting T of H2, 190.07.

This really violates the heat transfer rules.

So we have to restart to get a feasible solultion.

Let's now draw the network above the pinch.



b)below the pinch. **The rules: cpH>=cpC; NH>=NC**

$\Delta Q_{H1} = 2.29 \times (159 - 25) = 306.86 \text{ kW}$

$\Delta Q_{H2} = 0.42 \times (159 - 79) = 33.6 \text{ kW}$

$\Delta Q_{H3} = 0.54 \times (159 - 90) = 37.26 \text{ kW}$

$\Delta Q_{C1} = 0.93 \times (148 - 26) = 113.46 \text{ kW}$

$\Delta Q_{C2} = 1.56 \times (149 - 100) = 76.44 \text{ kW}$

$\Delta Q_{C3} = 0.45 \times (149 - 60) = 40.05 \text{ kW}$

There is one solusion after trial and error.

Because the most restricted location is at the pinch, if we don't split H1, just one streams and matches H1 with different cold streams at decreasing T, the minimum temperature difference will certainly never obey the HRAT. So H1 must be splited.

For the same reasons, I do not like to just use one cold stream of a large cp without spliting it.

C1 split into C1B1 matched with H3 that the two streams are satisfied, and C1B2 matched with one of split H1.

C2 matched with one of split H1.

C3 split into C3B1 matched with H2 that the two streams are satisfied, and C3B2 matched with one of split H1.

C1B1 - H3 : cp of C1B1 $= \frac{37.26}{148-26} = 0.305$ -> the rest cp, cp of C1B2 = 0.93 - 0.305 = 0.625

C3B1 - H2 : cp of C3B1 $= \frac{33.6}{149-60} = 0.378$ -> the rest cp, cp of C3B2 = 0.45 - 0.378 = 0.072

First for C1B2 - split H1, H1B1 : to obey the HRAT rule, the final T of H1B1 must >= (26+10) = 36 C

So just pick 36 C as the final T of H1B1 : cp of H1B1$= \frac{113.46-37.26}{159-36} = 0.620$

For C2 - split H1, H1B2 : also pick the allowable minimum final T of H1B2 -> 100+10 = 110 C

cp of H1B2$= \frac{76.44}{159-110} = 1.56 =$cp of C2

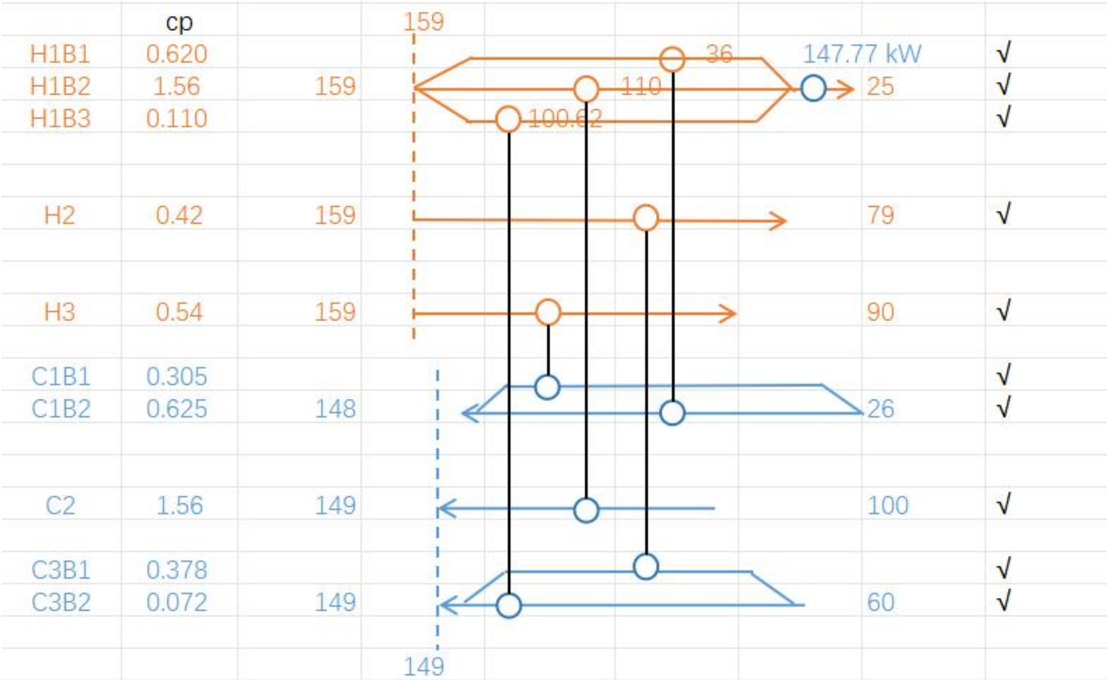
-> the rest cp, cp of H1B3 = 2.29 - 0.620 - 1.56 = 0.110 > 0.072, cp of C3B2 -> obey the rule of cp

Now we have all the streams except for the three split streams of H1 satisfied.

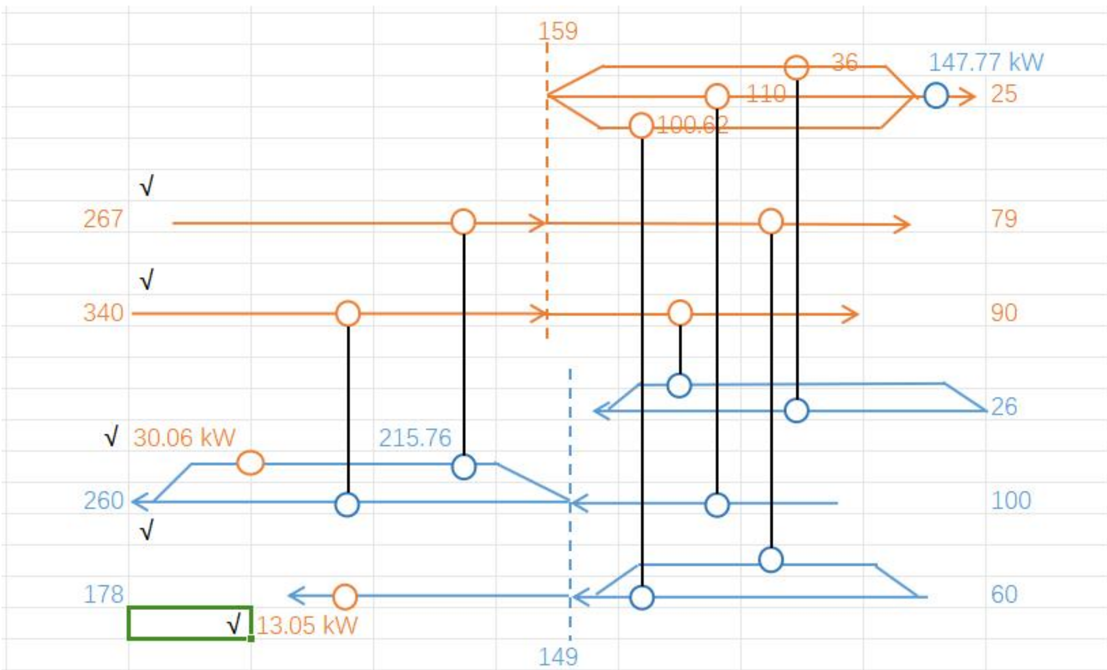
Let's calculate the final T of H1B3, as the final T of last two streams is defined earlier.

The final T of H1B3 : $T = 159 - \frac{40.05-33.6}{0.110} = 100.62$ C

Let's now draw the network below the pinch.



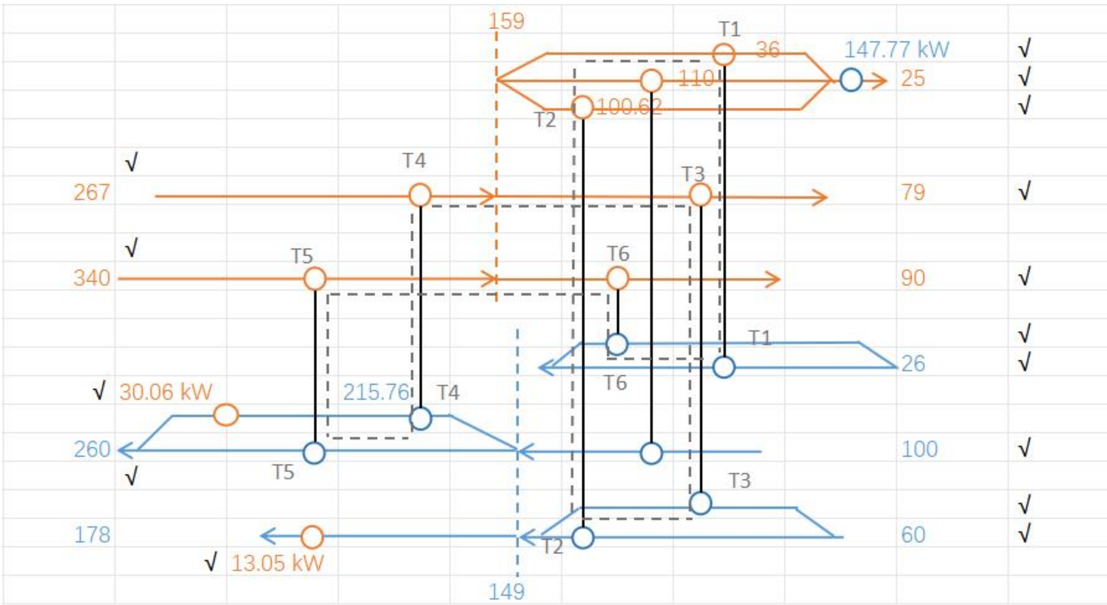
c)draw the whole network



d)relaxation with one random loop

As the graph shown below, there are 6 exchangers are involved.

By calculation, the original energy of each exchanger is listed below.



exchanger	T1	T2	T3	T4	T5	T6
energy	76.2	6.45	33.6	45.36	97.74	37.26

So the X will be 6.45, and the shifting Qs of each exchange are :

T1' = 76.2+X = 82.65 kW

T2' = 6.45-X = 0 -> T2 is removed

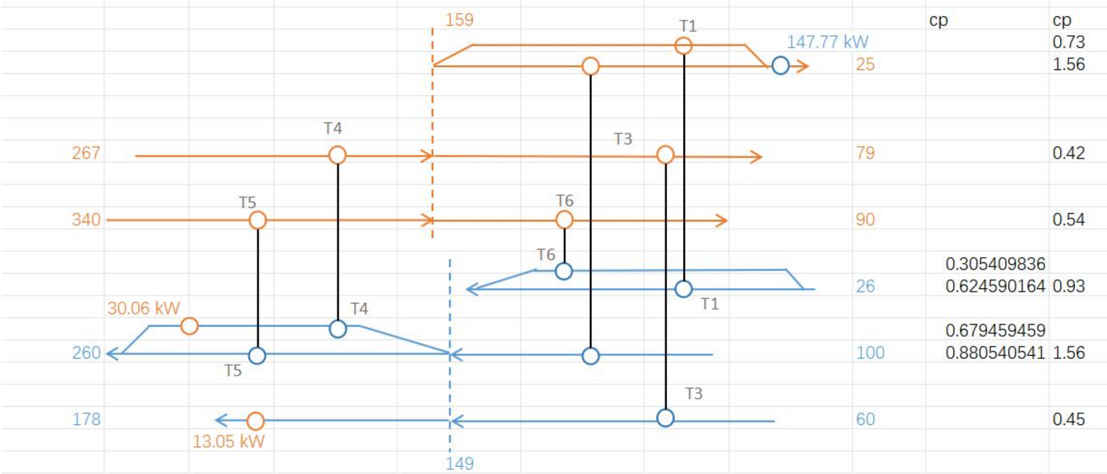
T3' = 33.6+X = 40.05 kW

T4' = 45.36-X = 38.91 kW

T5' = 97.74+X = 104.19 kW

T6' = 37.26-X = 30.81 kW

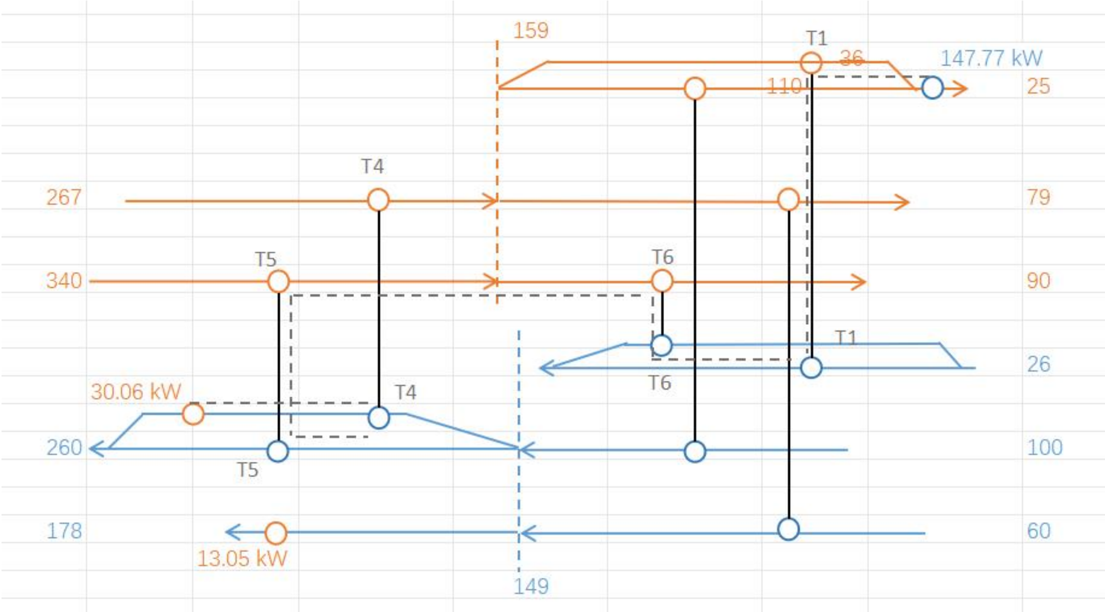
So the updated network is drawn below.



e)recalculate the network temperatures and identify any violations of HRAT = 10 C

	THhigh	THlow	TChigh	TClow	dThigh	dTlow	violation
T1	159	45.78	158.33	26	0.67	19.78	yes
T3	174.36	79.00	149.00	60.00	25.36	19.00	no
T4	267.00	174.36	215.76	158.49	51.24	15.86	no
T5	340.00	147.06	260.00	141.67	80.00	5.38	yes
T6	147.06	90.00	126.88	26.00	20.17	64.00	no

f)restore the original HRAT = 10 C throughour the network by exploiting a utility path



Hot utility : 147.77+Q

T1 : 82.65-Q

T6 : 30.81+Q

T5 : 104.19-Q

Cold utility 1 : 30.06+Q

	THhigh	THlow	TChigh	TClow
T1	159	(147.77+Q-(110-25)*1.56) /0.73+25	26+(82.65-Q)/ 0.625	26
T6	90+(30.81+Q) /0.54	90	26+(30.81+Q)/ 0.305	26
T5	340	340-(104.19-Q)/0.54	260	260-(104.19-Q)/0.88

We can get System of inequalities.

$$\begin{cases} 159 - (26 + (82.65 - Q)/0.625) \geq 10 \\ (147.77 + Q - (110 - 25) * 1.56)/0.73 + 25 - 26 \geq 10 \\ 90 + (30.81 + Q)/0.54 - 26 - (30.81 + Q)/0.305 \geq 10 \\ 340 - (104.19 - Q)/0.54 - 260 + (104.19 - Q)/0.88 \geq 10 \end{cases}$$

The result is $\begin{cases} Q \geq 5.82 \\ Q \geq -7.14 \\ Q \leq 7.15 \\ Q \geq 6.45 \end{cases}$, so pick Q = 6.45.

Then the Hot utility : 147.77+Q = 154.22; T1 : 82.65-Q = 76.2; T6 : 30.81+Q = 37.26;

T5 : 104.19-Q = 97.74; Cold utility 1 : 30.06+Q = 36.51

f)calculate the temperature interval of each exchanger

cp		T decreasing		
0.73	H1B1	159	54.34	25
1.56	H1B2	159	110	25
0.42	H2	267	174.36	79

0.54	H3	340	159	90
0.305	C1B1	148	26	
0.625	C1B2	148	26	
0.679	C2H1	260	206.27	149
0.881	C2H2	260	149	
1.56	C2	149	100	
0.45	C3	178	149	60

interval	T1	T3	T4	T5	T6	Trest	HU1	HU2	CU
THhigh	159.00	174.36	267.00	340.00	159.00	159.00	360.00	360.00	92.34
THlow	54.62	79.00	174.36	159.00	90.00	110.00	340.00	340.00	25.00
TChigh	148.00	149.00	206.27	260.00	148.00	149.00	260.00	178.00	45.00
TClow	26.00	60.00	149.00	149.00	26.00	100.00	206.27	149.00	15.00
dT	11.00	25.36	60.73	80.00	11.00	10.00	100.00	182.00	47.34
	28.62	19.00	25.36	10.00	64.00	10.00	133.73	191.00	10.00
LMTD	18.43	22.03	40.50	33.66	30.10	10.00	116.05	186.46	24.02
Q	76.20	40.05	38.91	97.74	37.26	76.44	36.51	13.05	154.22
area	41.36	18.18	9.61	29.03	12.38	76.44	3.15	0.70	64.21
sum	255.06								

g)calculate the cost before and after relaxation

The cost before relaxation is just calculated in HW2.But after calculation, it's found that the results about the ideal minimum area of HW2 is not equal to the results of the exchanger network before relaxation. So let's compare the data of area and corresponding total cost of the heat exchanger network before and after relaxation.

Here is the data sheet of exchanger network **before relaxation** with N = 10.

interval	T1	T2	T3	T4	T5	T6	Trest	HU1	HU2	CU
THhigh	159.00	159	159.00	267.00	340.00	159.00	159.00	360.00	360.00	89.53
THlow	36.00	100.62	79.00	159.00	159.00	90.00	110.00	340.00	340.00	25.00
TChigh	148.00	149	149.00	215.76	260.00	148.00	149.00	260.00	178.00	45.00
TClow	26.00	60	60.00	149.00	149.00	26.00	100.00	215.76	149.00	15.00
dT	11.00	10.00	10.00	51.24	80.00	11.00	10.00	100.00	182.00	44.53
	10.00	40.62	19.00	10.00	10.00	64.00	10.00	124.24	191.00	10.00
LMTD	10.49	21.85	14.02	25.24	33.66	30.10	10.00	111.68	186.46	23.12
Q	76.20	6.45	33.60	45.36	97.74	37.26	76.44	30.06	13.05	147.77
area	72.63	2.95	23.96	17.97	29.03	12.38	76.44	2.69	0.70	63.92
sum	302.68									

Cost of Utility :

Qh_{min} = 43.11 kW = 4.09e-5 MMBTU/s 1 MMBTU=1054 MJ

$C_E = c_Q Qh_{min}$ = 30*4.09e-5 RMB/s = 1.23e-3 RMB/s c_Q = 30 RMB/MMBTU

$$F = \frac{Q}{cp \cdot \Delta T} = \frac{147.77}{4.187 \times (45-15)} \text{ kg/s} = 1.176 \text{ kg/s}$$

$Qc_{min} = \frac{F}{\rho} = \frac{1.176}{998.95}$ m^3/s =1.178e-3 m^3/s = 0.259 Gallon/s 1 Gallon = 4.546 L

$C_{cw} = c_w Qc_{min}$ = 20*0.259e-3 RMB/s =5.18e-3 RMB/s c_w = 20 RMB/1000 Gallons

$C_u = C_E + C_{cw}$ = 6.41e-3 RMB/s

Cost of Capital:

N=9

$C_{ca} = N*[c_f+d(A_{min})^e]$ = 10*(120000+3500*302.68^0.5) RMB = 1808917 RMB

c_f=120000RMB d=3500RMB e=0.5

Total Annualized Cost :

Assmue annualized working time is 310 days with 24 hr/day.

TAC = $C_{ca}/n+C_E+C_{cw}$ = 1808917/10+6.41e-3*310*24*3600 RMB =352531 RMB/year

n = 10 years

From the relaxation procedure earlier, we have already get the information to calculate the cost.

So **the cost after relaxation**:

Cost of Utility :

Qh_{min} = 30.06+13.05+6.45 kW = 4.70e-5 MMBTU/s 1 MMBTU=1054 MJ

$C_E = c_Q Qh_{min}$ = 30*4.70e-5 RMB/s = 1.41e-3 RMB/s c_Q = 30 RMB/MMBTU

$$\mathrm{F} = \frac{\mathrm{Q}}{\mathrm{cp}\cdot\Delta\mathrm{T}} = \frac{147.77+6.45}{4.187\times(45-15)}\ \mathrm{kg/s} = 1.228\ \mathrm{kg/s}$$

$Qc_{min} = \frac{F}{\rho} = \frac{1.228}{998.95}\ \mathrm{m}^3/\mathrm{s}$ =1.229e-3 m^3/s = 0.270 Gallon/s 1 Gallon = 4.546 L

$C_{cw} = c_w Qc_{min}$ = 20*0.270e-3 RMB/s =5.41e-3 RMB/s c_w = 20 RMB/1000 Gallons

$C_u = C_E + C_{cw}$ = 6.82e-3 RMB/s

Cost of Capital:

N=9

$C_{ca} = N*[c_f+d(A_{min})^e]$ = 9*(120000+3500*255.06^0.5) RMB = 1583070.50 RMB

c_f=120000RMB d=3500RMB e=0.5

Total Annualized Cost :

Assmue annualized working time is 310 days with 24 hr/day.

TAC = $C_{ca}/n+C_E+C_{cw}$ = 1583070.50/10+6.82e-3*310*24*3600 RMB =340921 RMB/year

n = 10 years

In summary, after relaxation by my solution the total cost decreased.