DESIGN OF MAXIMUM ENERGY RECOVERY NETWORKS

MER NETWORKS

- Networks featuring minimum utility usage are called MAXIMUM ENERGY RECOVERY (MER) Networks.

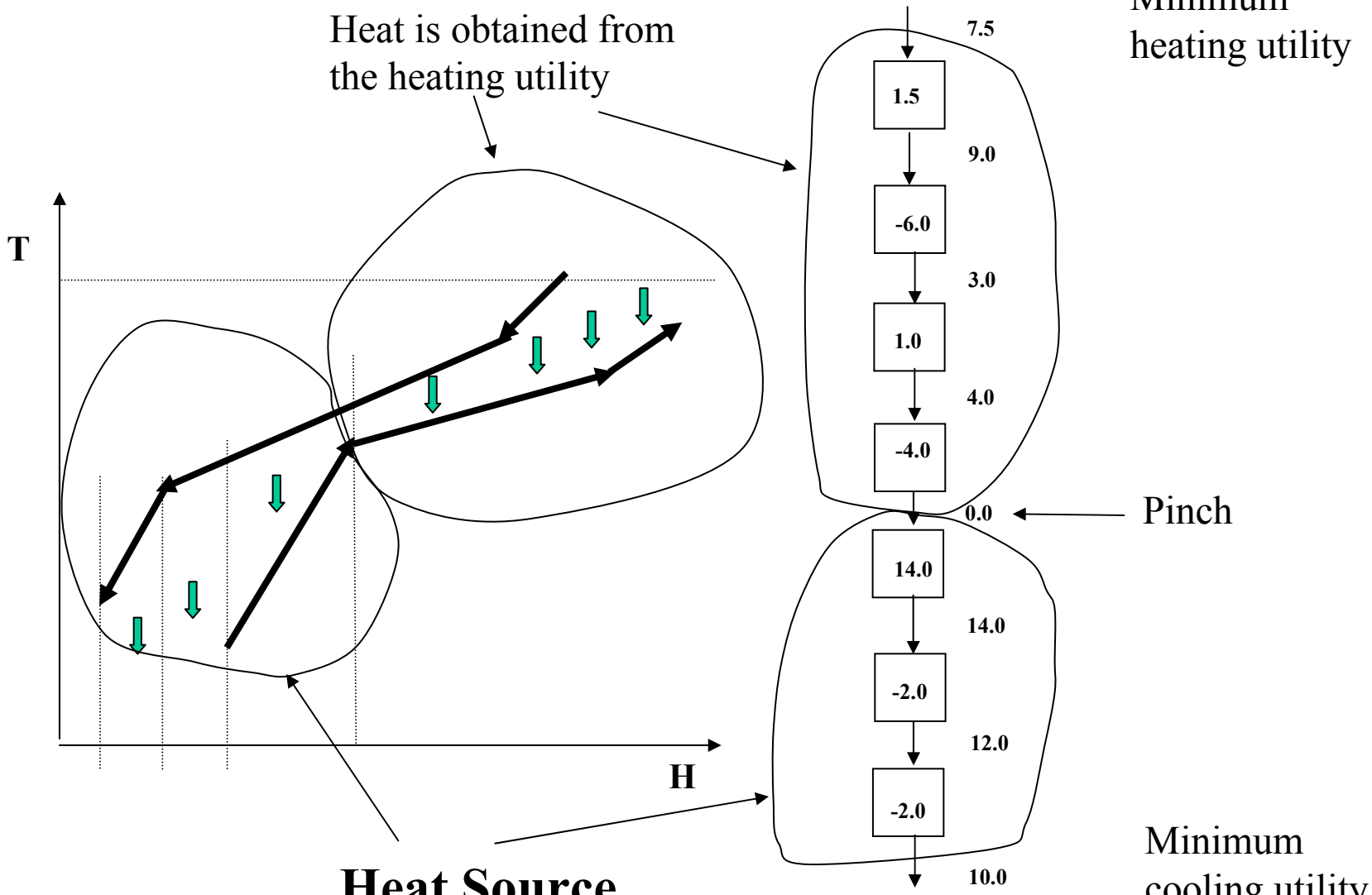
DIVISION AT THE PINCH

RECALL THAT

- No heat is transferred through the pinch.
- This makes the region above the pinch a HEAT SINK region and the region below the pinch a HEAT SOURCE region.

Heat Sink

Heat is obtained from the heating utility



Minimum heating utility

Pinch

Minimum cooling utility

Heat Source

Heat is released to cooling utility

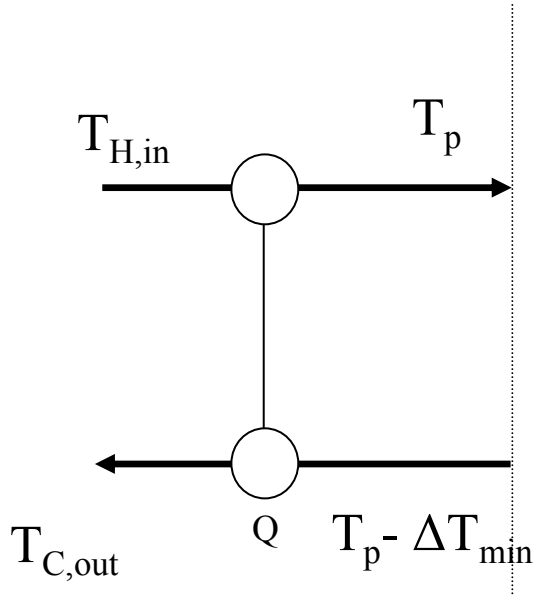
CONCLUSION

- One can analyze the two systems separately, that is,

- Heat exchangers will not contain heat transfer across the pinch.

PINCH MATCHES

- Consider two streams above the pinch



$T_{C,out} = T_p - \Delta T_{min} + Q/FCp_C$

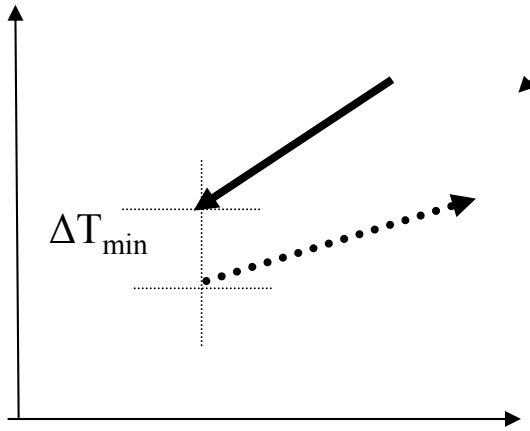
$T_{H,in} = T_p + Q/FCp_H$

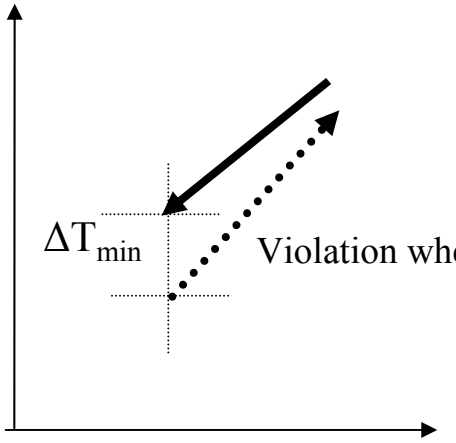
But $T_{H,in} > T_{C,out} + \Delta T_{min.}$

Thus replacing one obtains $Q/FCp_H > Q/FCp_C$

$FCp_H < FCp_C$

Golden rule for pinch matches above the pinch.

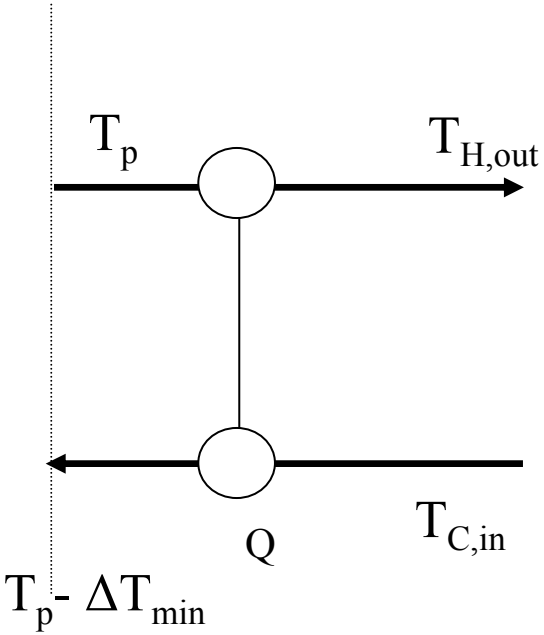




EXERCISE

- A similar rule is obtained below the pinch. Derive it and illustrate it.

ANSWER



$$T_{C,in} = T_p - \Delta T_{min} - Q/FCp_C$$

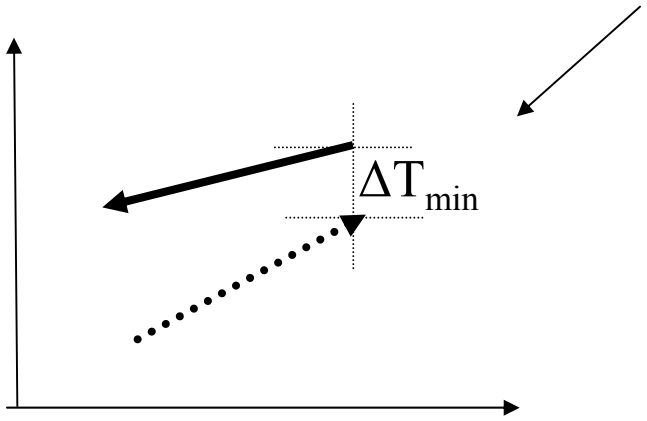
$$T_{H,out} = T_p - Q/FCp_H$$

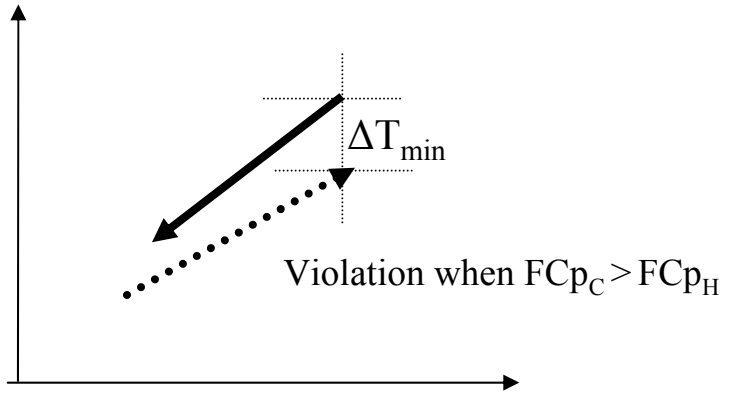
But $T_{H,out} > T_{C,in} + \Delta T_{min.}$

Thus replacing one obtains

$$FCp_C < FCp_H$$

Golden rule for pinch matches below the pinch.





CONCLUSION

- Since matches at the pinch need to satisfy these rules, one should start locating these matches first. Thus, our first design rule:

START BY MAKING PINCH MATCHES

QUESTION

- Once a match has been selected how much heat should be exchanged?

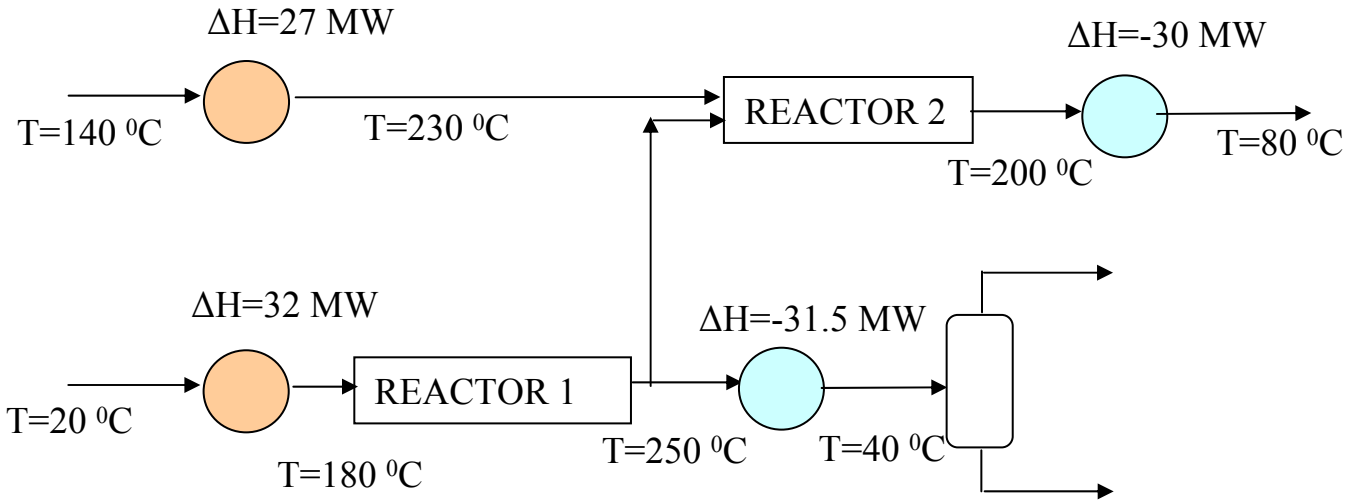
ANSWER

- As much as possible!
- This means that one of the streams has its duty satisfied!!

THIS IS CALLLED THE

TICK-OFF RULE

HANDS ON EXERCISE

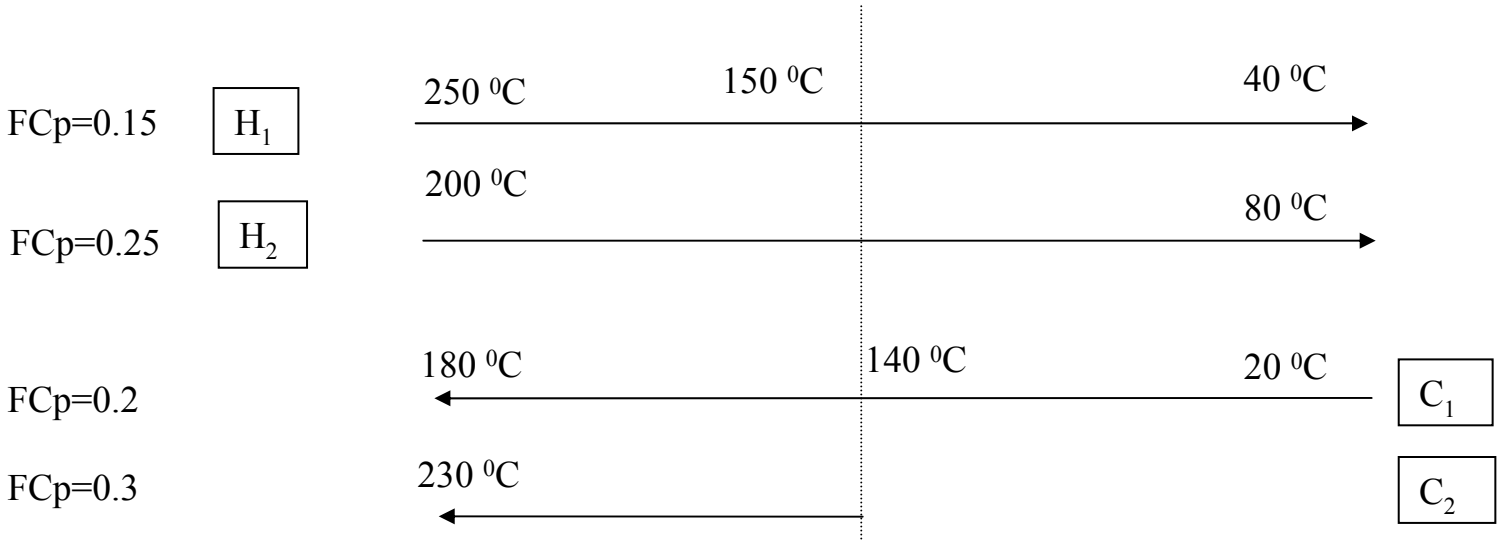


Stream	Type	Supply T (°C)	Target T (°C)	ΔH (MW)	F*Cp (MW °C^{-1})
Reactor 1 feed	Cold	20	180	32.0	0.2
Reactor 1 product	Hot	250	40	-31.5	0.15
Reactor 2 feed	Cold	140	230	27.0	0.3
Reactor 1 product	Hot	200	80	-30.0	0.25

ΔT_{min}=10 °C

PINCH=150 °C

HANDS ON EXERCISE



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ΔT_{min}=10 °C

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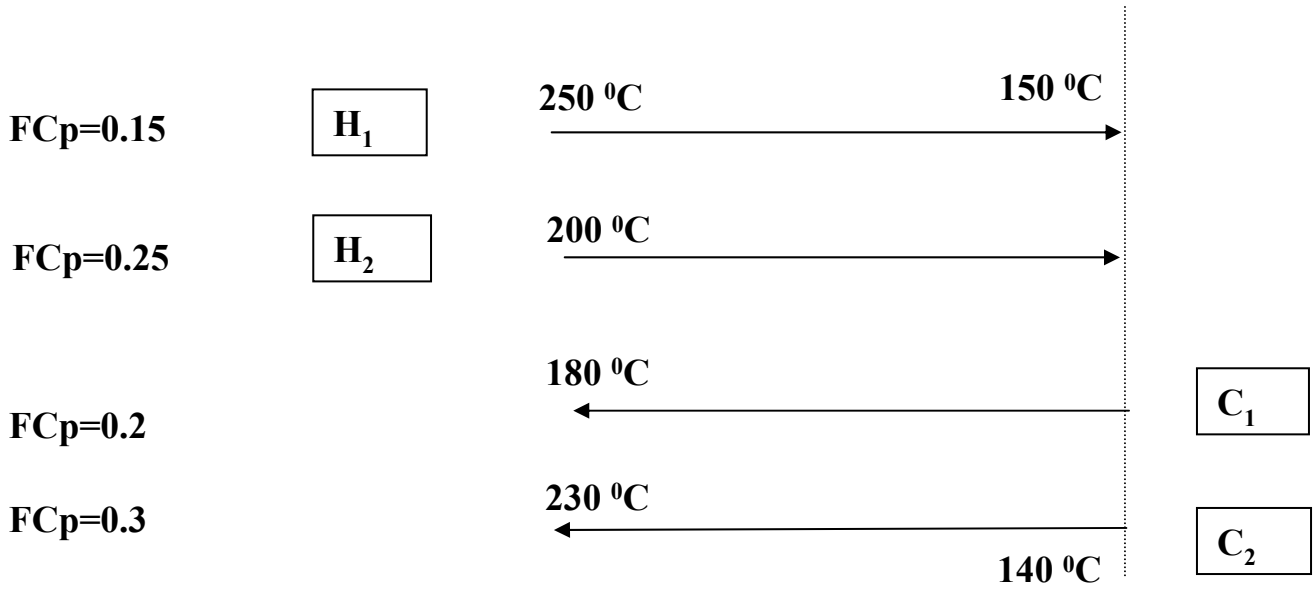
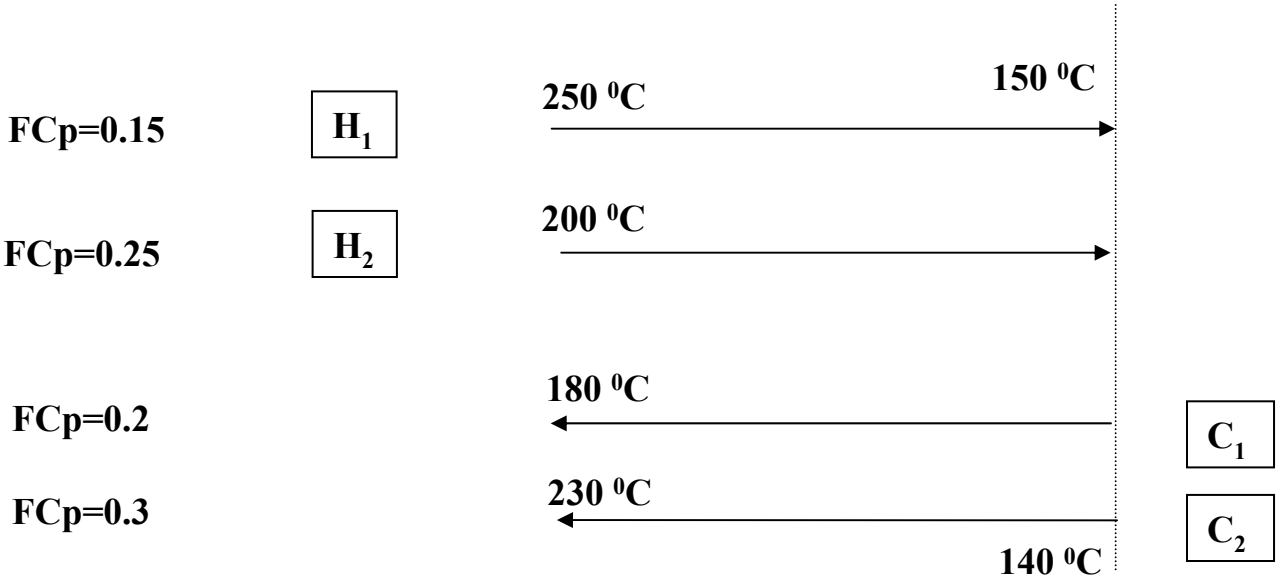
ABOVE THE PINCH



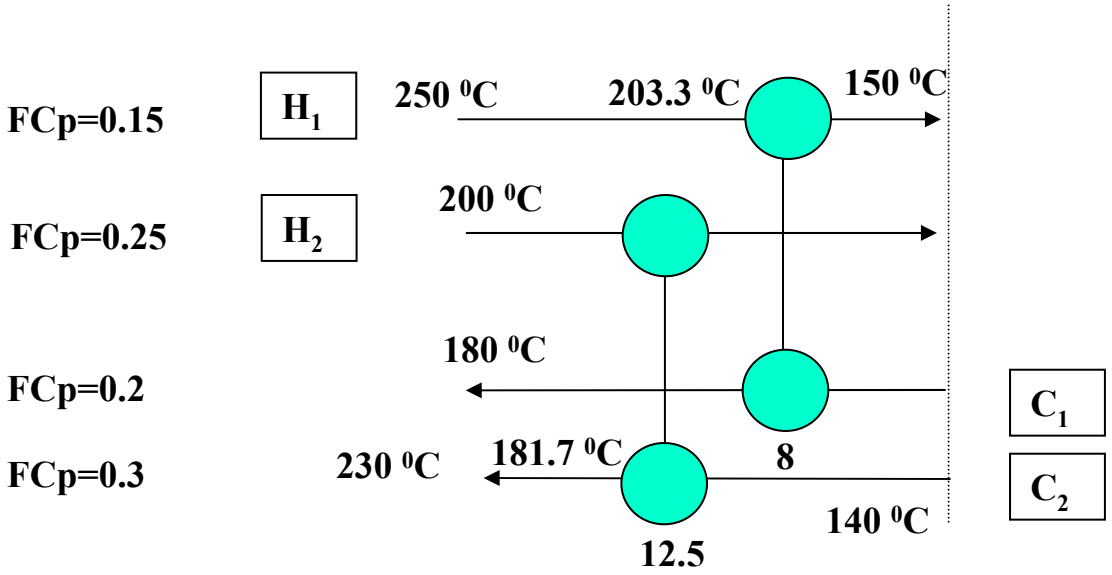
- Which matches are possible?

ANSWER (above the pinch)



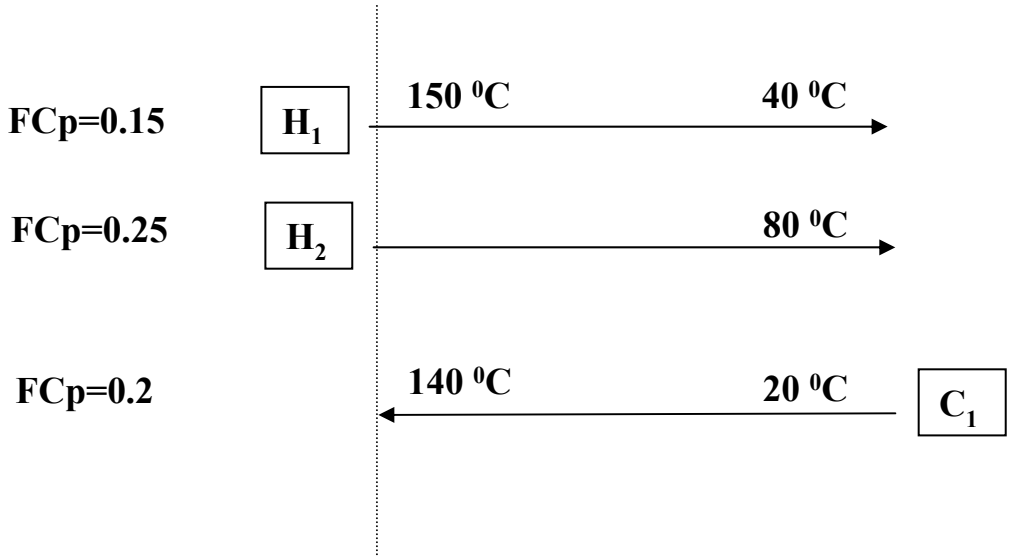
- The rule is that $FCp_H < FCp_C$. We therefore can only make the match H1-C1 and H2-C2.

ANSWER (above the pinch)



- The tick-off rule says that a maximum of 8 MW is exchanged in the match H1-C1 and as a result stream C1 reaches its target temperature.
- Similarly 12.5 MW are exchanged in the other match and the stream H2 reaches the pinch temperature.

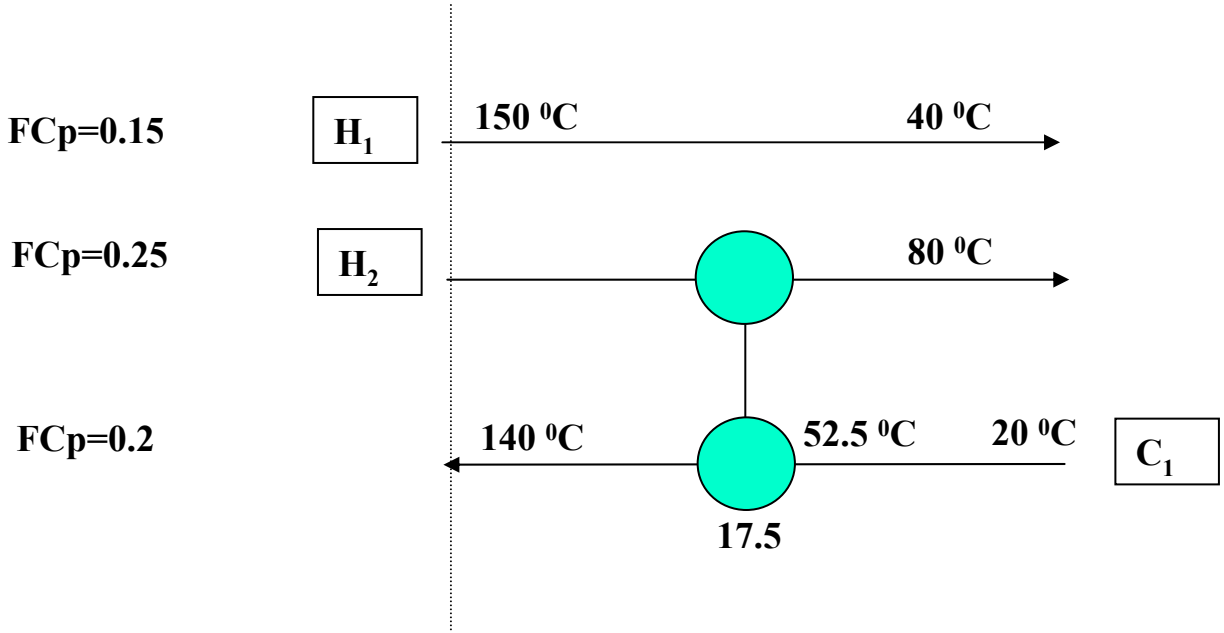
BELOW THE PINCH



- Which matches are possible?

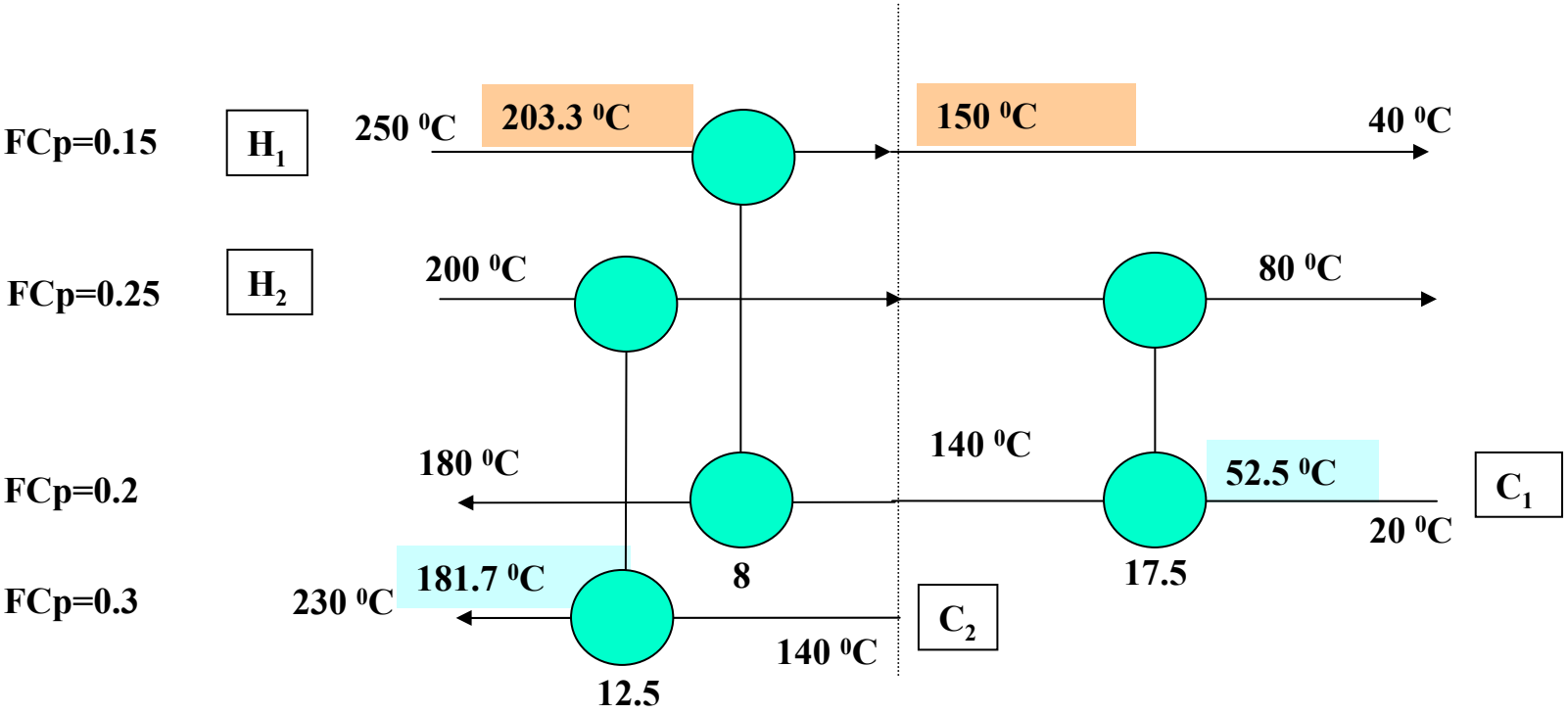
  The rule is that $FCp_C < FCp_H$. Thus, we can only make the match H2-C1

ANSWER (below the pinch)



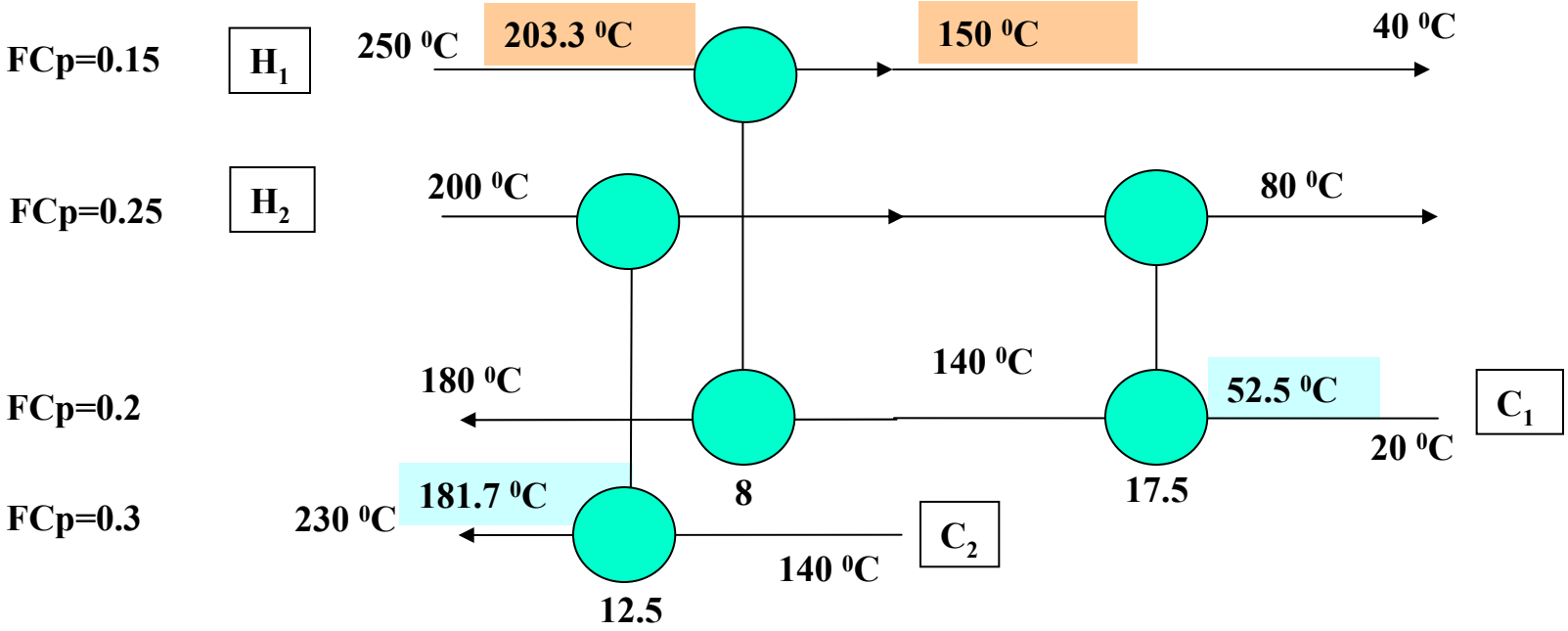
- The tick-off rule says that a maximum of 17.5 MW is exchanged in the match H2-C1 and as a result stream H2 reaches its target temperature.

COMPLETE NETWORK AFTER PINCH MATCHES



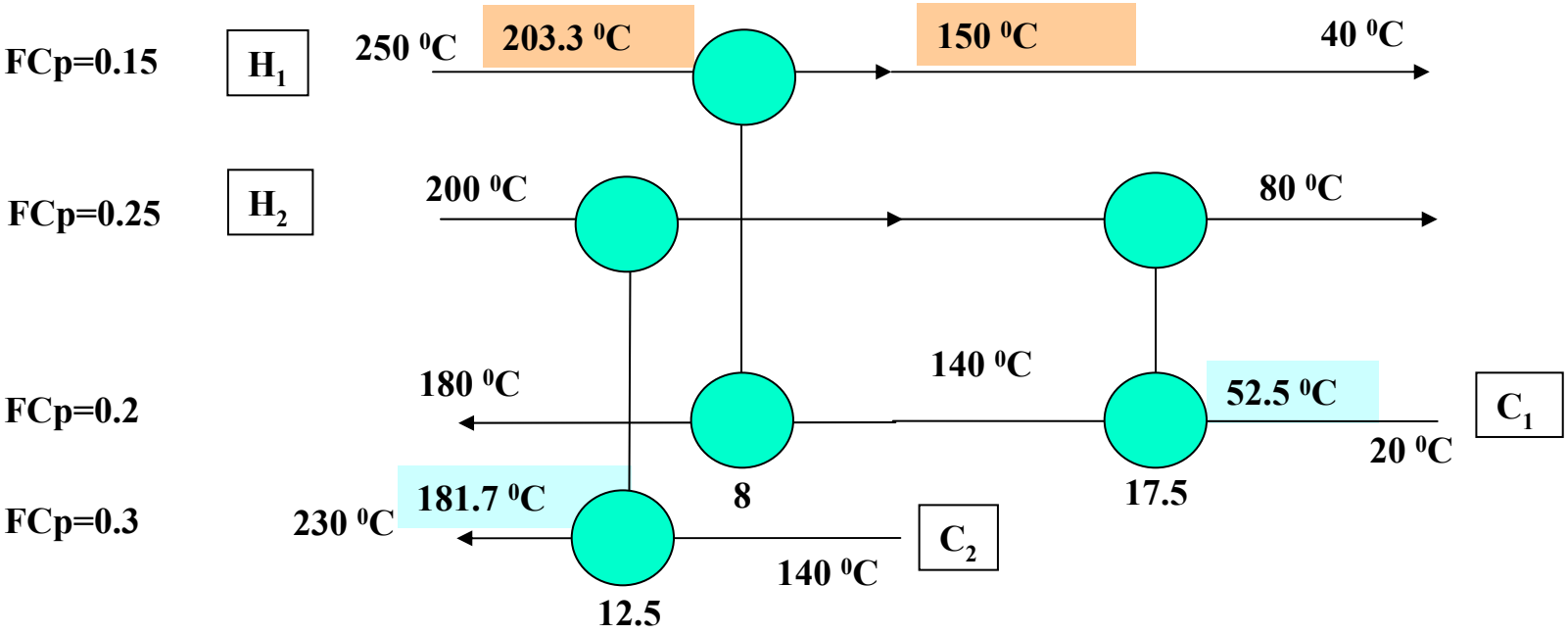
- Streams with unfulfilled targets are colored.

WHAT TO DO NEXT?



- **Away from the pinch, there is more flexibility to make matches, so the inequalities do not have to hold.**
- **The pinch design method leaves you now on your own!!!!!**
- **Therefore, use your judgment as of what matches to select!!**

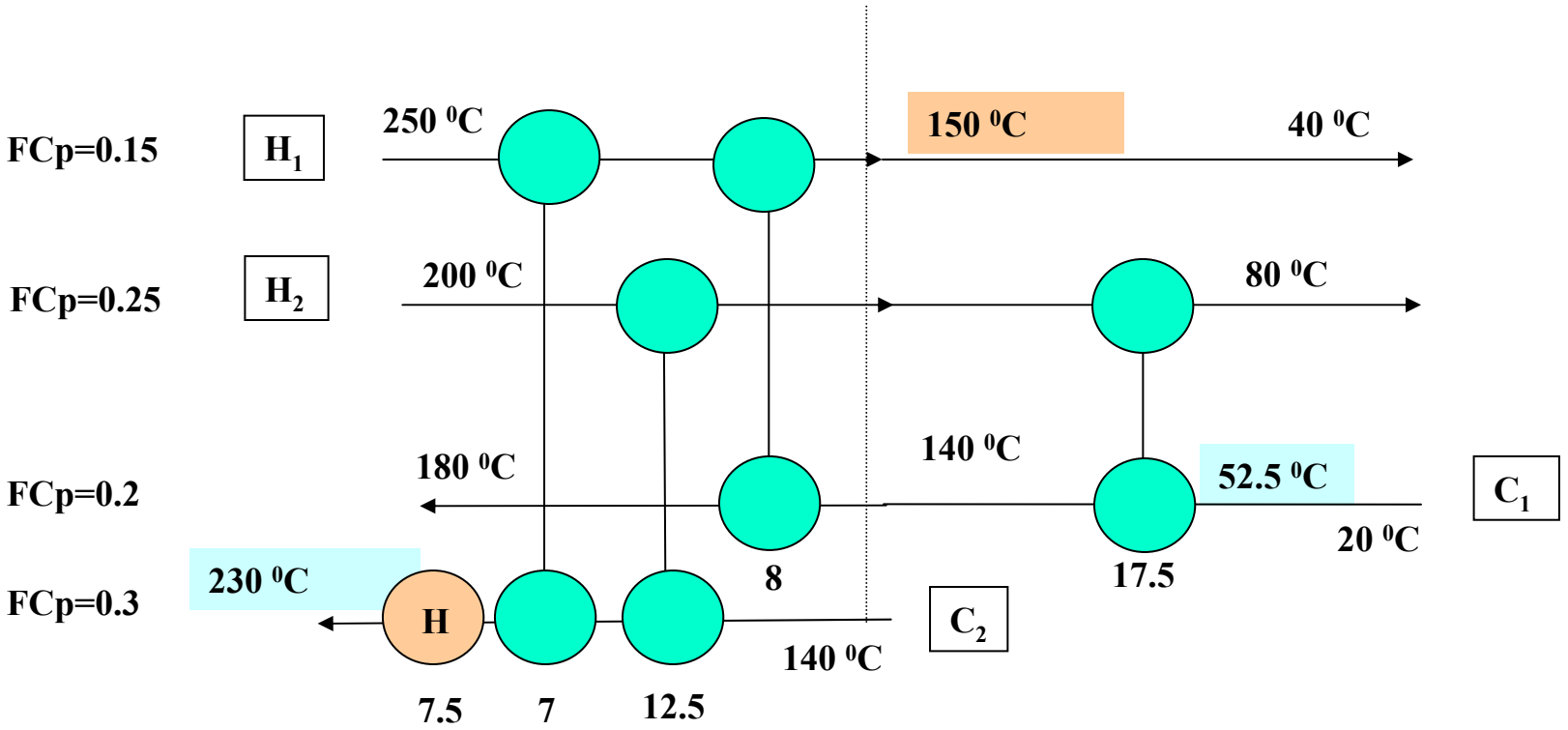
ANSWER



- **We first note that we will use heating above the pinch. Thus all hot streams need to reach their inlet temperature. We are then forced to look for a match for H1. Please locate it.**

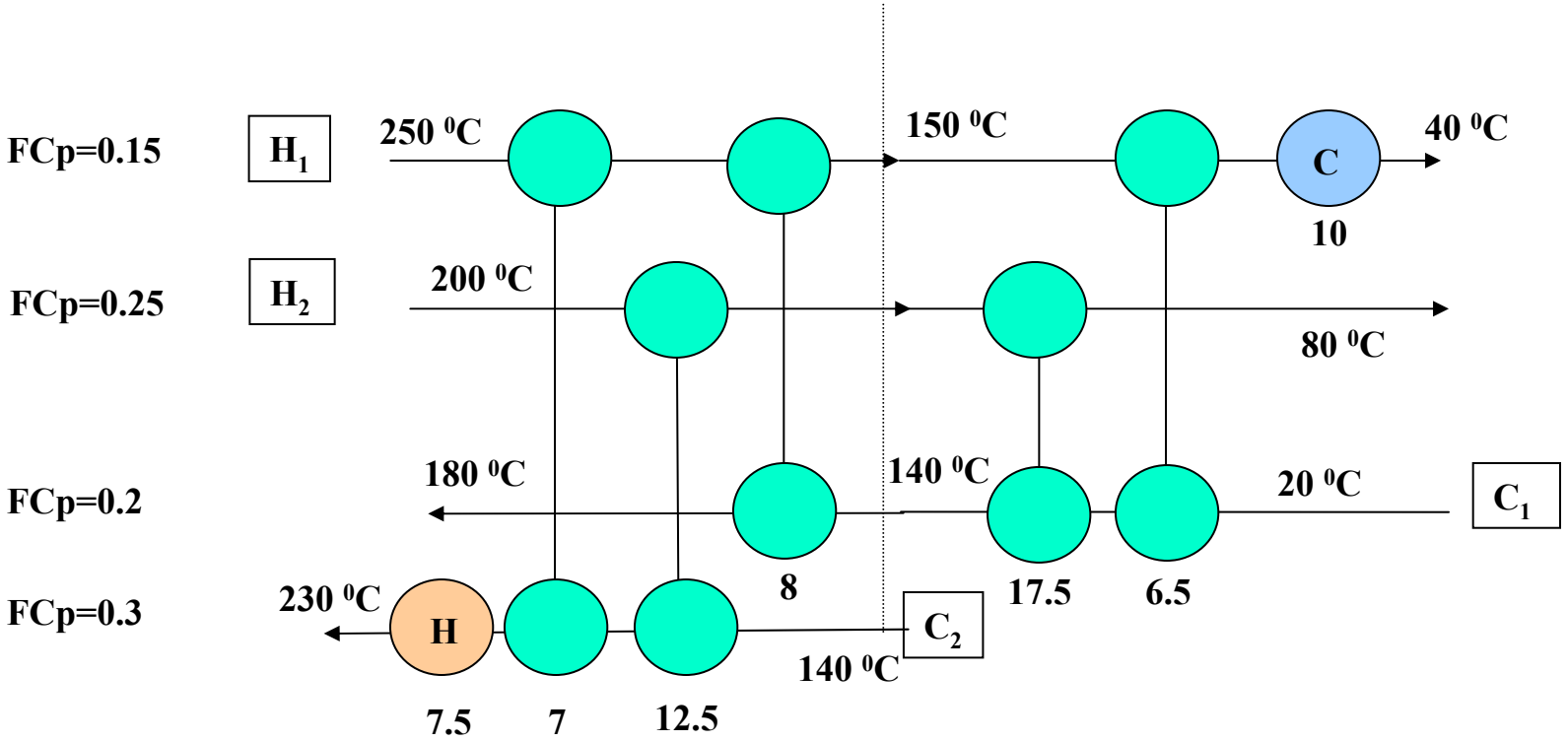
ANSWER

- The match is H1-C1. We finally put a heater on the cold stream



ANSWER

- **Below the pinch we try to have the cold streams start at their inlet temperatures and we later locate coolers (one in this case).**



DISCUSSION

- State what are your objections to the pinch design method, so far!!

THESE ARE MINE

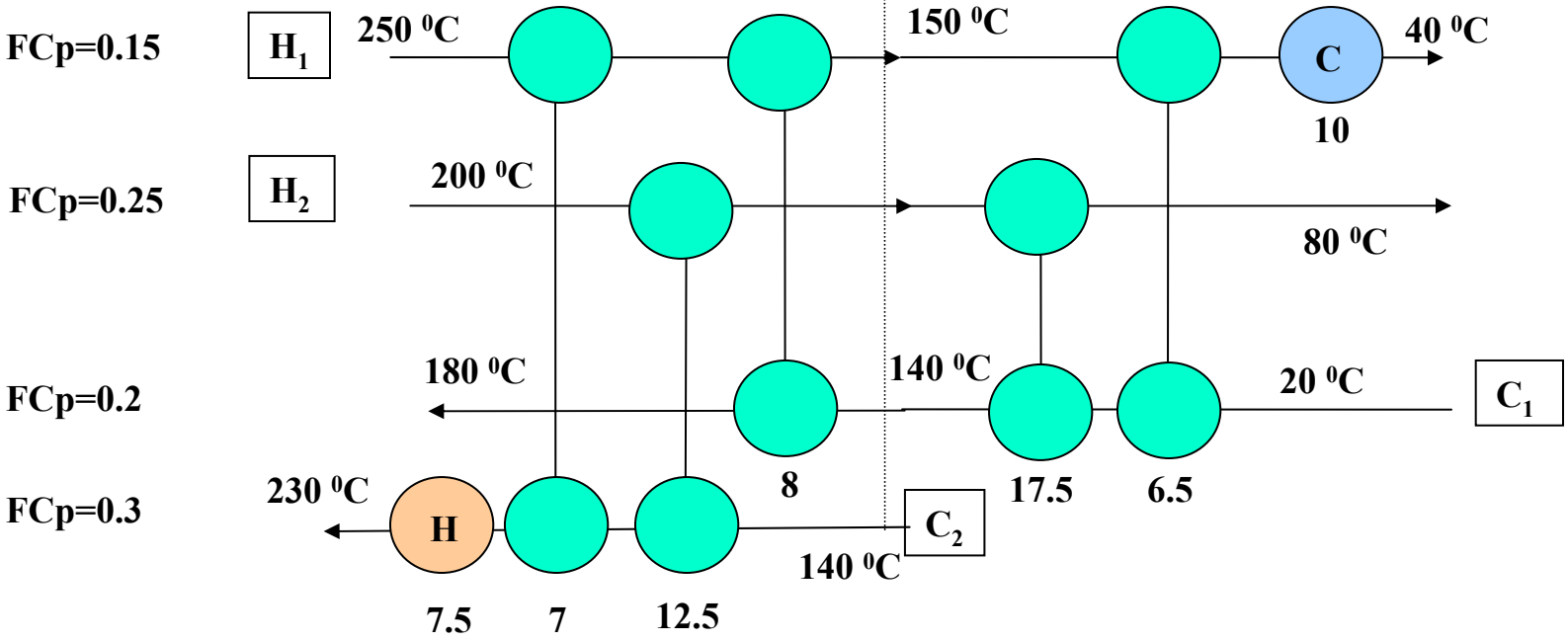
- It seems to imply building expertise
- It does not seem to guarantee that one will always obtain a good result.
- What if there are unequal number of streams at the pinch?
- What if the inequalities are not satisfied at the pinch?

GENERAL FORMULA FOR UNIT TARGETING

$$N_{min} = (S-P)_{\text{above pinch}} + (S-P)_{\text{below pinch}}$$

If we do not consider two separate problems, above and below the pinch we can get misleading results.

EXAMPLE



$$N_{min} = (S-P)_{\text{above pinch}} + (S-P)_{\text{below pinch}} =$$

$$=(5-1) + (4-1) = 7$$

If we do not consider two separate problems

Nmin= (6-1)= 5, which is wrong

Note: A heat exchanger network with 5 exchangers exists, but it is impractical and costly. This is beyond the scope of this course.

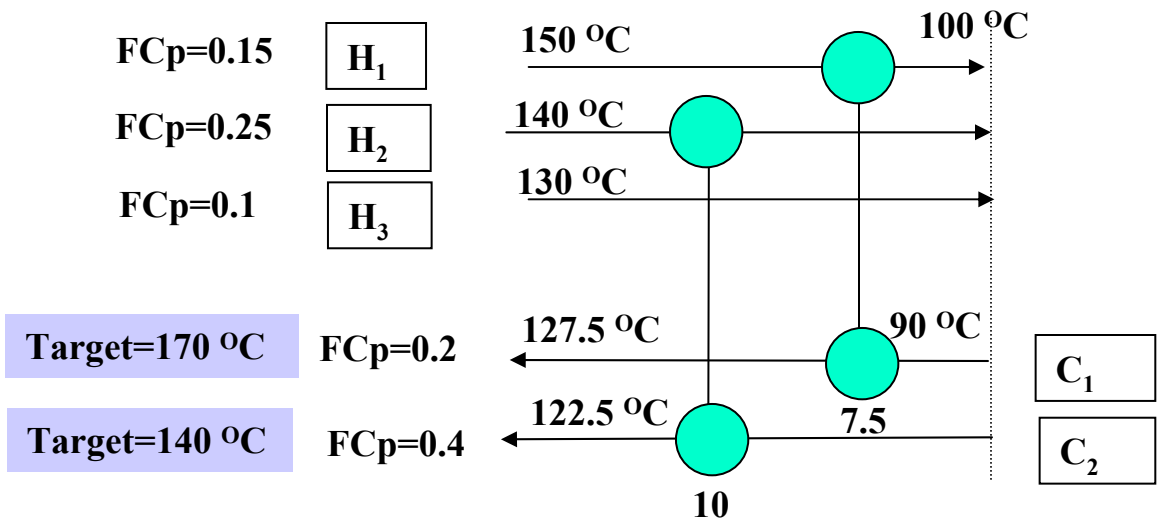
UNEQUAL NUMBER OF STREAMS AT THE PINCH

Above the pinch, we notice the following rule

$$S_H \leq S_C$$

UNEQUAL NUMBER OF STREAMS AT THE PINCH

Indeed, if the number of hot streams is larger than the number of cold streams, then no pinch matches are possible.

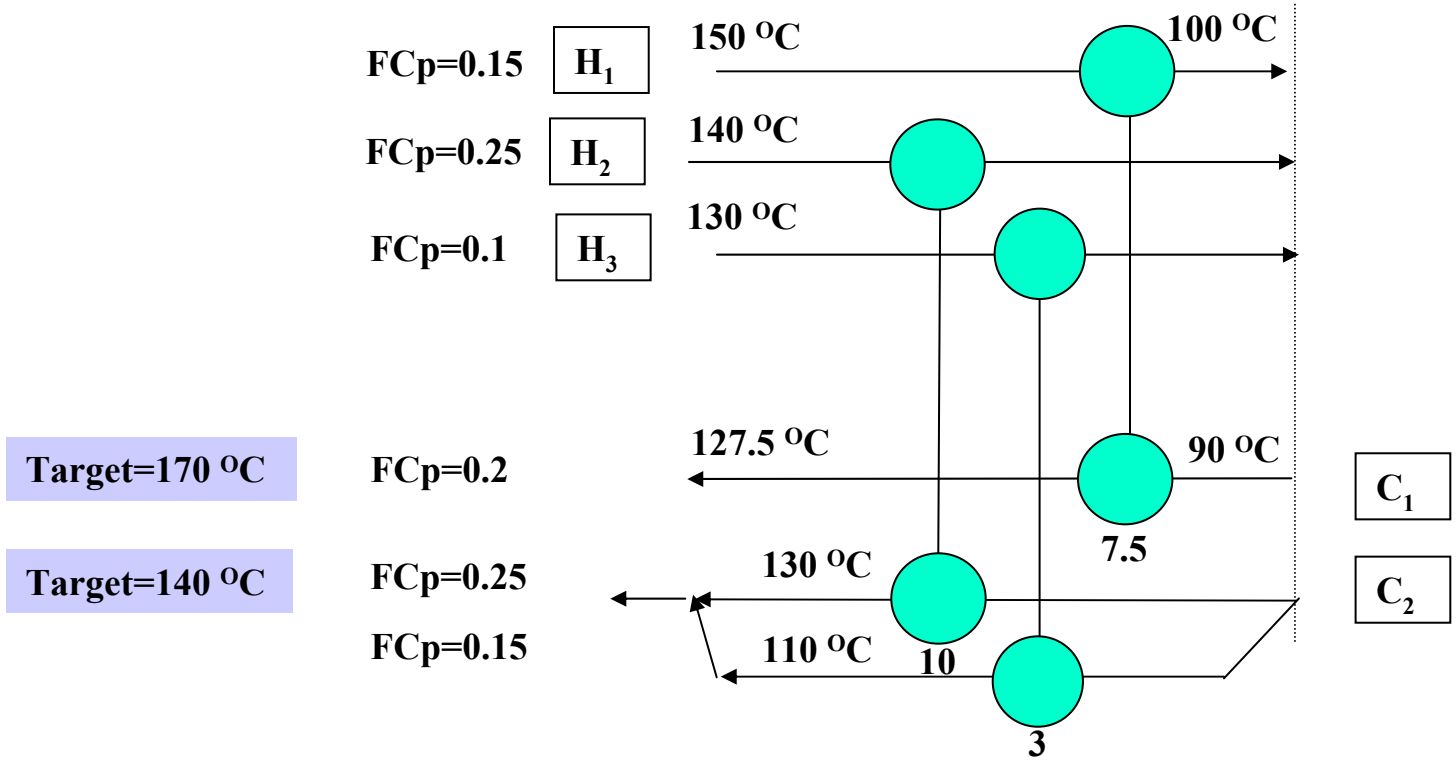


Assume the matches H_1-C_1 and the matches H_2-C_2 have been selected. Since H_3 needs to go to the pinch temperature, there is no cold stream left to match, even if there is portions of C_1 or C_2 that are left for matching. Such matching would be infeasible.

What is then, the solution?

ANSWER

Split cold stream until the inequality is satisfied.



Notice that different combinations of flowrates in the split satisfy the inequality.

UNEQUAL NUMBER OF STREAMS AT THE PINCH

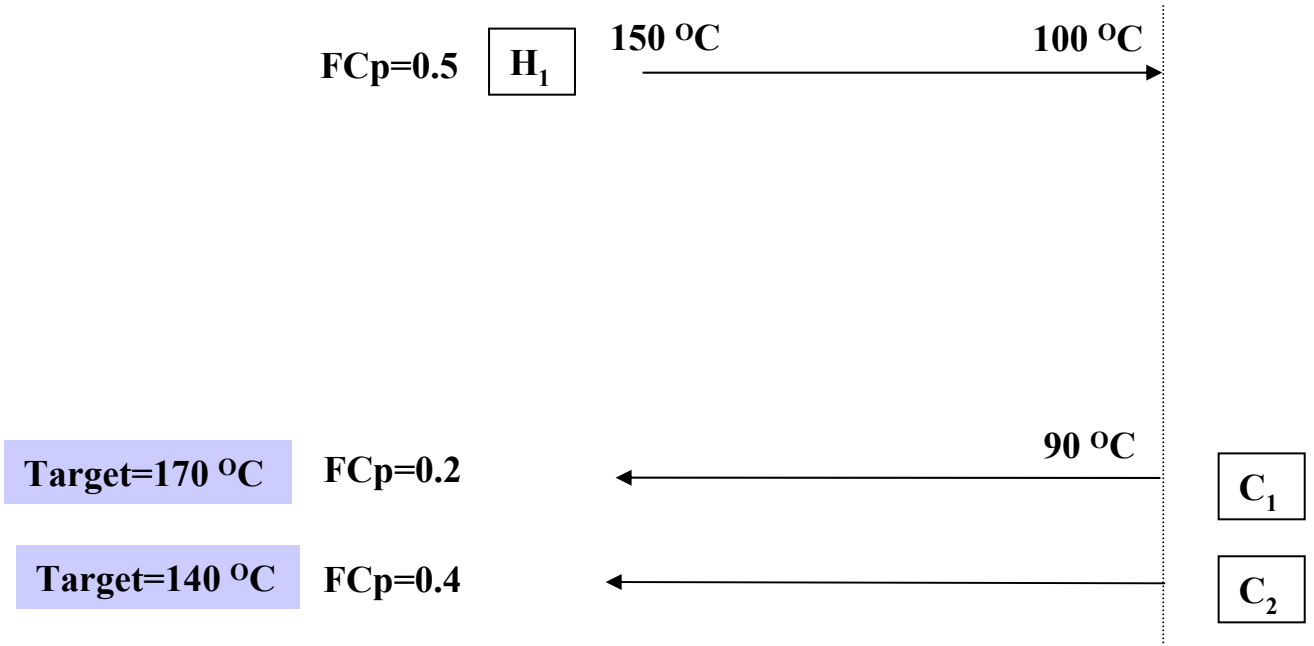
A similar rule can be discussed below the pinch, that is,

$$S_H \geq S_C$$

and similar splitting of hot streams may be necessary.

INEQUALITY NOT SATISFIED

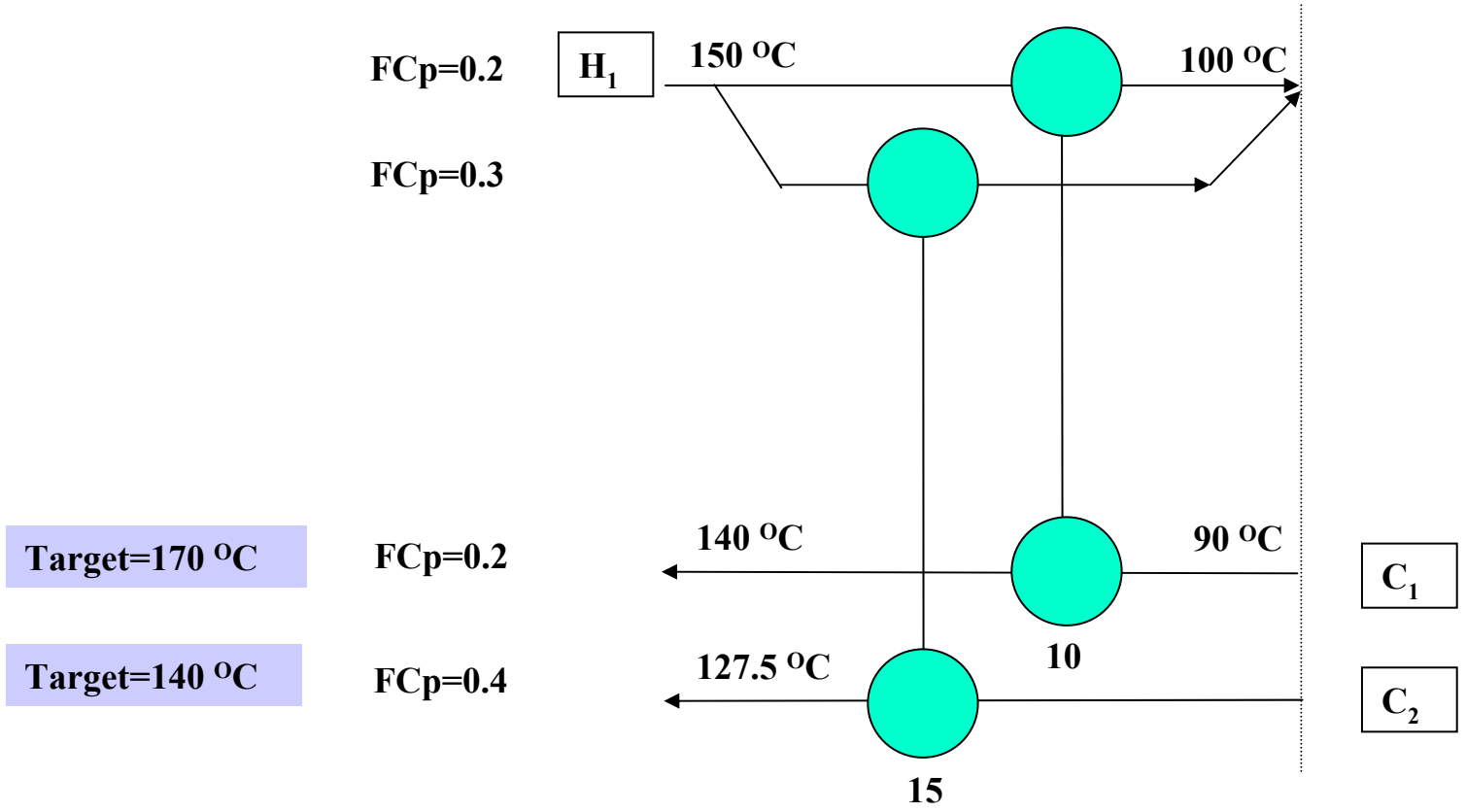
Consider the following case:



Suggest a solution.

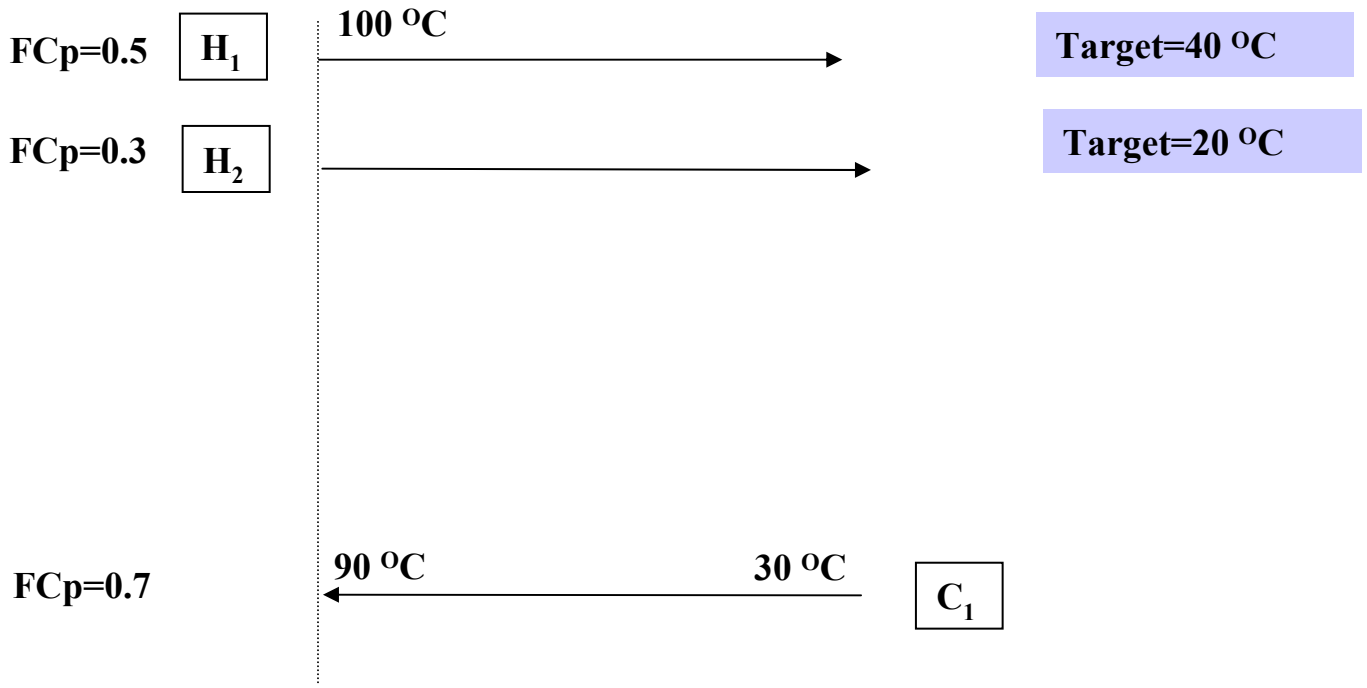
ANSWER

Split the hot stream



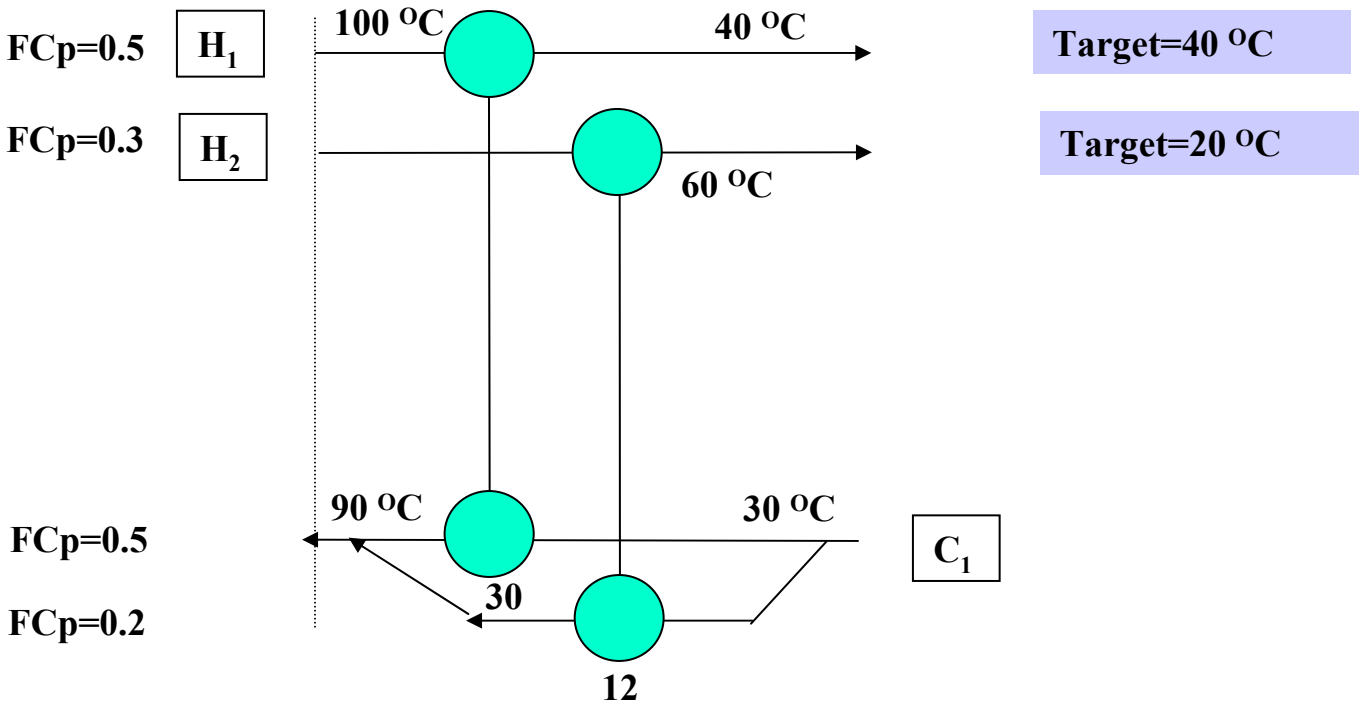
SOLVE THE FOLLOWING PROBLEM

Below the Pinch :



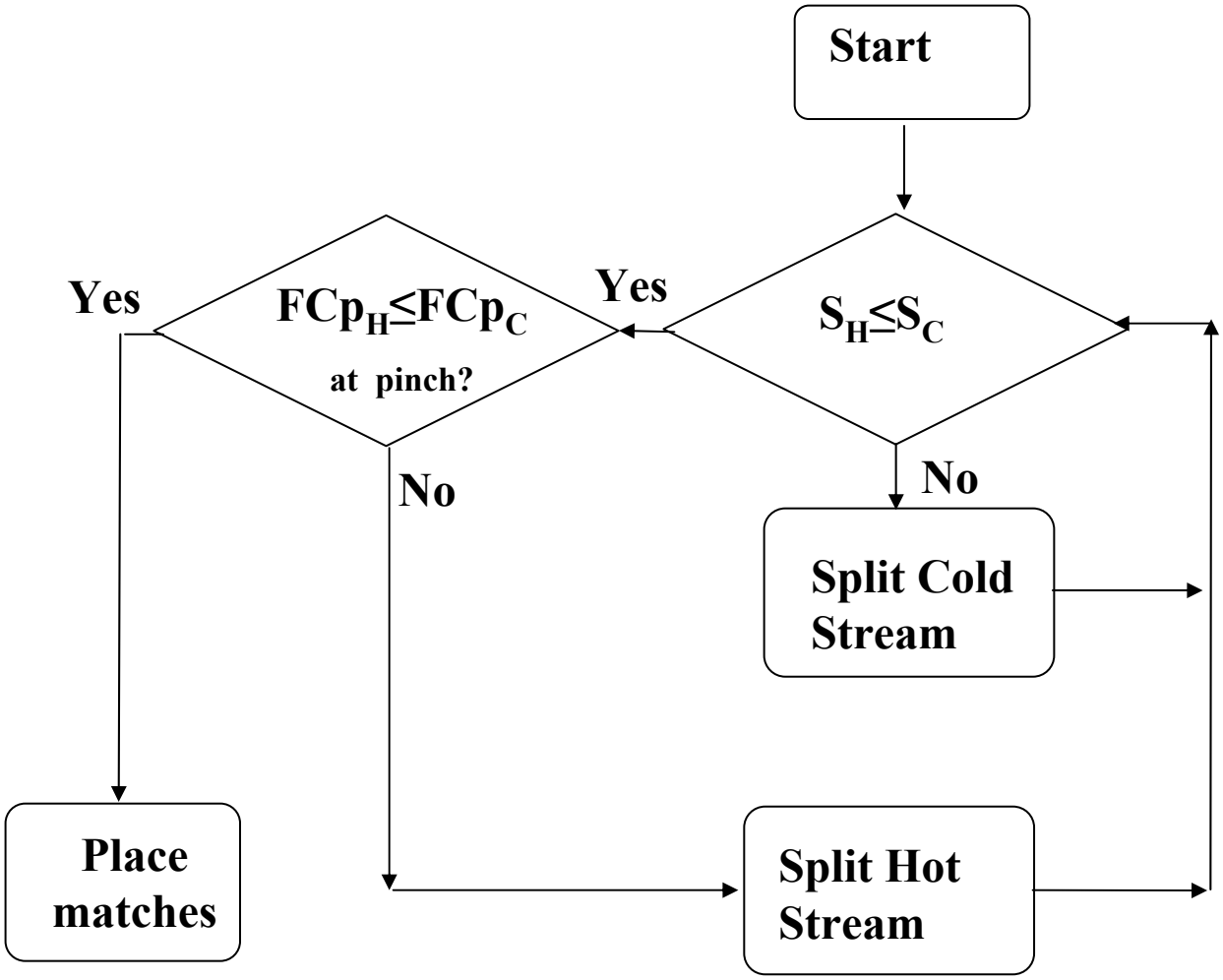
ANSWER

Below the Pinch :



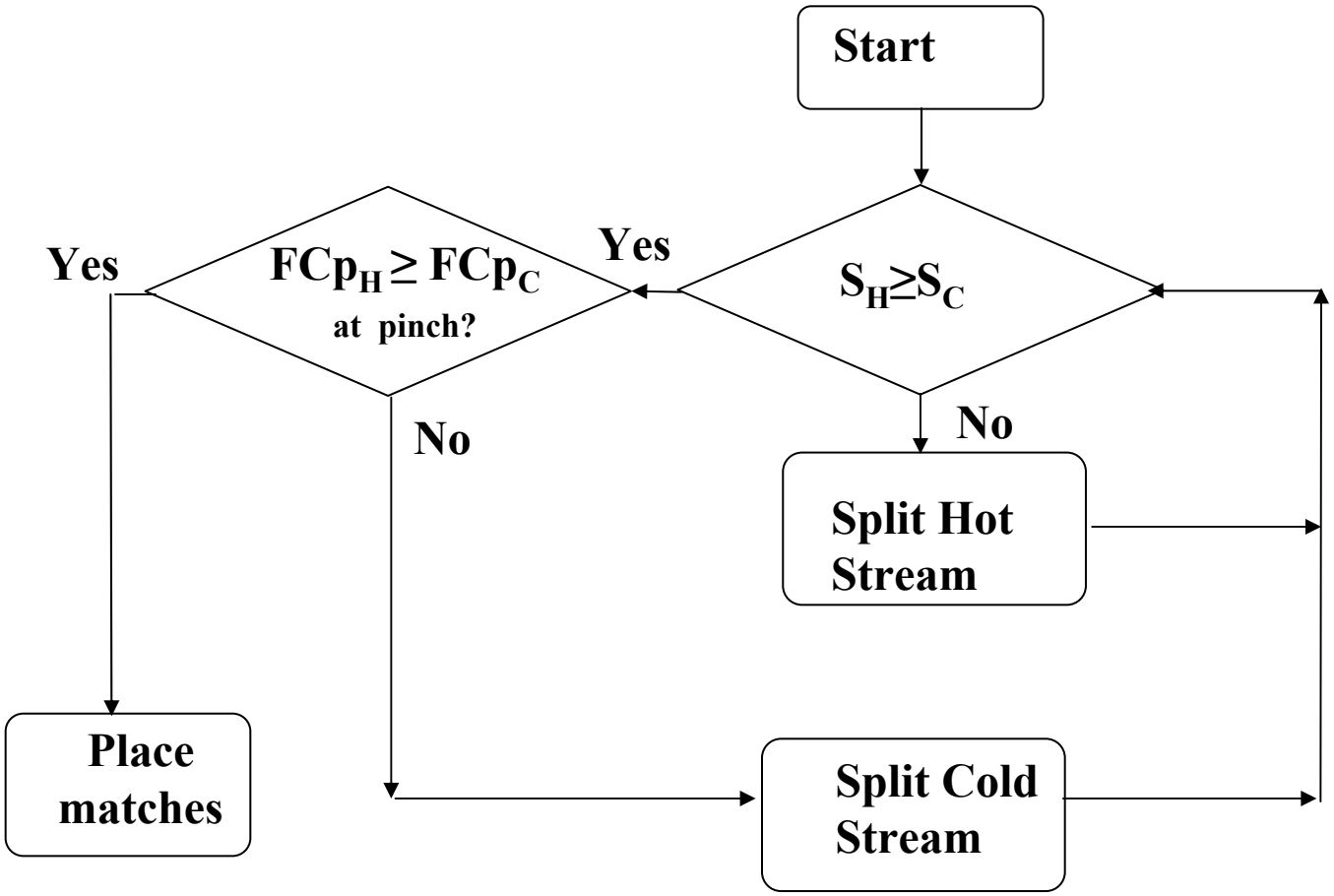
COMPLETE PROCEDURE

ABOVE THE PINCH



COMPLETE PROCEDURE

BELOW THE PINCH



HANDS ON EXERCISE

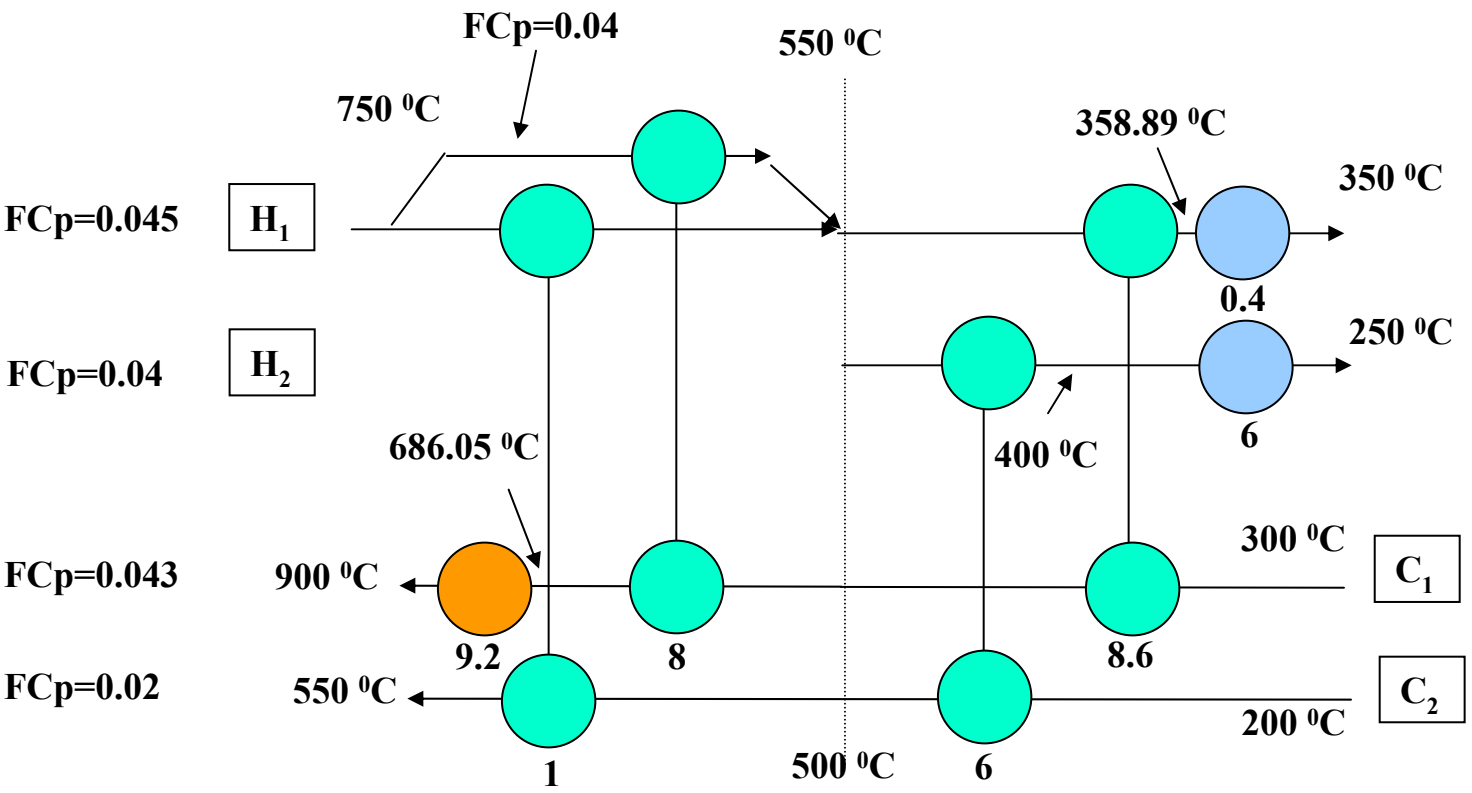
Type	Supply T (^oC)	Target T (^oC)	F*Cp (MW $^oC^{-1}$)
Hot	750	350	0.045
Hot	550	250	0.04
Cold	300	900	0.043
Cold	200	550	0.02

ΔT_{min}=50 ^oC

Minimum Heating Utility= 9.2 MW

Minimum Cooling Utility= 6.4 MW

ANSWER


FCp=0.04
550 ⁰C
750 ⁰C
358.89 ⁰C
350 ⁰C
FCp=0.045
H1
0.4
250 ⁰C
FCp=0.04
H2
6
400 ⁰C
686.05 ⁰C
300 ⁰C
FCp=0.043
900 ⁰C
C1
9.2
8
8.6
FCp=0.02
550 ⁰C
C2
200 ⁰C
1
500 ⁰C
6

ANSWER

We are minimizing the number of matches. We saw already that different answers can be obtained if separate regions are not considered.