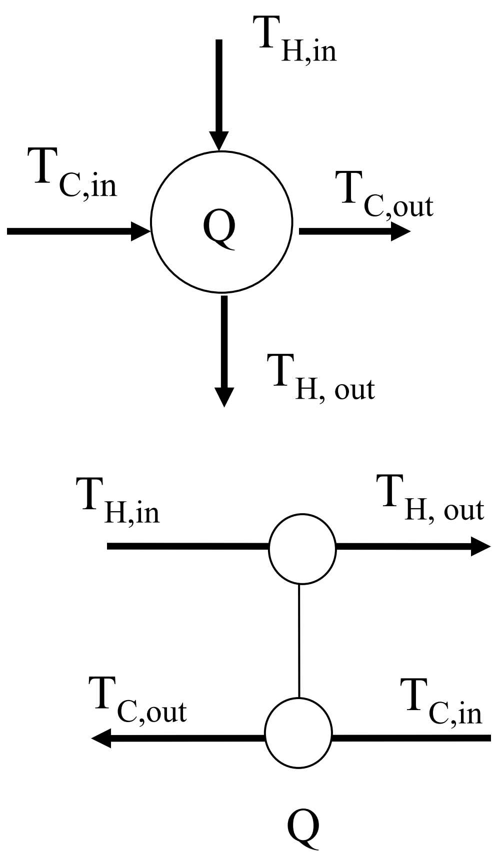
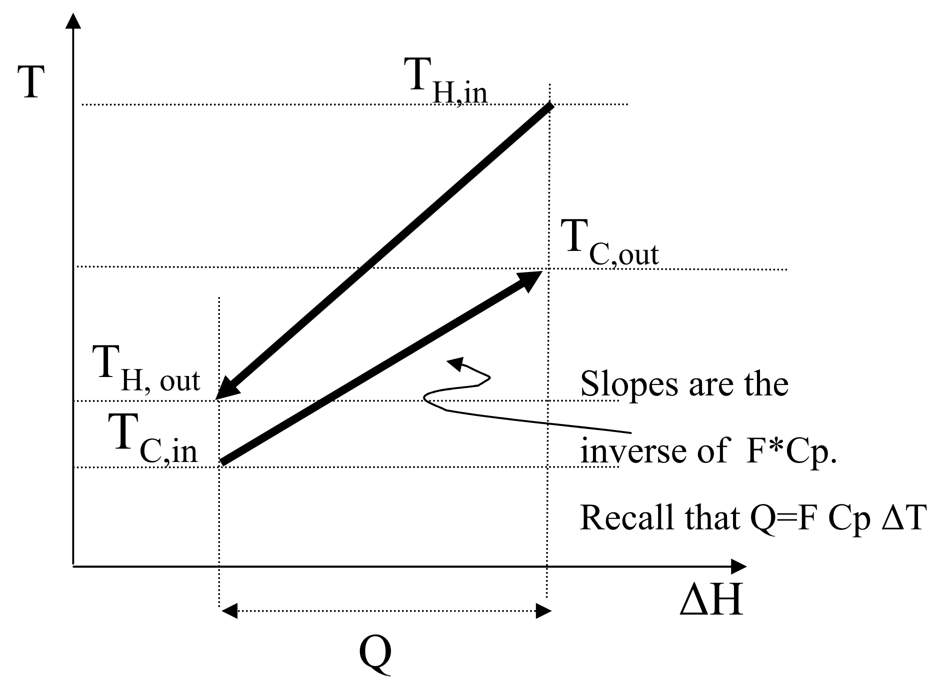
PINCH AND MINIMUM UTILITY USAGE

TEMPERATURE-ENTHALPY (T-H) DIAGRAMS

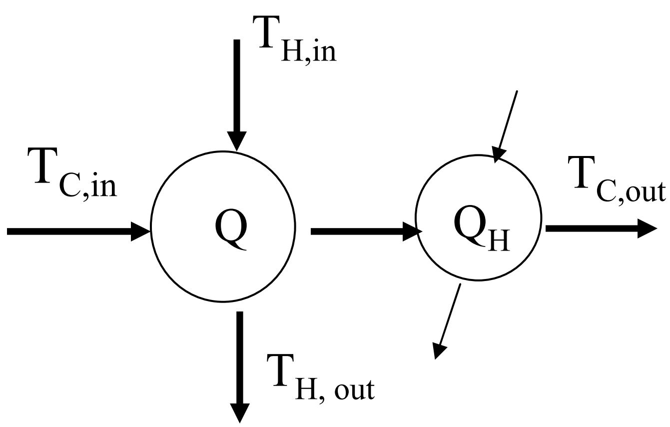
- Assume one heat exchanger. These are alternative representations

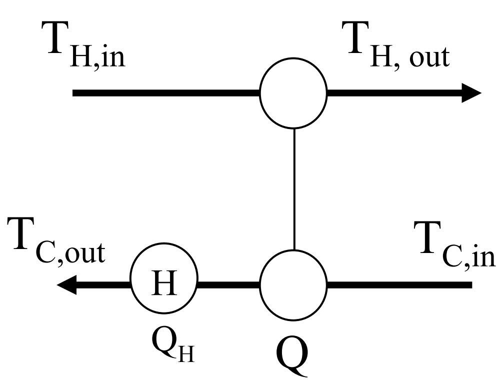


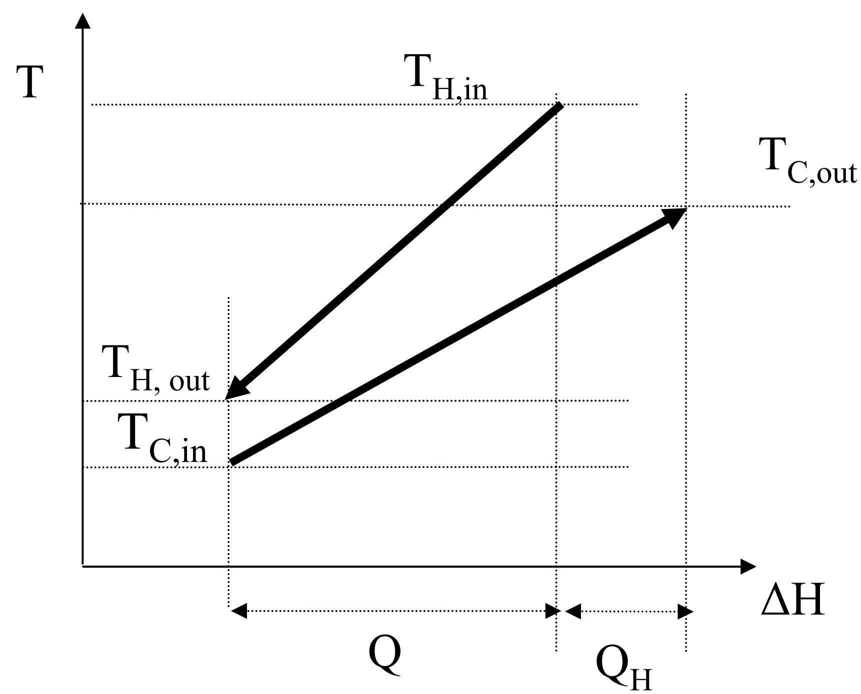


T-H DIAGRAMS

- Assume one heat exchanger and a heater

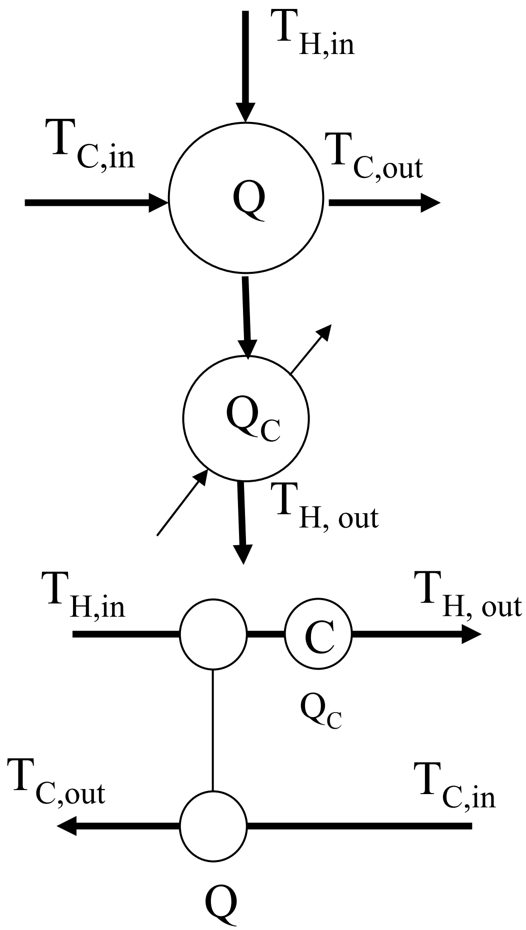


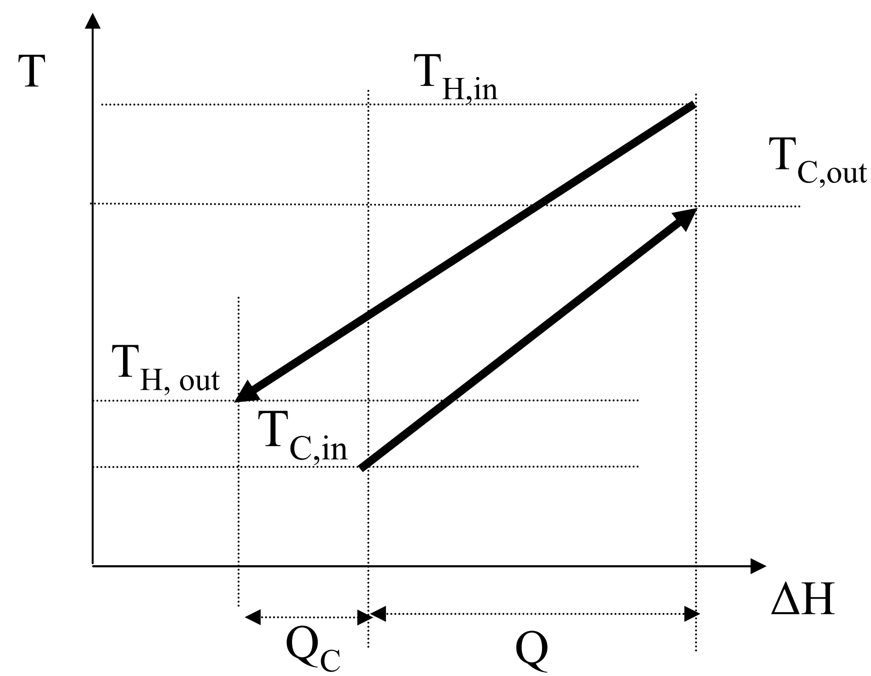




T-H DIAGRAMS

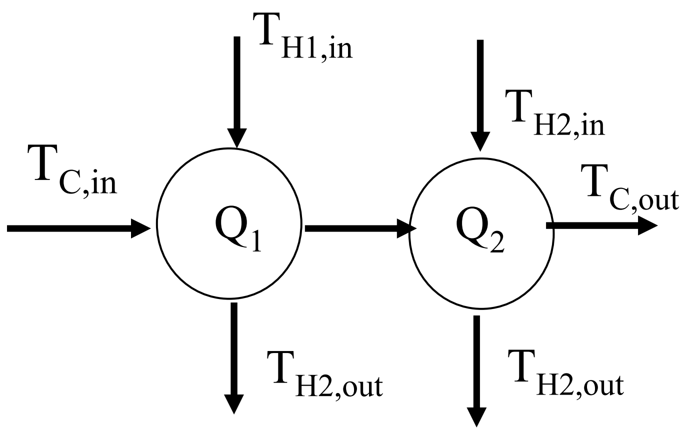
- Assume one heat exchanger and a cooler

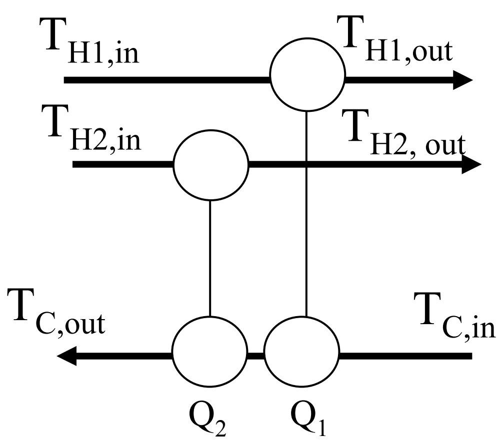


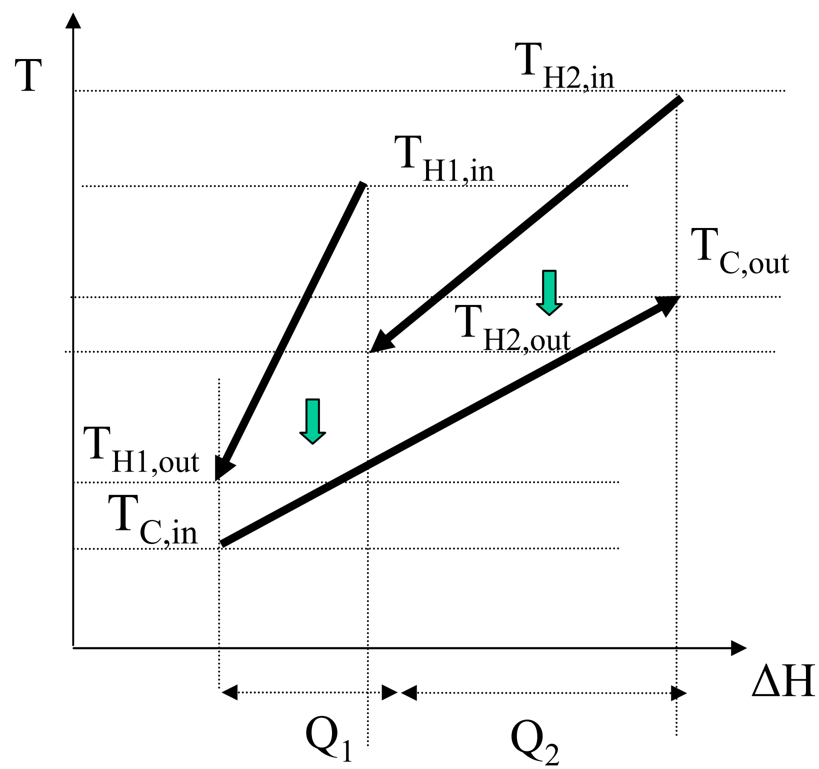


T-H DIAGRAMS

- Two hot-one cold stream

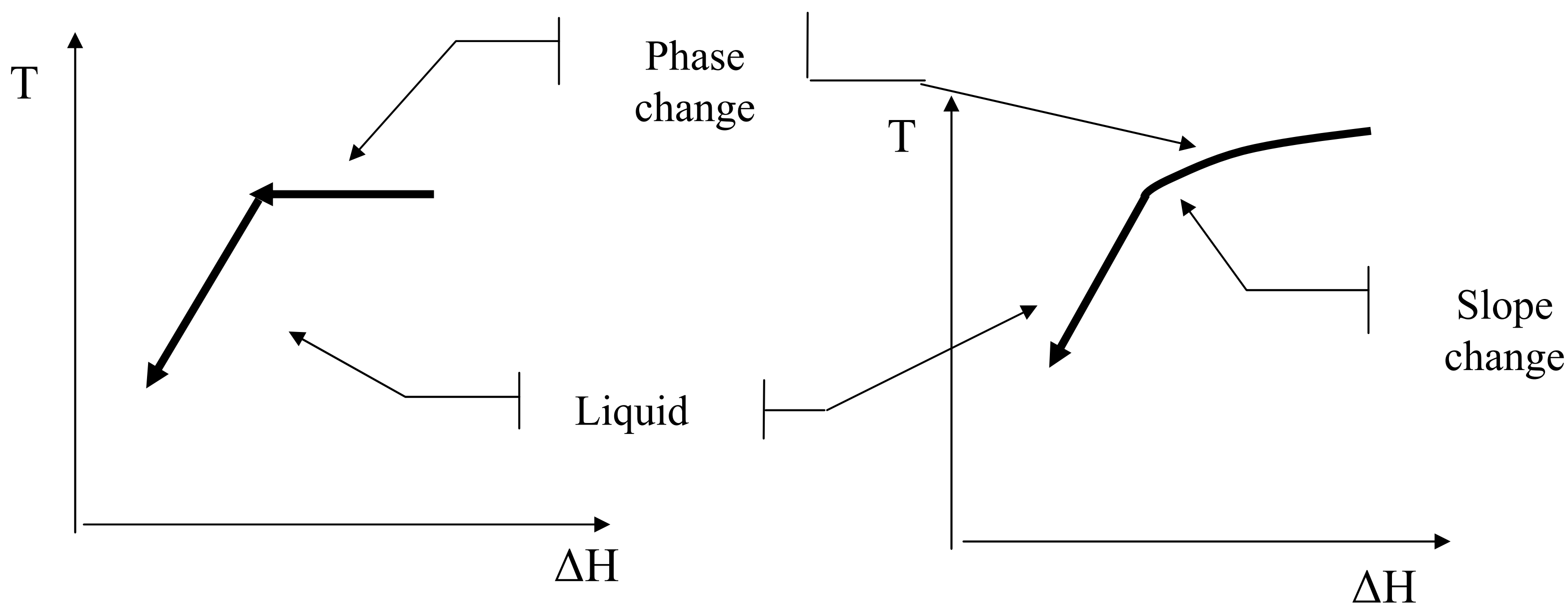






Notice the vertical arrangement of heat transfer

- How are streams subject to phase change represented?

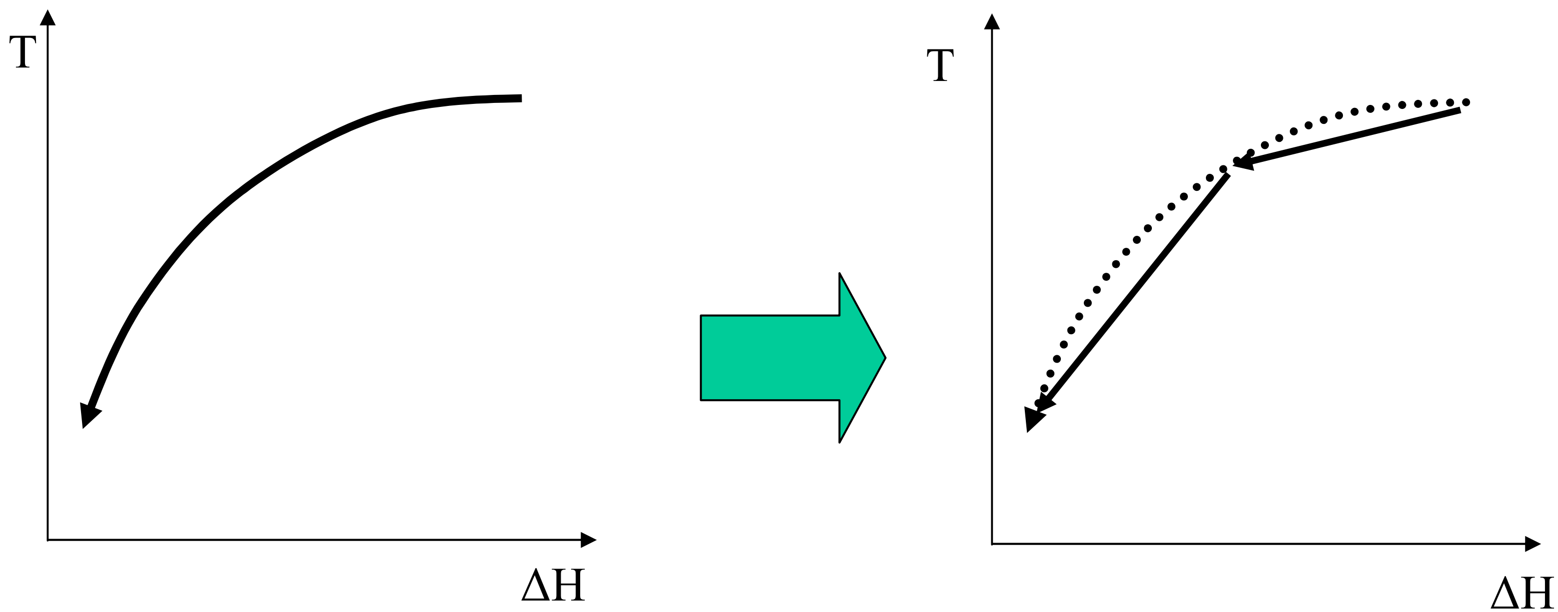


Single component

Multicomponent

ANSWERS

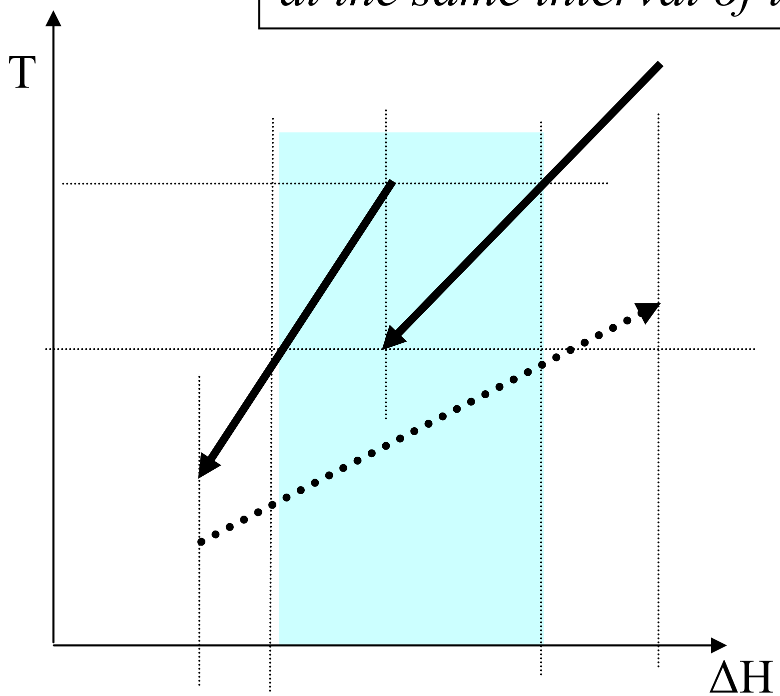
- How can one represent a stream that has a variable Cp?

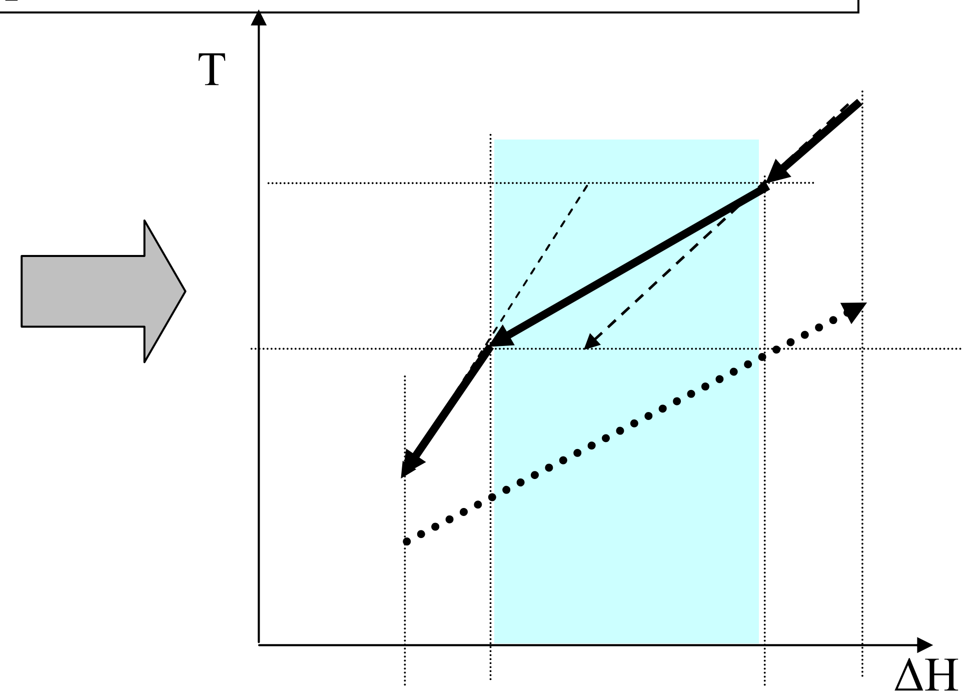


T-H DIAGRAMS

- Composite Curve

Obtained by lumping all the heat from different streams that are at the same interval of temperature.

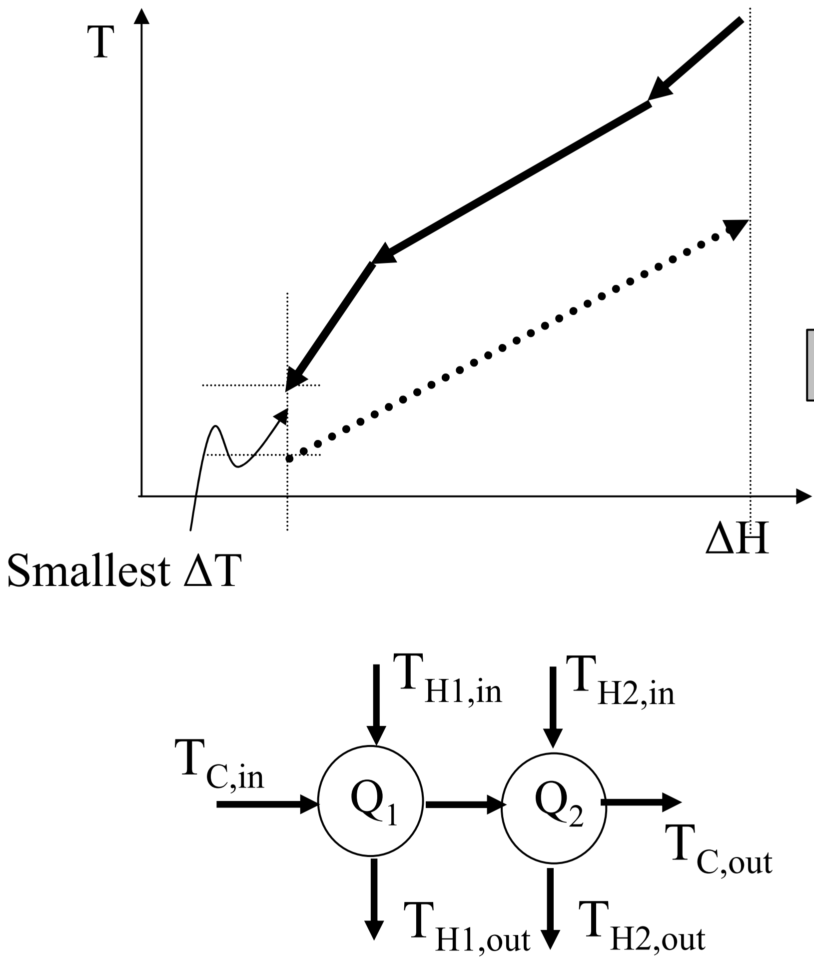


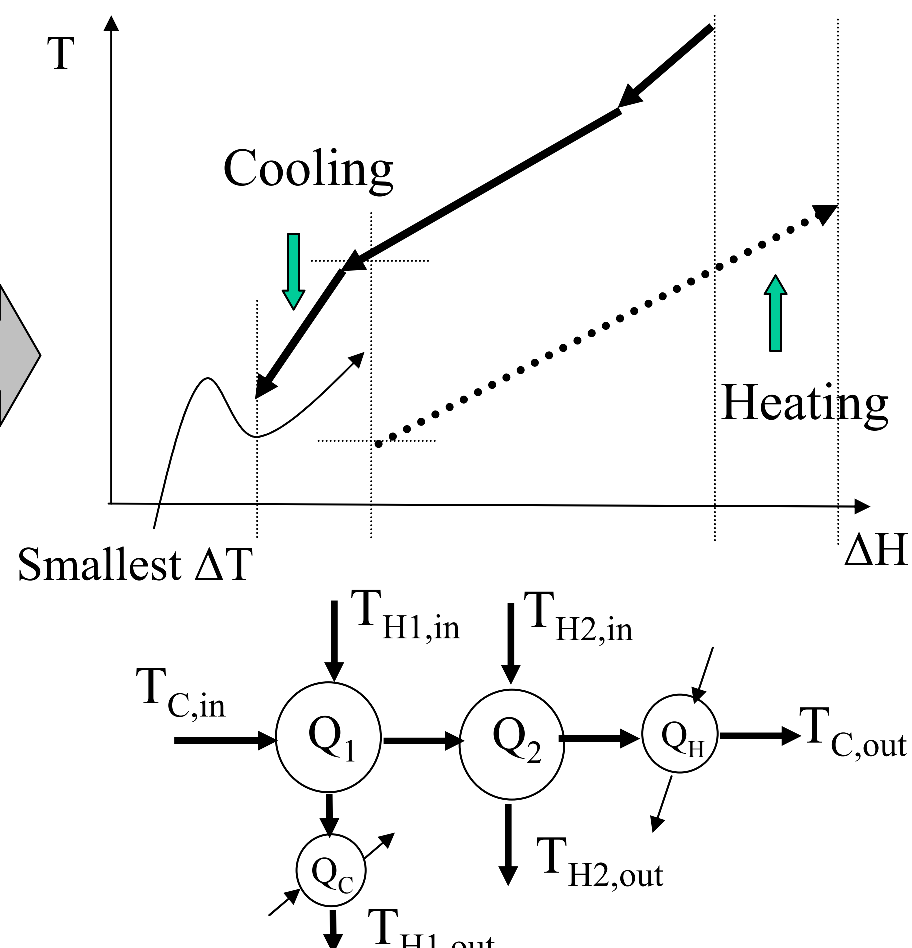


Remark: By constructing the composite curve we loose information on the vertical arrangement of heat transfer between streams

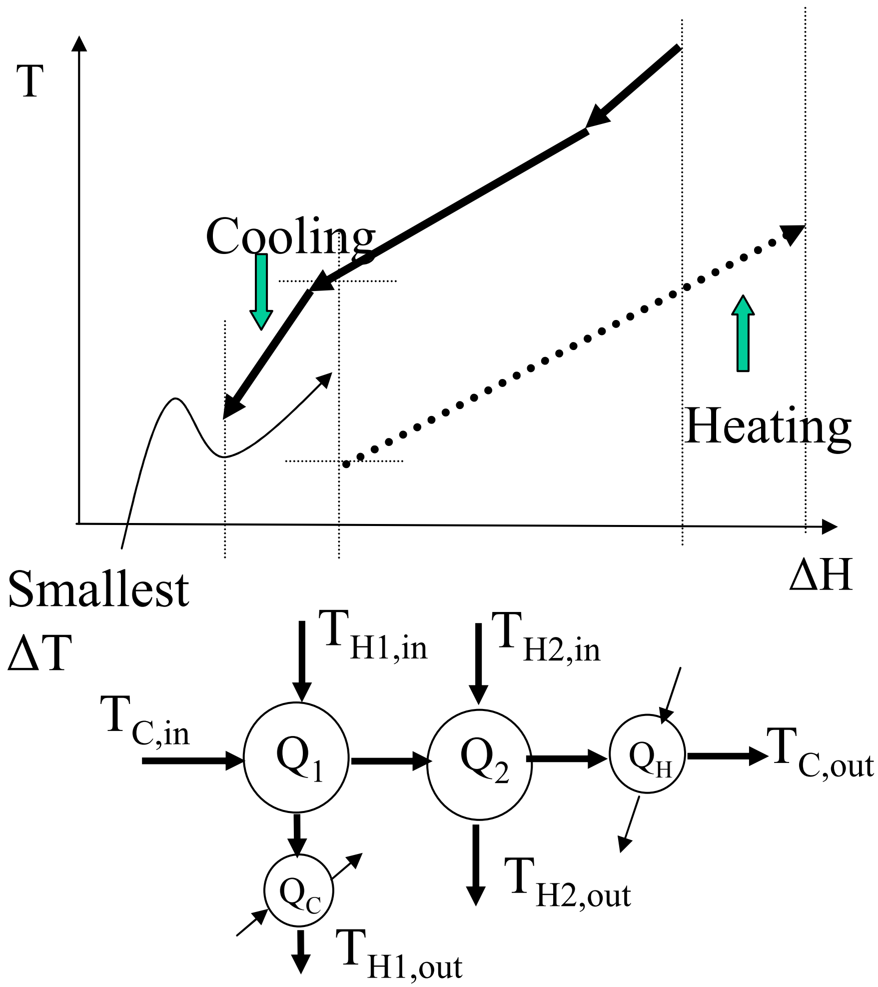
T-H DIAGRAMS

- Moving composite curves horizontally





T-H DIAGRAMS

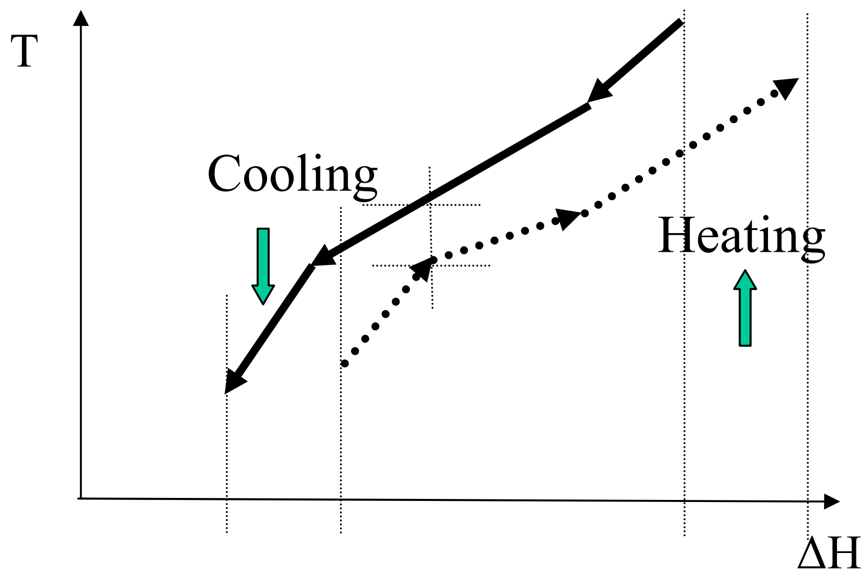


Moving the cold composite stream to the right

- Increases heating and cooling BY THE SAME AMOUNT
- Increases the smallest ΔT
- Decreases the area needed $A=Q/(U^* \Delta T)$

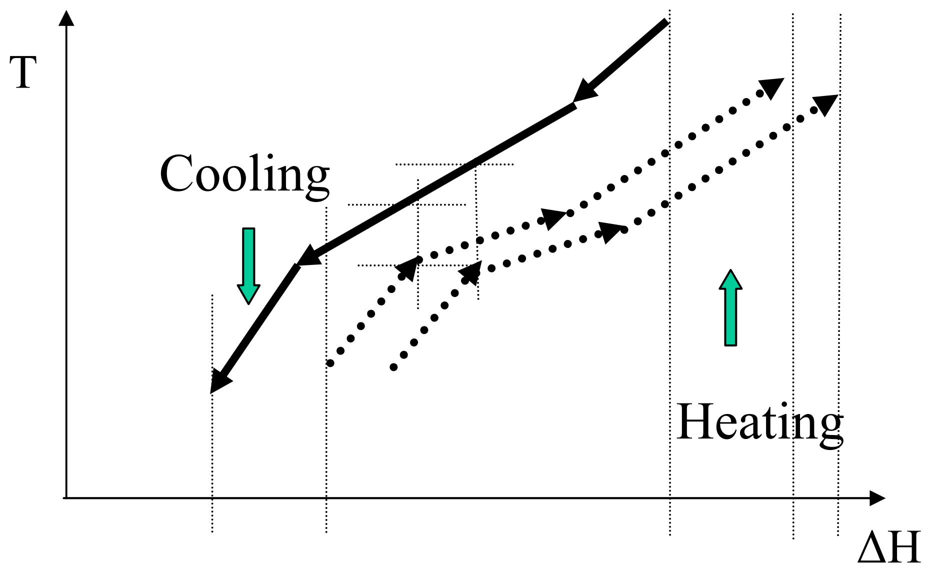
Notice that for this simple example the smallest ΔT takes place in the end of the cold stream

T-H DIAGRAMS



- ***In general, the smallest*** ΔT can take place anywhere.
- We call the temperature at which this takes place THE PINCH.

TEMPERATURE-ENTHALPY DIAGRAMS

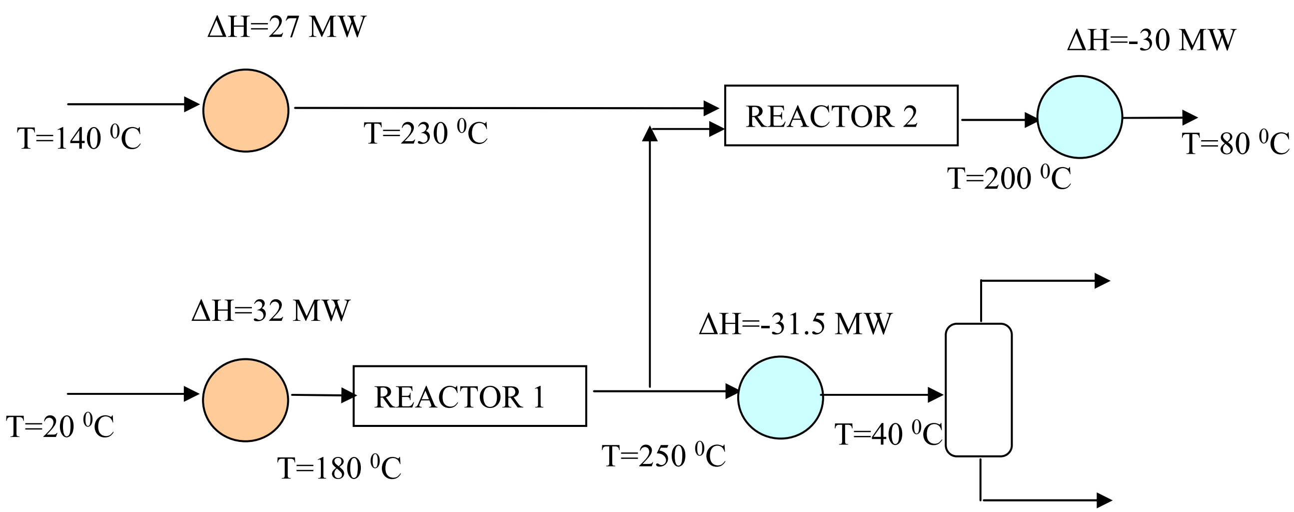


- ***From the energy point of view it is then convenient*** to move the cold stream to the left.
- However, the area may become too large.
- To limit the area, we introduce a minimum approach ΔT_{min}

GRAPHICAL PROCEDURE

- Fix ΔT_{min}
- Construct the hot and cold composite curve
- Draw the hot composite curve and leave it fixed
- Draw the cold composite curve in such a way that the smallest $\Delta T = \Delta T_{min}$
- The temperature at which $\Delta T = \Delta T_{min}$ is the PINCH
- The non-overlap on the right is the Minimum Heating Utility and the non-overlap on the left is the Minimum Cooling Utility

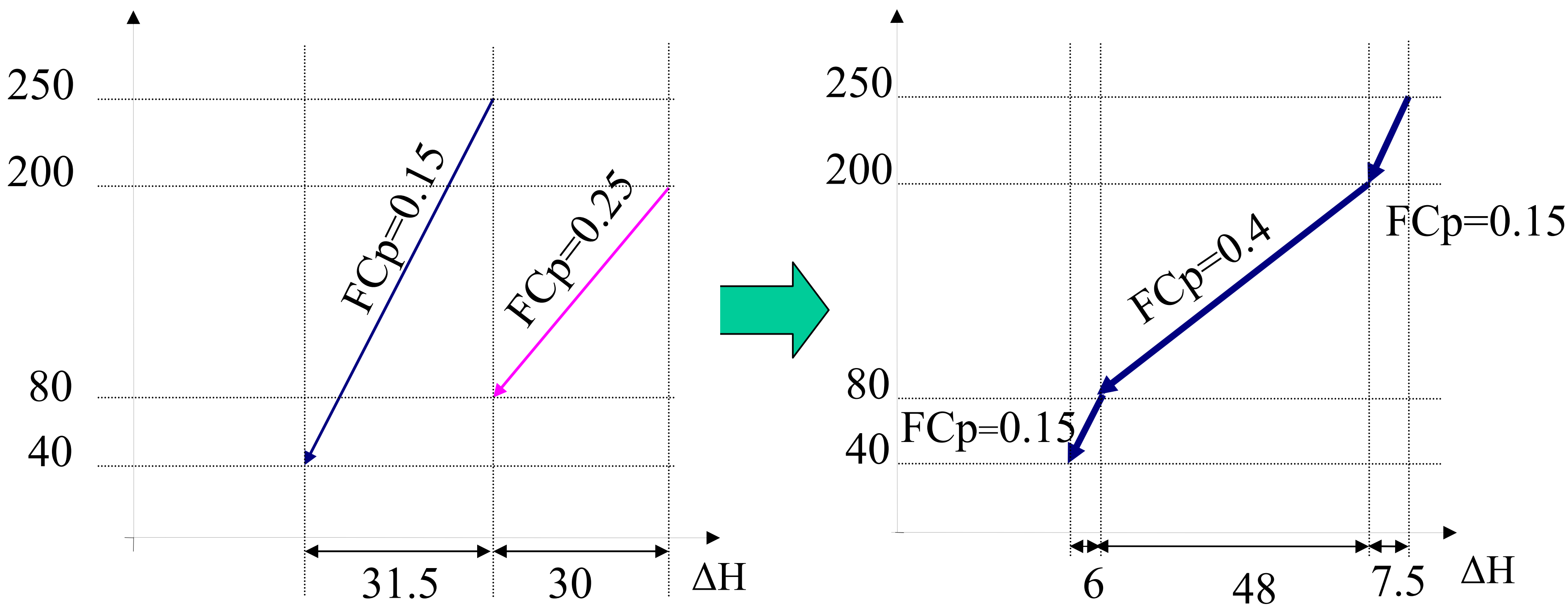
HANDS ON EXERCISE



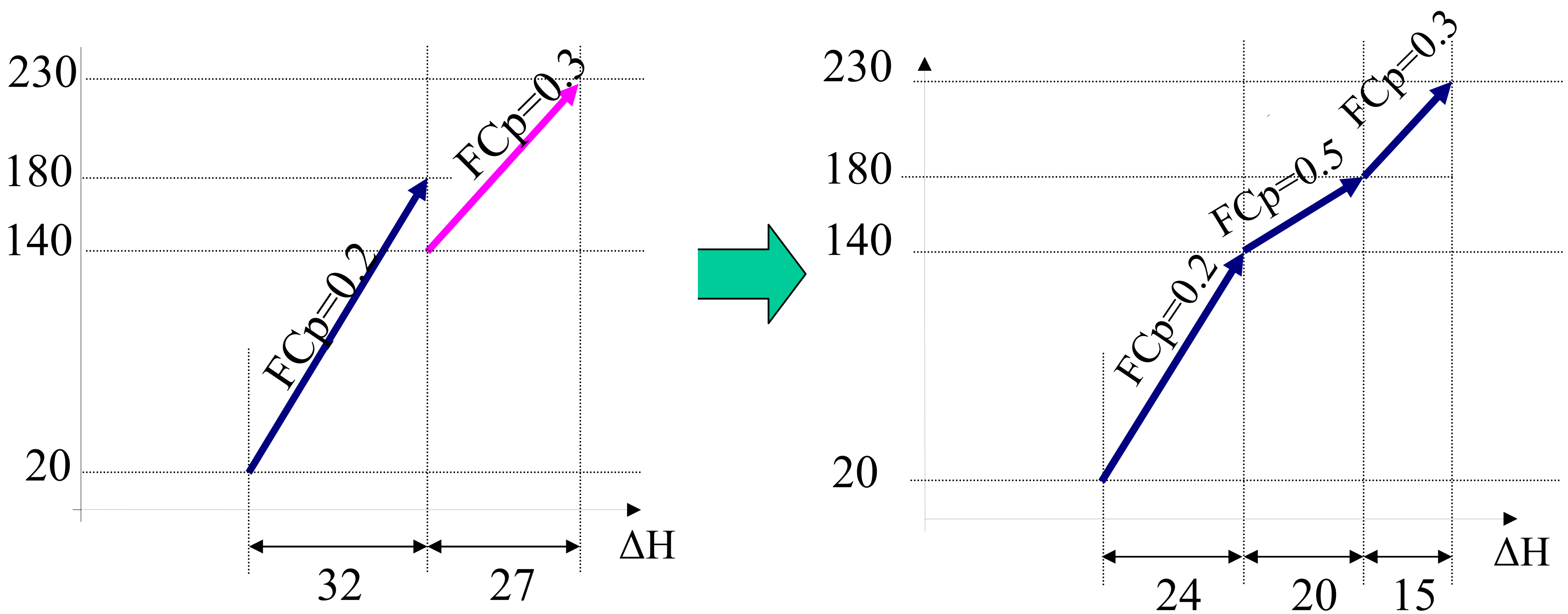
Stream	Type	Supply T (°C)	Target T (°C)	ΔH (MW)	F*Cp (MW °C^{-1})
Reactor 1 feed	Cold	20	180	32.0	0.2
Reactor 1 product	Hot	250	40	-31.5	0.15
Reactor 2 feed	Cold	140	230	27.0	0.3
Reactor 1 product	Hot	200	80	-30.0	0.25

ΔT_{min}=10 °C

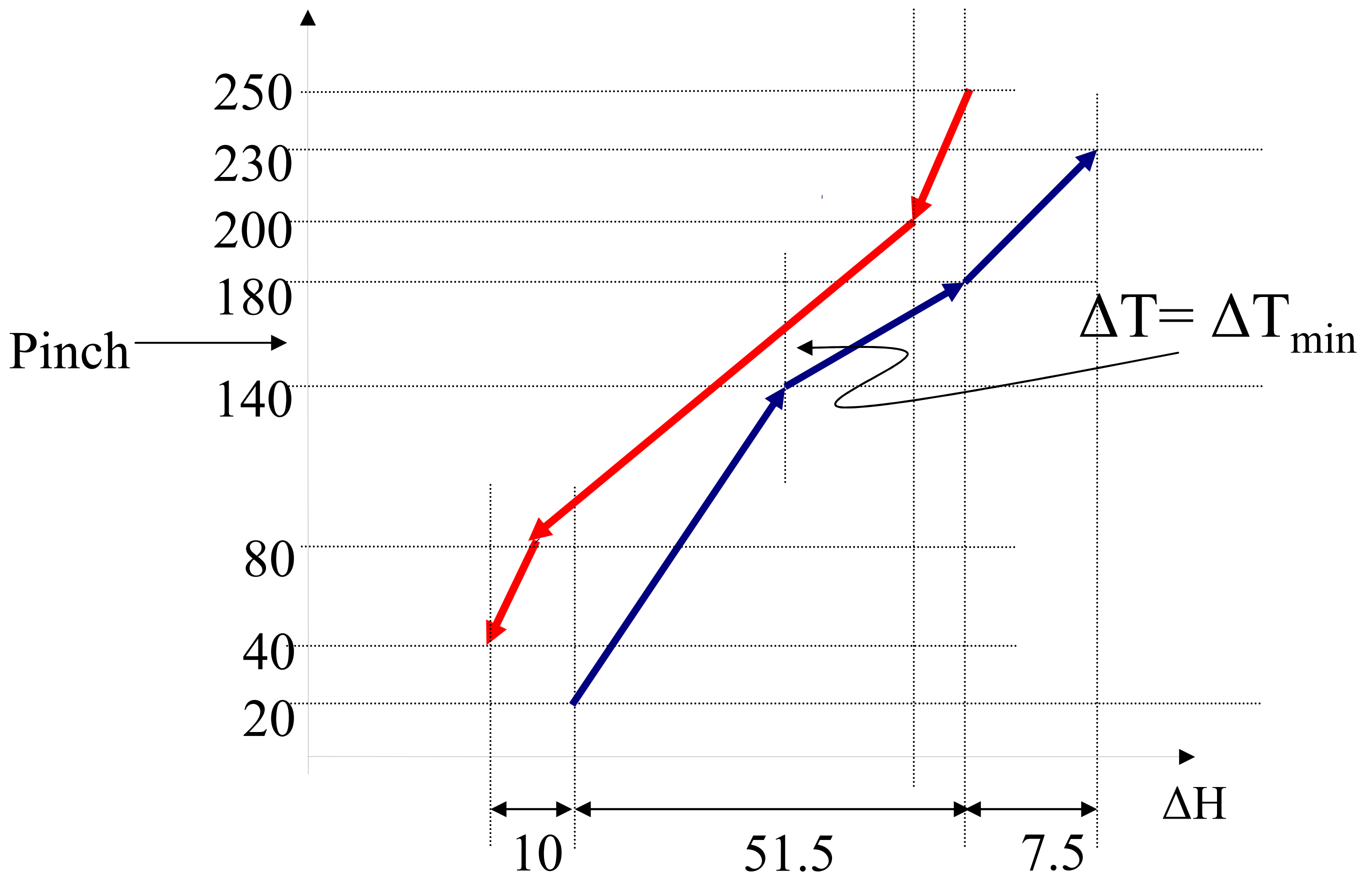
Answer: Hot Streams



Answer: Cold Streams



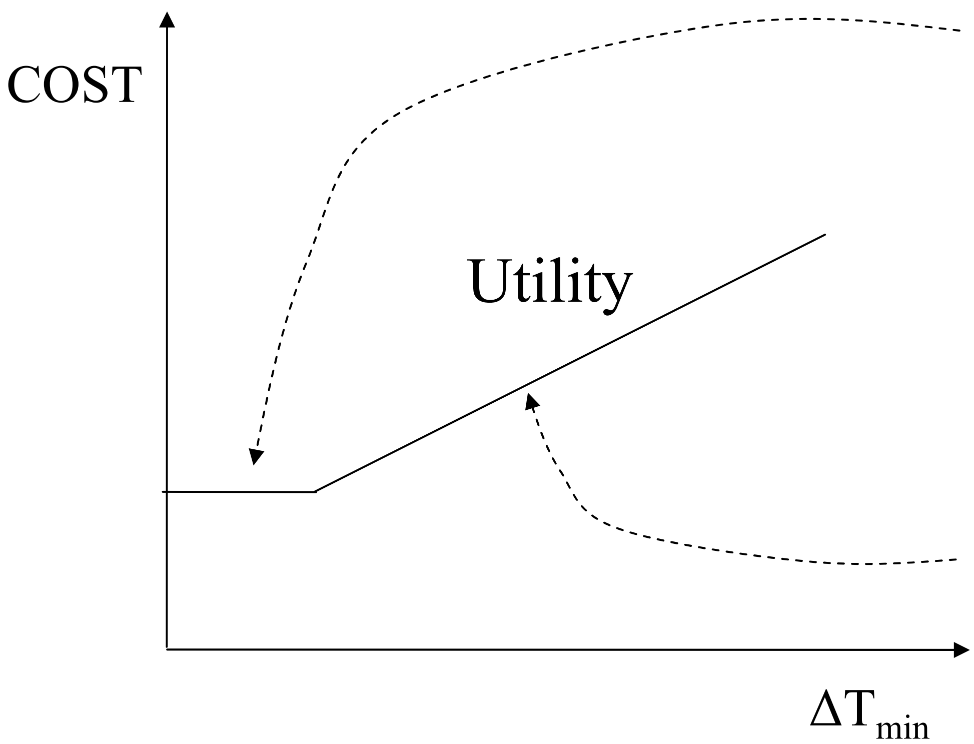
Answer: Both Curves Together.

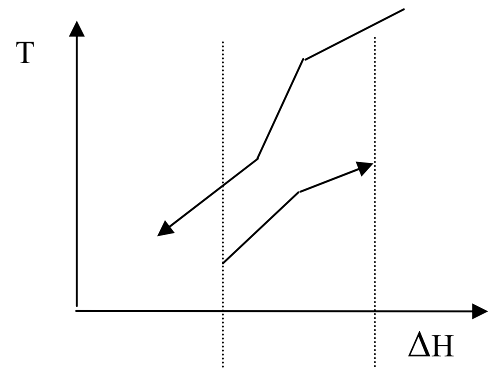


Important observation: The pinch is at the beginning of a cold stream or at the beginning of a hot stream.

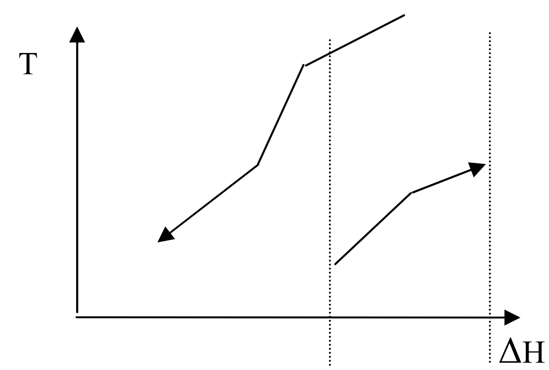
UTILITY COST vs. ΔT_{min}

- There is total overlap for some values of ΔT_{min}





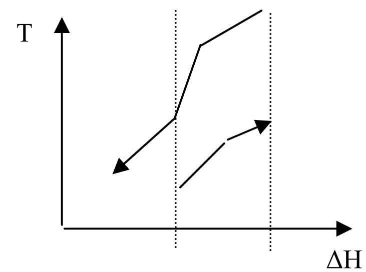
TOTAL OVERLAP



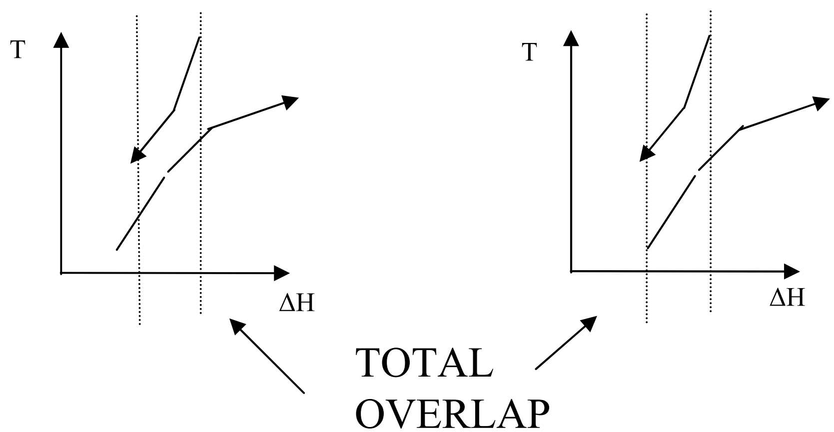
PARTIAL OVERLAP

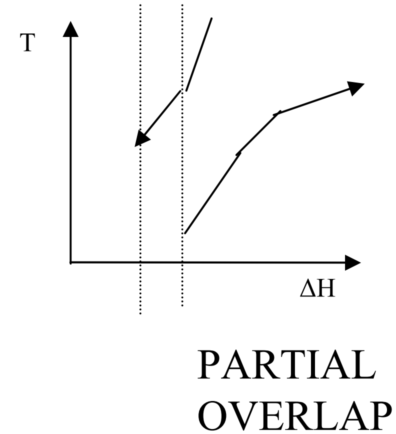
Note: There is a particular overlap that requires only cooling utility

- Overlap leads only to cooling utility



- Different instances where the cold stream overlaps totally the hot stream. Case where only heating utility





SUMMARY

- The pinch point is a temperature.
- Typically, it divides the temperature range into two regions.
- Heating utility can be used only above the pinch and cooling utility only below it.

PROBLEM TABLE

- Composite curves are inconvenient. Thus a method based on tables was developed.

- STEPS:
    1. Divide the temperature range into intervals and shift the cold temperature scale
    2. Make a heat balance in each interval
    3. Cascade the heat surplus/deficit through the intervals.
    4. Add heat so that no deficit is cascaded

PROBLEM TABLE

- We now explain each step in detail.

Consider the example 1.1

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
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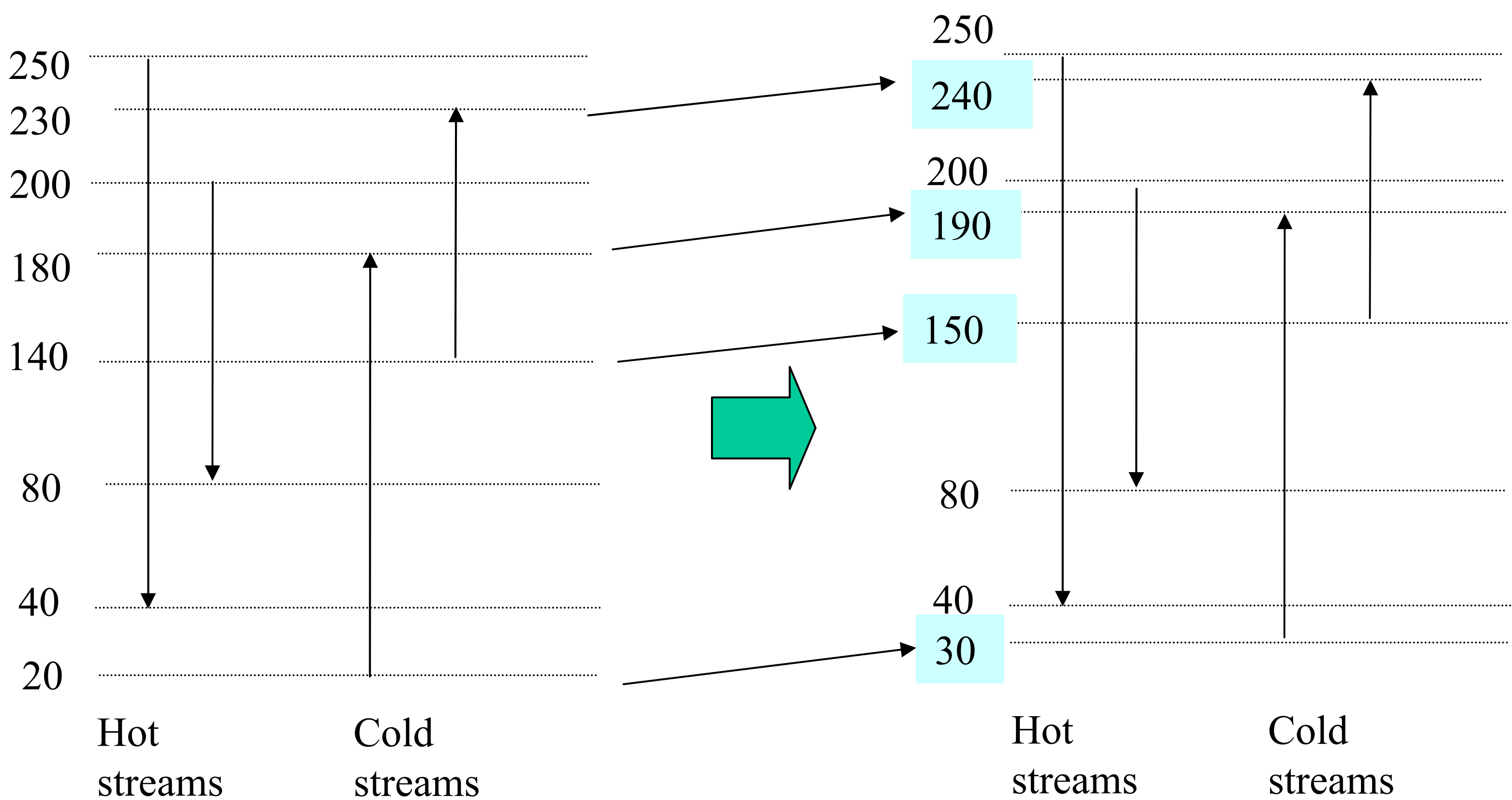
ΔT_{min}=10 °C

PROBLEM TABLE

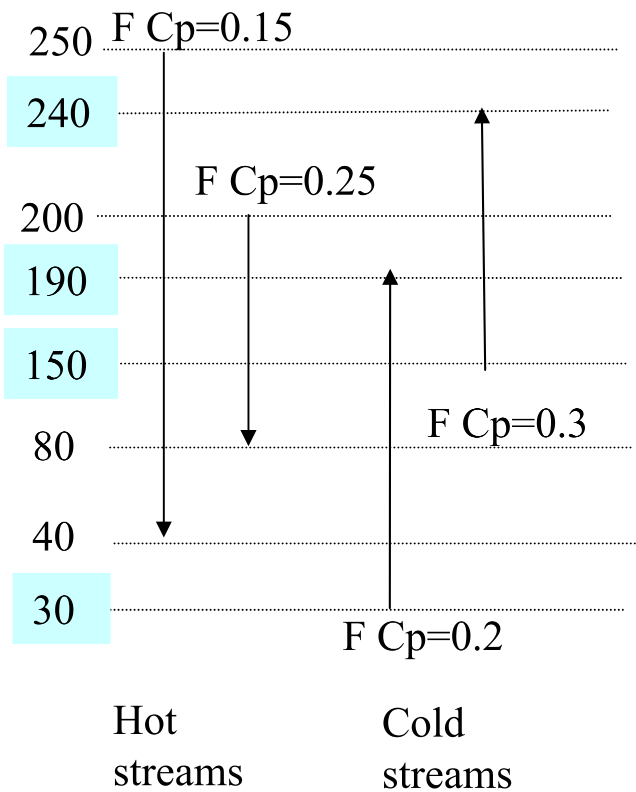
1. Divide the temperature range into intervals and shift the cold temperature scale



Now one can make heat balances in each interval. Heat transfer within each interval is feasible.

PROBLEM TABLE

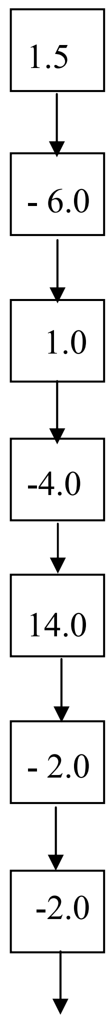
2. Make a heat balance in each interval. (We now turn into a table format distorting the scale)



$\Delta T_{interval}$	$\Delta H_{interval}$	**Surplus/Deficit?**
10	1.5	Surplus
40	- 6.0	Deficit
10	1.0	Surplus
40	-4.0	Deficit
70	14.0	Surplus
40	-2.0	Deficit
10	- 2.0	Deficit

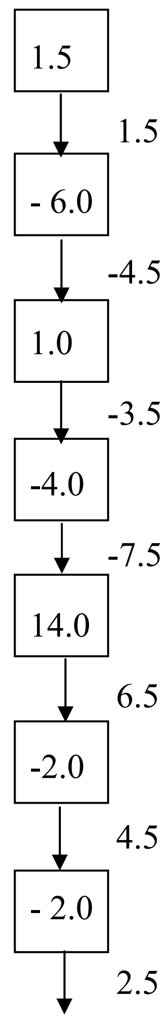
PROBLEM TABLE

3. Cascade the heat surplus through the intervals. That is, we transfer to the intervals below every surplus/deficit.



This interval has a surplus. It should transfer 1.5 to interval 2.

This interval has a deficit. After using the 1.5 cascaded it transfers –4.5 to interval 3.

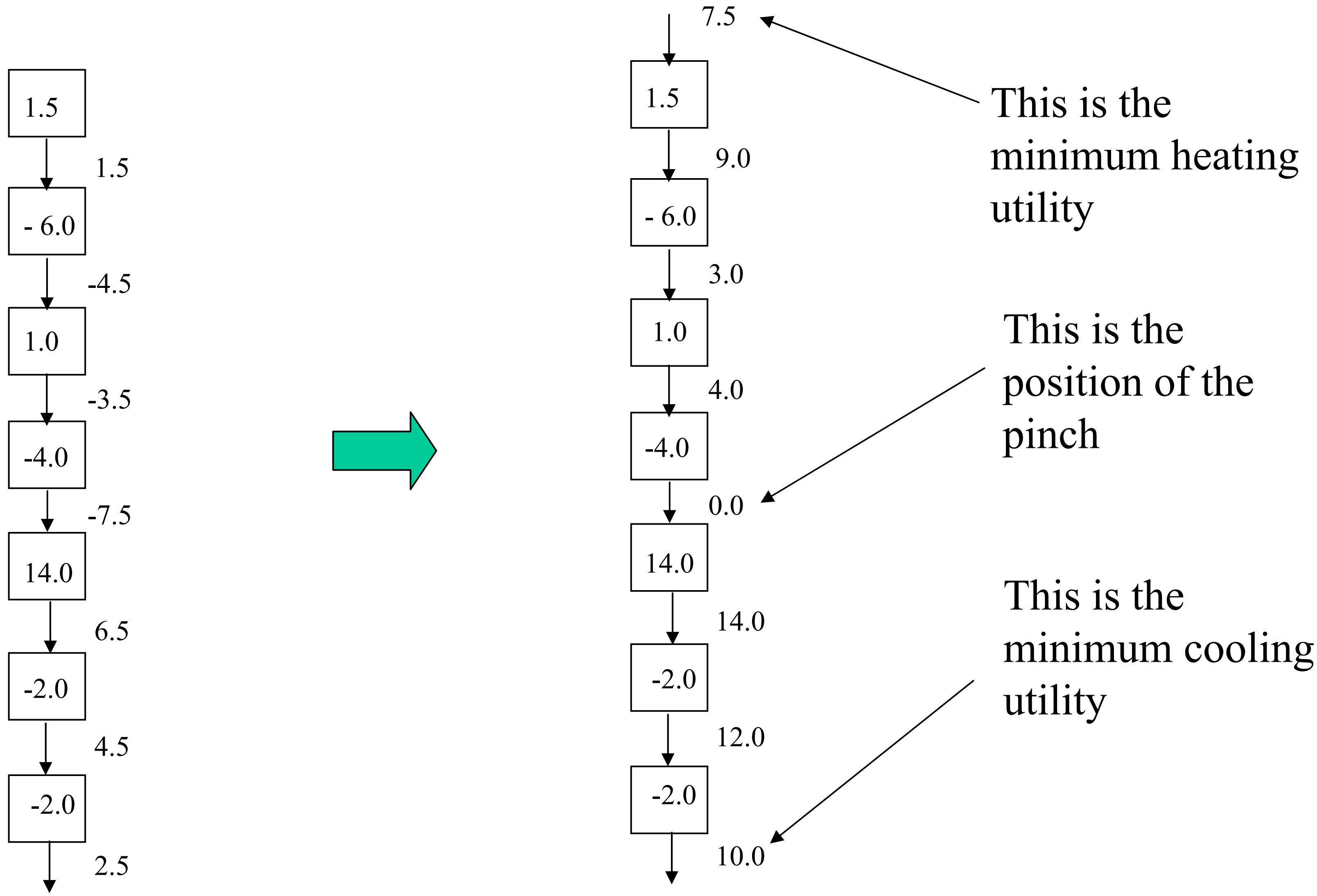


The largest deficit transferred is -7.5.

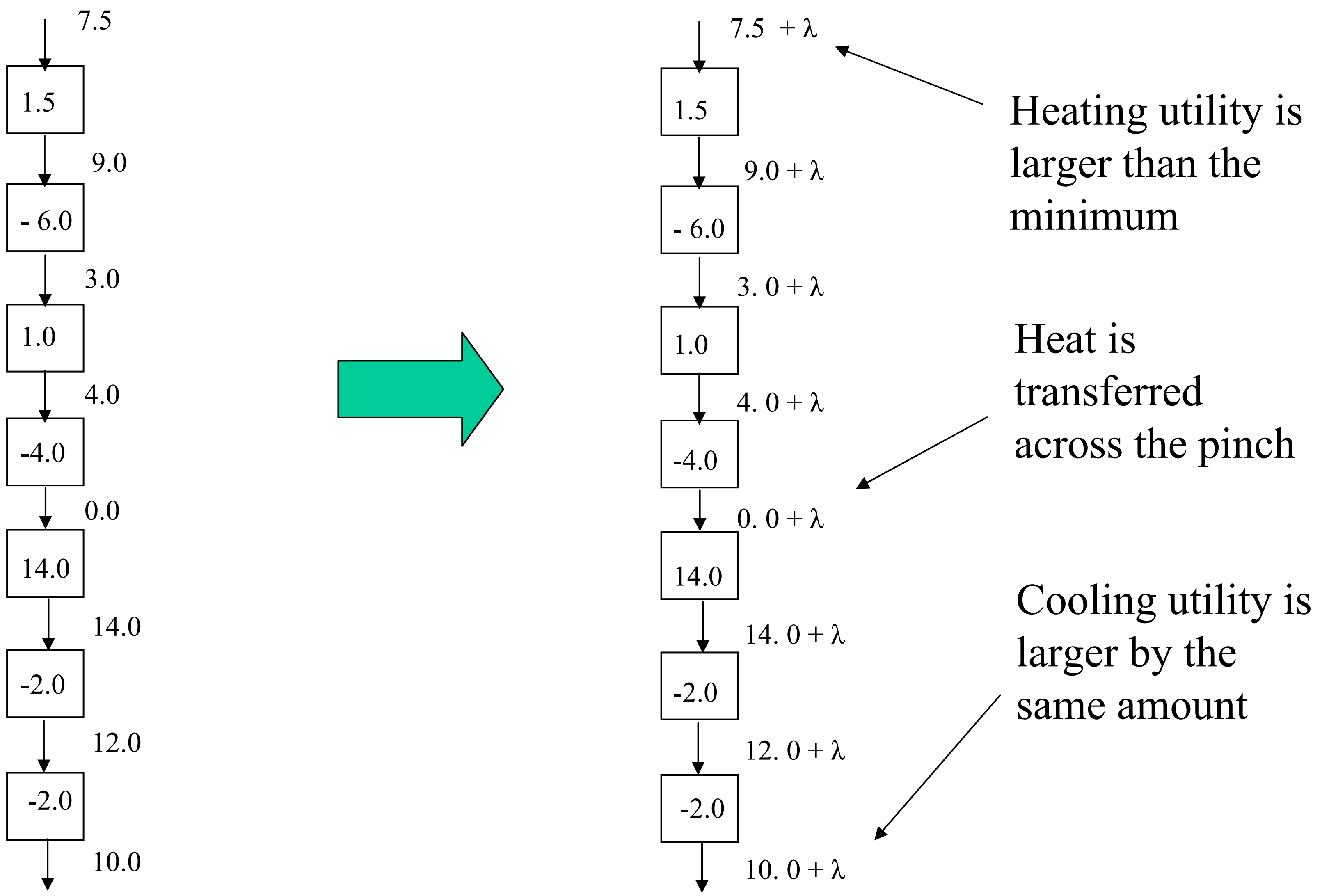
Thus, 7.5 MW of heat need to be added on top to prevent any deficit to be transferred to lower intervals

PROBLEM TABLE

4. Add heat so that no deficit is cascaded.



If the heating utility is increased beyond 7.5 MW the cooling utility will increase by the same amount

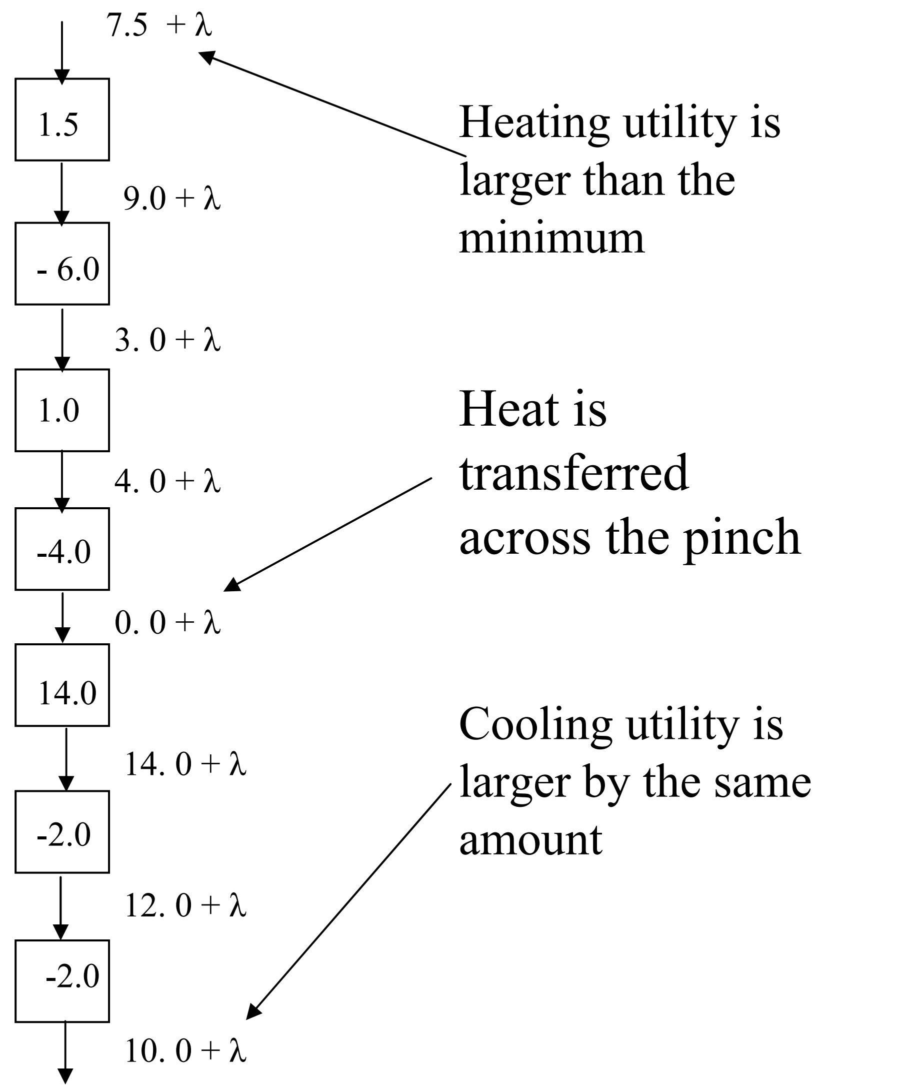


IMPORTANT CONCLUSION

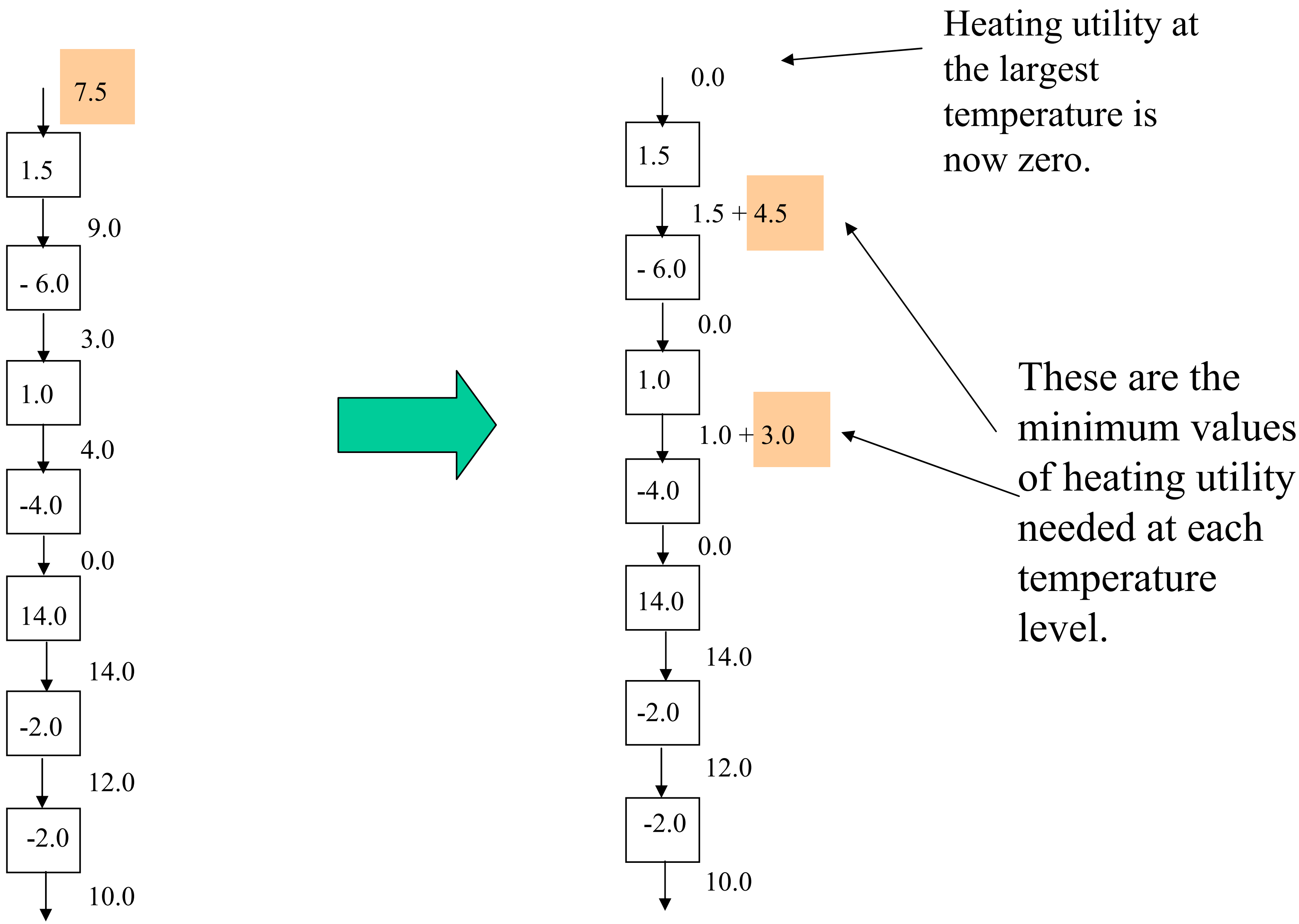
DO NOT TRANSFER HEAT ACROSS THE PINCH

THIS IS A GOLDEN RULE OF PINCH TECHNOLOGY.

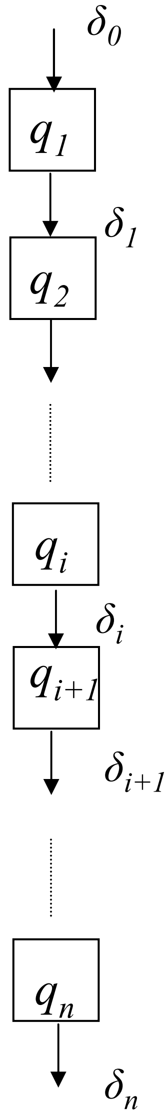
- ***WE WILL SEE LATER HOW THIS IS RELAXED FOR DIFFERENT PURPOSES***
- ***WHEN THIS HAPPENS IN BADLY INTEGRATED PLANTS THERE ARE HEAT EXCHANGERS WHERE SUCH TRANSFER ACROSS THE PINCH TAKES PLACE***



Heating utility of smaller temperatures



MATHEMATICAL MODEL



Let q_i be the surplus or demand of heat in interval i .
It is given by:

$$q_i = \sum_{k \in \Gamma_i^H} F_k^H cp_k^H (T_{i-1} - T_i) - \sum_{s \in \Gamma_i^C} F_s^C cp_s^C (T_{i-1} - T_i)$$

The minimum heating utility is obtained by solving the following linear programming (LP) problem

$$S_{\min} = Min\ \delta_0$$

$$s.t$$

$$\delta_i = \delta_{i-1} + q_i \quad \forall i = 1, \dots m_I$$

$$\delta_i \geq 0$$

We showed already how to find the solution to this problem. We remark now this mathematical model because we will extend it later to one that will enable us to design networks.

IS PINCH TECHNOLGY CURRENT?

- YES and NO.
- It is a good first approach to most problems.
- Pinch technology is at the root of any other heat integration technology. It is impossible to understand them without the basic concepts of pinch technology.

WHAT IS A PINCH DESIGN

- A heat exchanger network obtained using the pinch design method is a network where no heat is transferred from a hot stream whose temperature is above the pinch to a cold stream whose temperature is below the pinch.