PART 1

PINCH AND MINIMUM UTILITY USAGE
TEMPERATURE-ENTHALPY (T-H) DIAGRAMS

- Assume one heat exchanger. These are alternative representations.

\[ T_{H,in} \rightarrow Q \rightarrow T_{C,\text{out}} \]

\[ T_{C,in} \rightarrow Q \rightarrow T_{H,\text{out}} \]

Slopes are the inverse of \( F \cdot C_p \).

(Recall that \( Q = F \cdot C_p \cdot \Delta T \))
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
 Streams under phase change

We say this stream has “variable Cp”
Piece-wise linear representation
Remark: By constructing the composite curve we loose information on the vertical arrangement of heat transfer between streams.

Obtained by lumping all the heat from different streams that are at the same interval of temperature.
Composite Curves (T-H DIAGRAMS)

- Moving composite curves horizontally

Smallest $\Delta T$

$T$

$\Delta H$

Cooling

Heating

$T_{C,in}$

$T_{H1,in}$

$T_{H2,in}$

$T_{C,out}$

$T_{H1,out}$

$T_{H2,out}$

$Q_1$

$Q_2$

$Q_H$

$T_{H1,in}$

$T_{H2,in}$
Moving the cold composite stream to the right

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

Notice that for this simple example the smallest ΔT takes place in the end of the cold stream
Composite Curves (T-H DIAGRAMS)

- *In general, the smallest* \( \Delta T \) *can take place anywhere.*

- We call the temperature at which this takes place THE PINCH.
Composite Curves (T-H 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 $\Delta T_{\text{min}}$

$\Delta T_{\text{min}}$ is also known as HRAT (Heat Recovery Approximation Temperature)
GRAPHICAL PROCEDURE

• Fix $\Delta T_{\text{min}}$ (HRAT)
• Draw the hot composite curve and leave it fixed
• Draw the cold composite curve in such a way that the smallest temperature difference is equal to $\Delta T_{\text{min}}$
• The temperature at which $\Delta T=\Delta T_{\text{min}}$ 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
### EXAMPLE

<table>
<thead>
<tr>
<th>Stream</th>
<th>Type</th>
<th>Supply T (°C)</th>
<th>Target T (°C)</th>
<th>ΔH (MW)</th>
<th>F*Cp (MW °C⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactor 1 feed</td>
<td>Cold</td>
<td>20</td>
<td>180</td>
<td>32.0</td>
<td>0.2</td>
</tr>
<tr>
<td>Reactor 1 product</td>
<td>Hot</td>
<td>250</td>
<td>40</td>
<td>-31.5</td>
<td>0.15</td>
</tr>
<tr>
<td>Reactor 2 feed</td>
<td>Cold</td>
<td>140</td>
<td>230</td>
<td>27.0</td>
<td>0.3</td>
</tr>
<tr>
<td>Reactor 2 product</td>
<td>Hot</td>
<td>200</td>
<td>80</td>
<td>-30.0</td>
<td>0.25</td>
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ΔT\text{min}=10 °C
Hot Composite Curve

![Graph showing Hot Composite Curve with FCp values 0.15 and 0.25]
Cold Composite Curve

\[ \Delta H \]

\[ \text{FCp} = 0.2 \quad \text{FCp} = 0.3 \]

\[ \Delta H \]

\[ \text{FCp} = 0.2 \quad \text{FCp} = 0.5 \quad \text{FCp} = 0.3 \]

\[ \Delta H \]

230
180
140
20

32
27

24
20
15
Observation: The pinch is at the beginning of a cold stream or at the beginning of a hot stream
Note: There is a particular overlap that requires only cooling utility
Special Overlap Cases

- Overlap leads only to cooling utility

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

We prefer this arrangement even if $\Delta T > \Delta T_{\text{min}}$

TOTAL OVERLAP

PARTIAL OVERLAP
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
We now explain each step in detail using our example

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ΔT_{min} = 10 °C
## PROBLEM TABLE

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

<table>
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<th>Hot streams</th>
<th>Cold streams</th>
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<td>150</td>
</tr>
<tr>
<td>150</td>
<td>80</td>
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</table>

Now one can make heat balances in each interval. Heat transfer within each interval is feasible.
2. Make a heat balance in each interval.

<table>
<thead>
<tr>
<th>ΔT_{interval}</th>
<th>ΔH_{interval}</th>
<th>Surplus/Deficit</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>1.5</td>
<td>Surplus</td>
</tr>
<tr>
<td>40</td>
<td>-6.0</td>
<td>Deficit</td>
</tr>
<tr>
<td>10</td>
<td>1.0</td>
<td>Surplus</td>
</tr>
<tr>
<td>40</td>
<td>-4.0</td>
<td>Deficit</td>
</tr>
<tr>
<td>70</td>
<td>14.0</td>
<td>Surplus</td>
</tr>
<tr>
<td>40</td>
<td>-2.0</td>
<td>Deficit</td>
</tr>
<tr>
<td>10</td>
<td>-2.0</td>
<td>Deficit</td>
</tr>
</tbody>
</table>

F Cp = 0.15

- 250: Hot streams
- 240: Cold streams

F Cp = 0.25

- 200: Hot streams
- 190: Cold streams

F Cp = 0.2

- 150: Hot streams
- 140: Cold streams

F Cp = 0.3

- 80: Hot streams
- 70: Cold streams
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.
4. Add heat so that no deficit is cascaded.

This is the position of the pinch

This is the minimum heating utility

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

Heat is transferred across the pinch.

Heating utility is larger than the minimum.

Cooling utility is larger by the same amount.
IMPORTANT CONCLUSION

DO NOT TRANSFER HEAT ACROSS THE PINCH

THIS IS A GOLDEN RULE OF PINCH TECHNOLOGY.

• WHEN THIS HAPPENS IN BADLY INTEGRATED PLANTS THERE ARE HEAT EXCHANGERS WHERE SUCH TRANSFER ACROSS THE PINCH TAKES PLACE
Multiple Utilities

These are the minimum values of heating utility needed at each temperature level.

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Heating Utility</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>-6.0</td>
<td>3.0</td>
</tr>
<tr>
<td>1.0</td>
<td>1.0 + 3.0</td>
</tr>
<tr>
<td>-4.0</td>
<td>0.0</td>
</tr>
<tr>
<td>14.0</td>
<td>14.0</td>
</tr>
<tr>
<td>-2.0</td>
<td>12.0</td>
</tr>
<tr>
<td>-2.0</td>
<td>10.0</td>
</tr>
</tbody>
</table>

Heating utility at the largest temperature is now zero.

These are the minimum values of heating utility needed at each temperature level.