Threshold Problems

**Key words:** Threshold

There are some special category of problems, known as threshold problems, do not have a pinch to divide the problem into two parts. Threshold problems only need a single thermal utility (either hot or cold but not both) over a range of minimum temperature difference ranging from zero to threshold temperature.

![Diagram](image)

**Fig.3.26** (a), (b) & (c) Threshold problems for different $\Delta T_{min}$ values

For example, in Fig.3.26(a) the problem which is at $\Delta T_{min} = T_{threshold}$ requires only one utility i.e. hot utility of $Q_H$ amount. When $\Delta T_{min} \leq T_{threshold}$ as in the case of Fig.3.26(b) at positions “A” and “B” the hot utility demand is still $Q_H$. In the case of “A” two levels of hot utility is required. In the case of position “B” the hot utility demand is $Q_1$ and $Q_2$ sum of which is equal to $Q_H$. Hence it can be concluded that for $\Delta T_{min} \leq T_{threshold}$ the energy demand is not a function of relative positions of Hot and cold composite curves. This is a weakness of pinch analysis[1,2]. However, this weakness can be supplemented
through exergy analysis which provides the lost in-sight. For “a” and “B” positions of cold composite the exergy needs are strongly affected, because of the different temperature levels[2].

![Diagram](image)

**Fig.3.27 (a), (b) & (c) Threshold problems for different \( \Delta T_{\text{min}} \) values**

Fig.3.27(a) shows a threshold problem for which hot utility is zero. It only demands cold utility up to \( T_{\text{threshold}} \). Fig.3.27(b) shows the effect of energy demand in terms of cold and hot utilities if the cold composite curve is shifted horizontally to positions “A” and “C”. At position “B” which is at \( \Delta T_{\text{min}} = T_{\text{threshold}} \) the hot utility demand is zero whereas the cold utility demand is \( Q_C \). When the cold composite is shifted to position “A” where \( \Delta T_{\text{min}} < T_{\text{threshold}} \) it demands \( Q_{C1} \) cold utility at a higher level and \( Q_{C2} \) cold utility at a lower level. Where, the sum of \( Q_{C1} \) and \( Q_{C2} \) being equal to \( Q_C \). For the position “C” where \( \Delta T_{\text{min}} > T_{\text{threshold}} \) the process demands both cold and hot utilities. Thus in this case also for \( \Delta T_{\text{min}} \leq T_{\text{threshold}} \) the cold utility demand is constant and hot utility demand is zero which is shown in Fig.3.27(c).

In contrast to the threshold problem Fig.3.28 shows a “pinched” problem. In this figure both hot and cold utilities are required even if \( \Delta T_{\text{min}} \) is reduced to zero( Fig.3.28(b)). Further, both the utilities are a function of \( \Delta T_{\text{min}} \).
Threshold problems can be divided into two broad categories for purpose of design. In the first type, the closest temperature approach between the hot and cold composites is at the “non-utility” end and the curves diverge away from this point (Fig. 3.29(a) & (b)). The second type, there is an intermediate near-pinches, which can be identified from the composite curves as a region of close temperature approach (Fig. 3.29(c) & (d)).
Threshold Processes

Module-03

Lecture-08

Capital-energy trade-off for threshold problems

Fig.3.30 shows the fixed cost-energy cost trade off as a function of $\Delta T_{\text{min}}$. It can be clearly observed that the optimum value either appears when $\Delta T_{\text{min}}$ is at $T_{\text{threshold}}$ or more than $T_{\text{threshold}}$. It never happens when $\Delta T_{\text{min}} < T_{\text{threshold}}$. This is because when $\Delta T_{\text{min}} \leq T_{\text{threshold}}$ the operating costs are constant since utility demand is constant. Fig.3.30(a) shows that optimum is at $T_{\text{threshold}}$ where as Fig.3.30(b) shows that it is at location where $\Delta T_{\text{min}} > T_{\text{threshold}}$. In this case there is a demand for both the utilities and thus the problem where there is a pinch. However, in the case demonstrated in Fig.3.30(a) there is no pinch.

It can be noted that although threshold problems common and these do not have a process pinch, utility pinches can be introduced in such problems by the induction of multiple utilities.
Threshold problems are generally handled in design as multiple pinch problems.

Example 01

A four stream threshold problem is given in Table 3.9. The Hot and cold composite curves are given in Fig.3.31. The hot utility demand for this problem at $\Delta T_{\text{min}}$ equal to 10 °C is zero and cold utility demand is 239.5 kW. Fig.3.32 shows the hot and cold utility demand as a function of $\Delta T_{\text{min}}$ and the value of $T_{\text{threshold}}$. 
Table 3.9: Four stream problem utility prediction for $\Delta T_{\text{min}}$ equal to 10°C.

<table>
<thead>
<tr>
<th>Name of the stream</th>
<th>Supply Temperature $T_s$, °C</th>
<th>Target Temperature $T_t$, °C</th>
<th>CP $\text{kW/}^\circ\text{C}$</th>
<th>$\Delta H$, kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot-1</td>
<td>190</td>
<td>55</td>
<td>3.5</td>
<td>-472.5</td>
</tr>
<tr>
<td>Hot-2</td>
<td>155</td>
<td>40</td>
<td>1.8</td>
<td>-207</td>
</tr>
<tr>
<td>Cold-1</td>
<td>20</td>
<td>140</td>
<td>2</td>
<td>240</td>
</tr>
<tr>
<td>Cold-2</td>
<td>70</td>
<td>150</td>
<td>2.5</td>
<td>200</td>
</tr>
</tbody>
</table>

Fig. 3.31 Hot and cold composite curves for the threshold problem given in Table 3.9

Cold utility = 239.5 kW

Fig. 3.32 Hot and cold utility demand and threshold temperature for problem given in Table 3.9

Cold Utility = 239.5 kW

Threshold Temperature 36.7°C
Example -02

A four stream threshold problem is given in Table 3.10. The Hot and cold composite curves are given in Fig.3.33. The cold utility demand for this problem at $\Delta T_{\text{min}}$ equal to 10 $^\circ$C is zero and hot utility demand is 267 kW. Fig.3.34 shows the hot and cold utility demand as a function of $\Delta T_{\text{min}}$ and the value of $T_{\text{threshold}}$.

Table 3.10: Four stream problem for utility prediction for $\Delta T_{\text{min}}$ equal to 10$^\circ$C.

<table>
<thead>
<tr>
<th>Name of the stream</th>
<th>Supply Temperature $T_s$, °C</th>
<th>Target Temperature $T_t$, °C</th>
<th>$CP$ kW/°C</th>
<th>$\Delta H$ kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot-1</td>
<td>350</td>
<td>290</td>
<td>3.5</td>
<td>-210</td>
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<tr>
<td>Hot-2</td>
<td>400</td>
<td>290</td>
<td>1.8</td>
<td>-198</td>
</tr>
<tr>
<td>Cold-1</td>
<td>150</td>
<td>350</td>
<td>2</td>
<td>400</td>
</tr>
<tr>
<td>Cold-2</td>
<td>290</td>
<td>400</td>
<td>2.5</td>
<td>275</td>
</tr>
</tbody>
</table>

Fig.3.33 Hot and cold composite curves for the threshold problem given in Table 3.10
Fig. 3.34 Hot and cold utility demand and threshold temperature for problem given in Table 3.10

References

3. Linnhoff March, “Introduction to Pinch Technology” Targeting House, Gadbrook Park, Northwich, Cheshire, CW9 7UZ, England
4. Chemical Process Design and Integration, Robin Smith, John Wiley & Sons Ltd.