Chapter IV

Trading Off Energy Against Capital

4.1 Minimum Number of Units

The capital cost of a chemical or petrochemical process tends to be dominated by the number of items on the flowsheet. This is certainly true for the heat exchanger network and there is a strong incentive to reduce the number of matches between hot and cold streams.

Hohmann [21: 67] defined the "quasi-minimum" number of units for a stream system as

$$N_{min} = N_{source} + N_{sink} - 1 \qquad \text{............(4-1)}$$

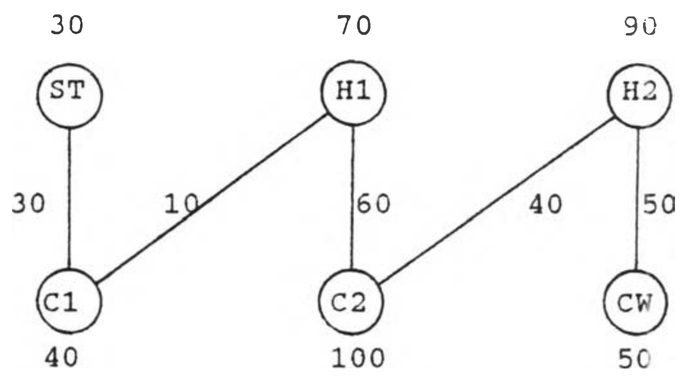
where : Nmin is the quasiminimum number of units

Nsource is the number of source streams

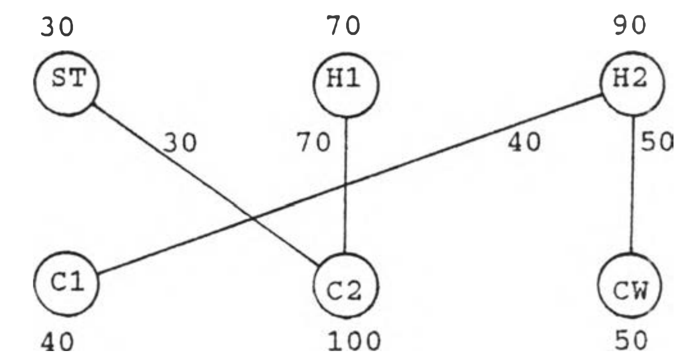
Nsink is the number of sink streams

The source streams include hot streams and hot utilities while sink streams include cold streams and cold utilities. It is normally possible in heat exchanger network design to find a Nmin solution, as will be shown.

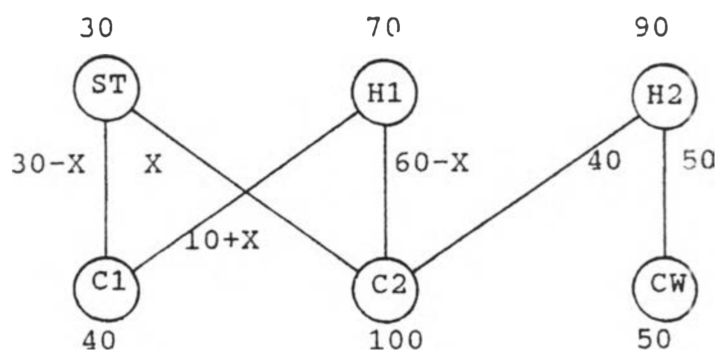
Figure 4.1 shows a problem having two hot streams (H1,H2) and two cold streams (C1,C2). The circles represent these streams, and the connecting lines represent heat transfer units. Figure 4.1(a) is used to verify the formula. It can be seen that the number of



(a) number of unit is one less than the number of streams include utilities



(b) same principle for separate components



(c) one unit more for every loop

Figure 4.1 Principle of subsets and loops units is one less than the total number of streams plus utilities in the problem as specified by equation (4-1).

However, the formula is not always correct as we can see by examining Figure 4.1(b) and (c). In Figure 4.1(b) a design is shown having one unit less, without increasing any utility. However, we may speculate that there are two completely separate networks in this design, if we apply the formula (4-1) to each individually. The total for the overall system is therefore (3-1) + (3-1) = 4 units or one less than in Figure 4.1(a). This situation is termed "subset equality".

In Figure 4.1(c) a design is shown having one unit more than the design in Figure 4.1(a), the new unit being the match between ST and C2. The extra unit introduces what is known as a "loop", a close path, into the system. The loop can be traced through the connection to C1, from C1 to H1, from H1 to C2, and from C2 back to ST.

To incorporate the subset equality and loop phenomena in an equation, Boland and Linnhoff [21: 67] explained equation (4-1) by applying Euler's network relation in graph theory as

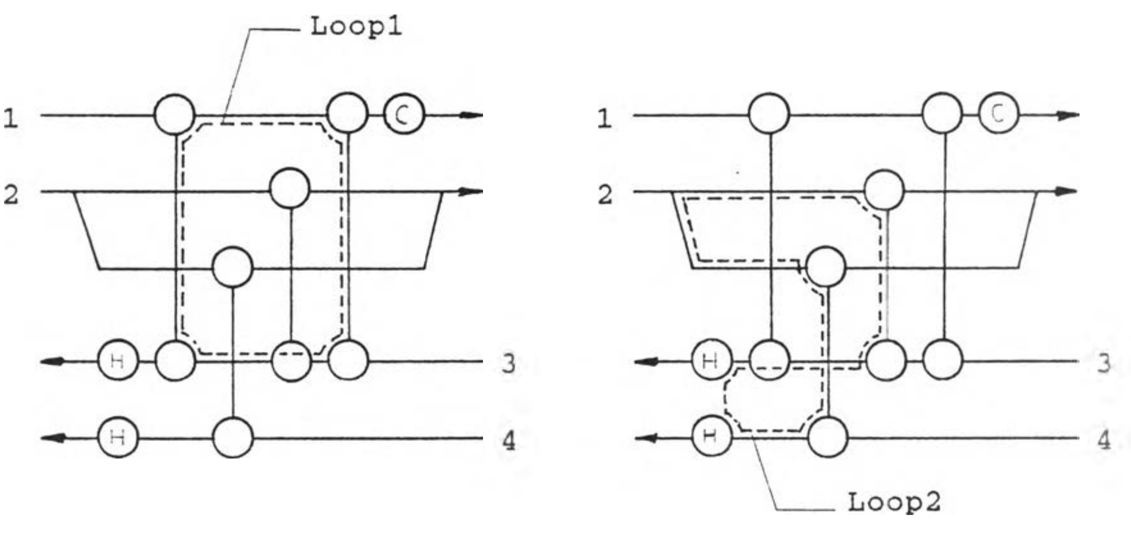
Number of lines = Number of points + Number of independent cycles - Number of components ....(4-2)

For heat exchanger networks, streams are points while heat tramsfer units represent the lines linking these points. Equation (4-2) can be restated as

Nunit = Nsource + Nsink + Number of independent heat load loop - Number of components ....(4-3)

For a system containing only one component and no loop equation (4-3) can be reduced to equation (4-1).

Therefore, if more than the quasi-minimum number of units are used there must be some heat load loop in the network. As an example, Figure 4.2 has two more units than the quasiminimum. Hence there must be two loops in the design network. Figure 4.2(a) and (b) show these loops.



(a) (b)

Figure 4.2 Showing two heat load loops

4.2 Optimum δTmin

In the "pinch" type problem, obviously an increase in δTmin results to increase both utility consumption and required heat transfer area. Since the larger the size of heat exchanger, the cheaper its cost per unit area, there must be an optimum value of utility increase which establishes the correct trade off between utility costs and capital costs (energy plus annualised capital). This optimum value coincides with the optimum δTmin.

To evaluate optimum δTmin, let us consider Figure 4.3, which shows, qualitatively the variation of a network annualised capital cost and annualised utility cost with variation in δTmin. Obviously when δTmin is equal to zero the heat exchanger network cost is infinite, as an

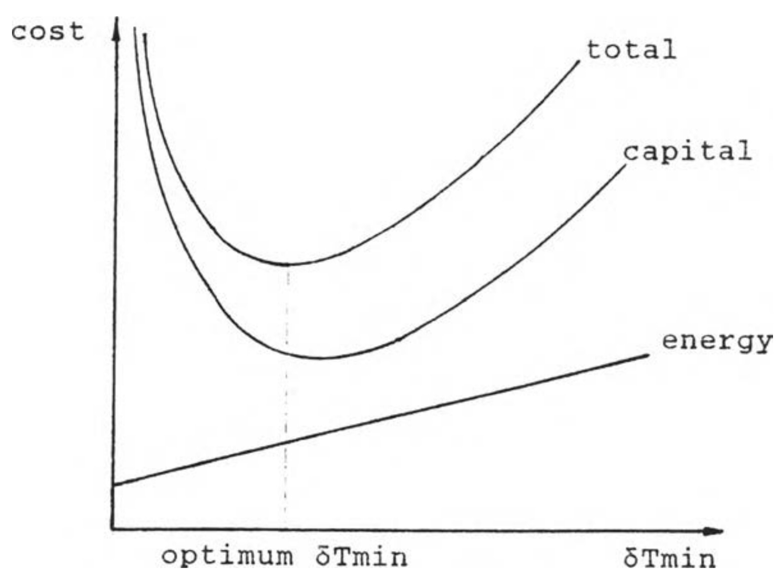


Figure 4.3 Network cost as a function of δTmin

infinite heat exchanger surface area is required. The utility usage and utility cost is at a minimum. As δTmin is increased, the network capital cost initially falls sharply but at higher value of δTmin "flattens out" and in certain problem may tend to rise again. Utility cost increase steadily with the increase in δTmin.

It is evident from Figure 4.3 that the total network cost passes through a minimum value which corresponds to a particular utility usage and δTmin.