Chapter II

Pinch Design Method

The pinch design method consists of three main steps. The first step is the preliminary thermodynamic analysis, the so-called heat-cascade calculation determining the minimum energy consumption and pinch temperature. The second step is the so-called pinch design, which involves assignment of the necessary stream splitting and appropriate structure in the neighbourhood of the pinch temperature based on the pinch design rules for avoiding the violation of minimum energy consumption. The third step is to construct the subnetworks on both sides of the pinch, gradually moving away from the pinch temperature according to heuristic rules.

2.1 Energy Targets

The starting point for an energy integration analysis is to predict the minimum heating and cooling requirements for a heat exchanger network. These can be achieved without having to specify any heat exchanger network. Similarly, we can calculate the minimum number of exchangers required to obtain the minimum unit requirements without having to specify a network. The minimum energy requirements and minimum number of exchangers provide targets for the subsequent design of a heat exchanger network.

2.1.1 First law analysis

First we consider a very simple problem where we have two streams that need to be heated and two streams that need to be cooled, as specified by the data given in Table 2.1. If we simply calculate the heat available in the hot streams and the heat required by the cold streams, the difference between these two values is the net amount of heat that we would have to remove or supply to satisfy the first law. The results are also shown in Table 2.1, and the first two entries are determined as follows:

$$Q1 = CP1 * \delta T1 = (2kW/^{\circ}c)*(150-60)^{\circ}c$$

$$= 180 \text{ kW}$$

$$Q2 = CP2 * \delta T2 = 8*(90-60)$$

$$= 240 \text{ kW}$$

Thus, 67.5 kW must be supplied from utilities if there are no restrictions on temperature-driving forces.

Table 2.1 Data for example problem [26: 745]

Stream no.	Type	Heat capacity flowrate(kw/°c)	Tsupply (°c)	Ttarget (°c)	Heat load (kW)
1	hot	2.0	150	60	180.0
2	hot	8.0	90	60	240.0
3	cold	2.5	20	125	-262.5
4	cold	3.0	25	100	-225.0
					- 67.5

The first-law calculation does not consider the fact that we can transfer heat from a hot stream to a cold stream only if the temperature of the hot stream exceeds that of the cold one. Hence, to obtain a physically realizable estimate of the required heating and cooling duties, a positive temperature driving force must always exist between the hot and cold streams. In other words, any heat exchanger network that we develop must satisfy the second law as well as the first law.

2.1.2 Prediction of energy targets using composite curve

The temperature-enthalpy diagram can be used to represent the thermal characteristics of process streams, as illustrated in Figure 2.1. Differential heat flow dQ, when added to a process stream, will increase its enthalpy, δH, by CP.dT, where

CP = heat capacity flowrate (kW/°K)
= mass flow * specific heat
dT = differential temperature change (°K).

Hence, with CP assumed constant, for a stream that requires heating (cold stream) from a supply temperature, Ts, to a target temperature, Tt, the total heat added will be equal to the stream enthalpy change, i.e.

$$Q = \int_{Ts}^{Tt} CP.dT = CP(Tt-Ts) = \delta H \quad ....(2-1)$$

In addition, the slope of the line representing the stream on the diagram is dT/dQ = 1/CP.

The T/H diagram can be used to represent heat exchange. Since we are only interested in enthalpy changes of a stream, any given stream can be plotted anywhere on the enthalpy axis, provided it has the same slope and runs between the same supply and target temperature.

For the plotting of a given set of hot and cold streams on the T/H diagram, it can be represented by two composite curves known as the hot composite and the cold composite curve, as shown typically in Figure 2.2. The hot composite is represented by the curve with the arrow head pointing to the left, and the cold composite vice versa. The hot composite must always be hotter than the

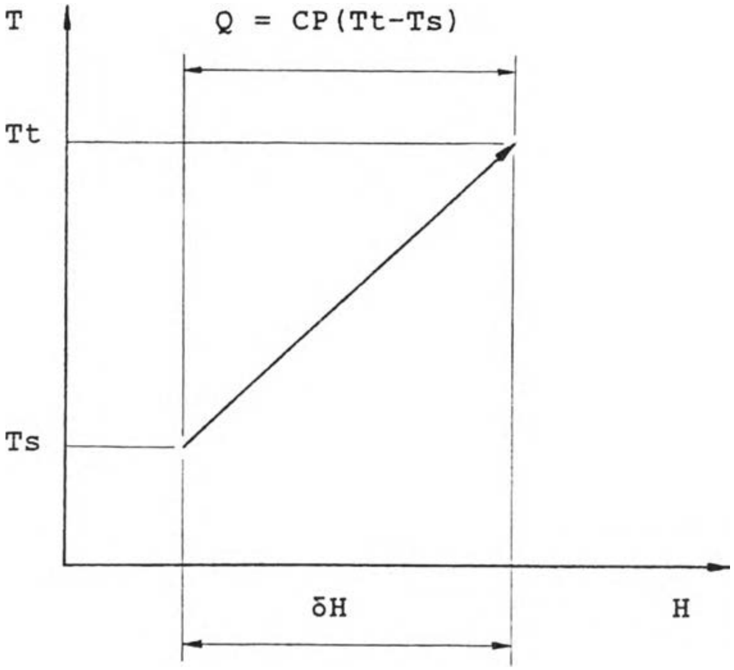


Figure 2.1 Representation of process stream in the T/H diagram

cold composite by at least δTmin (the minimum possible temperature difference). Thus, heat exchange between hot and cold process streams is possible to the extent that the composite curves overlap.

The "over-shoot" of the hot composite represents the minimum amount of external cold utility required and the "over-shoot" of cold composite represents the minimum amount of external hot utility required, for a given value of δTmin.

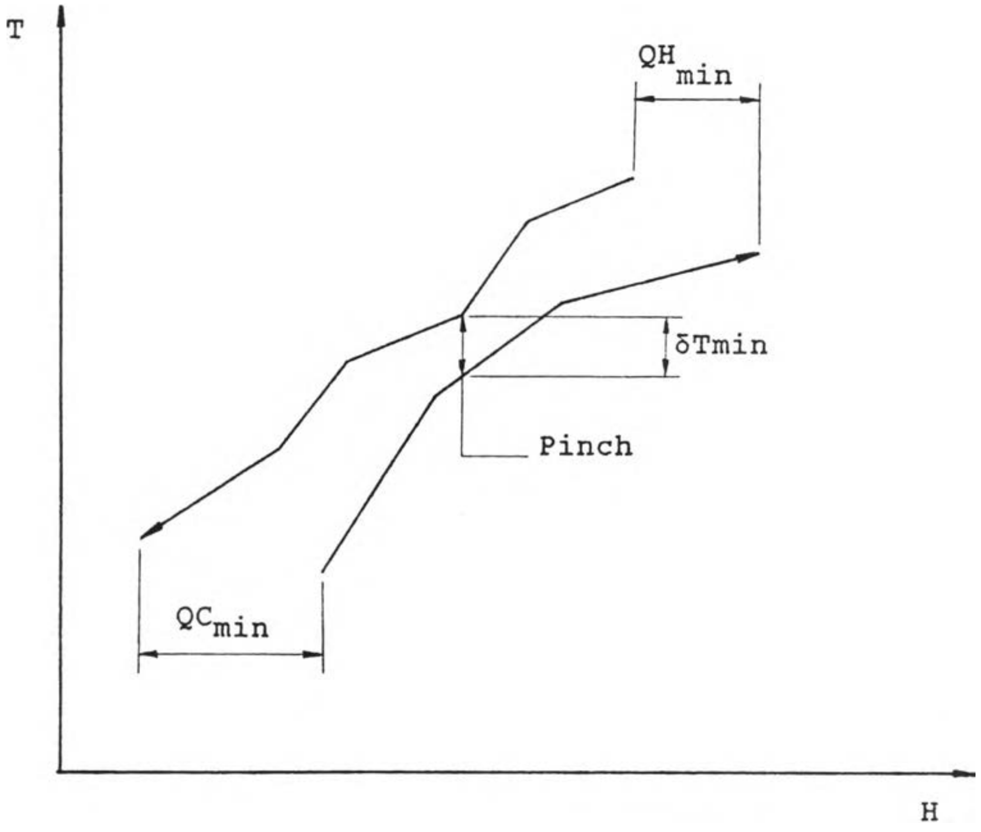


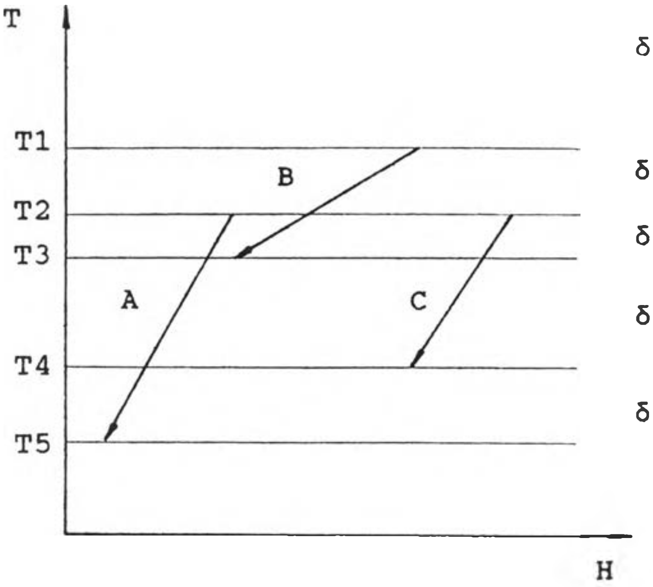
Figure 2.2 Energy targets and "the pinch" with composite curves

In general, δTmin occurs at only one point, termed the "pinch". This means that it is possible to design a network using the minimum utility requirements, where only the heat exchangers at the pinch need to operate at δT value down to δTmin.

2.1.2.1 Construction of composite curve

Figure 2.3 illustrates a procedure for constructing the composite curve, for a three-stream problem. In figure 2.3(a) the three hot streams are plotted separately, with their supply and target temperatures defining a series of "interval" temperatures T1 to T5. Between T1 and T2 only stream B exists, and so the heat available in this enterval is given by $CP_B(T1 - T2)$. However, between T2 and T3 all three streams exist, and so the heat available in the interval is $(CP_A + CP_B + CP_C)(T2 - T3)$. A series of value of δH for each interval can be obtained in this way, and the result replotted against the interval temperatures as shown in Figure 2.3(b). The resulting T/H plot is a single curve representing all the hot streams. A similar procedure give a composite of all cold streams in a problem.

Figure 2.4 illustrates a schematic way of constructing a composite curve for a two-stream problem. The curve can be constructed by connecting sequentially the lines expressing the relationships of heat content versus temperature for streams in the same temperature range.



δH in the interval

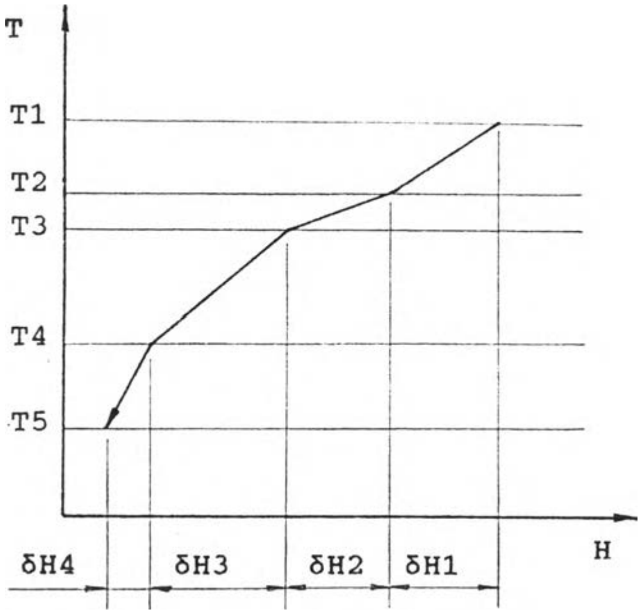
$\delta H1 = (T1-T2)CP_B$

$\delta H2 = (T2-T3)(CP_A+CP_B+CP_C)$

$\delta H3 = (T3-T4)(CP_A+CP_C)$

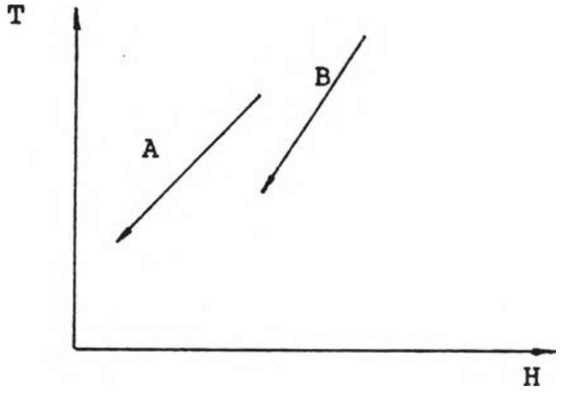
$\delta H4 = (T4-T5)CP_A$

(a) Individual hot stream on T/H diagram

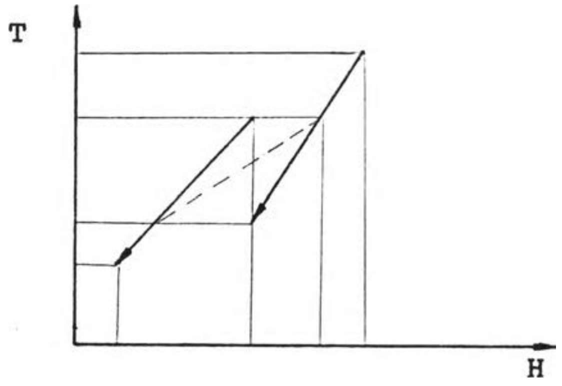


(b) Complete composite curve

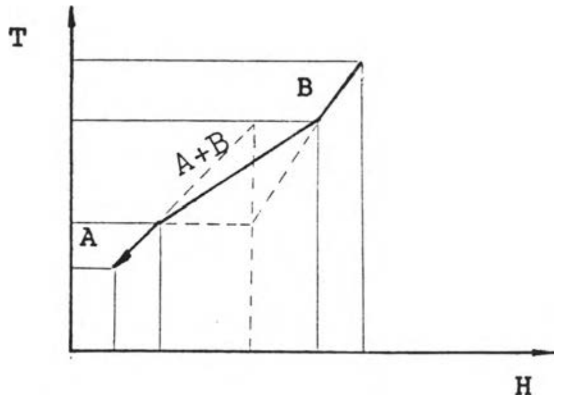
Figure 2.3 Construction of composite curve [25: 23]



(a) Individual hot streams on T/H diagram



(b) Combine lines in the same temperature range (draw diagonal line)



(c) Complete composite curve

Figure 2.4 Graphical construction of composite curve

2.1.3 Prediction of energy target using problem table method [16: 633]

In the description of the construction of composite curves (see figure 2.3), it has been shown how enthalpy balance intervals are set up based on the stream supply and target temperatures. The same can be done for the hot and cold streams together, to allow for the maximum possible amount of heat exchange within each temperature interval. The only modification needed is to ensure that, within any interval, the hot streams and cold streams are at least δT_{min} apart. This method will be illustrated by solving a four-stream problem, whose data are given in Table 2.1.

Any network which will solve the problem may be thought of as an array of N subnetworks. Each subnetwork includes all streams or parts of streams which fall within a defined temperature interval. The temperatures T1, T2, ...Tn+1 are deduced from the table data in the following way. Each stream's supply and target temperatures are listed after the temperatures of the hot streams have been reduced by the minimum temperature difference, δT_{min} (20 °C in this example). The highest temperature in the list is called T1, the second highest T2 and so on. Generally, the following expression holds

$$N <= 2*Z-1 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2-2)$$

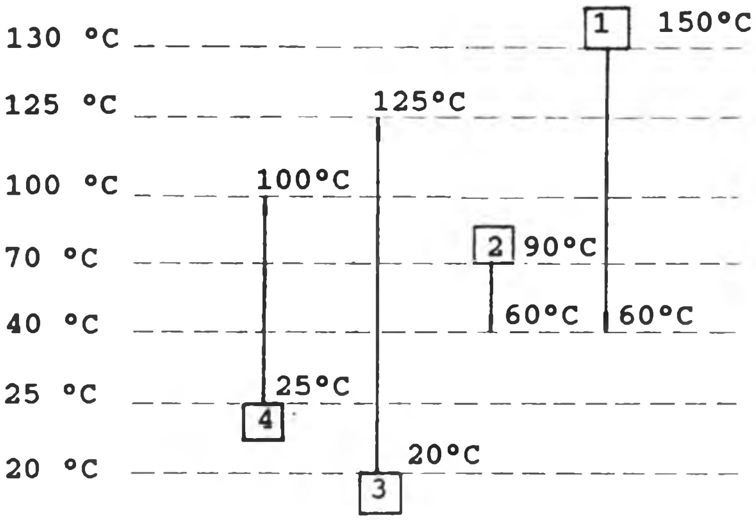
where Z is the number of streams existing in the problem,

and N is maximum number of subnetworks.

Each subnetwork will have either a net surplus or net deficit of heat, as dictated by enthalpy balance, but never both. Enthalpy balances can easily be calculated for any subnetwork i according to

$$H_i = (T_i - T_{i+1}) * (\Sigma CPc - \Sigma CPh)_i \quad .... \quad (2-3)$$

The last column of Figure 2.5(b) indicates whether a subnetwork is in heat surplus or heat deficit. Since surplus heat in any subnetwork i is hot enough to supply any duty in subnetwork i+1, hence instead of sending the surplus heat to the cold utility, it can be sent down to an adjacent subnetwork. It is therefore possible to set up heat cascade as shown in Figure 2.6. Assuming that no heat is supplied to the first subnetwork from the hot utility, then the surplus of 10 kW from SN(1) is cascaded into SN(2). SN(2) has a 12.5 kW deficit, hence after accepting the 10 kW it can be regarded as passing on a 2.5 kW deficit to SN(3). SN(3) has a 105 kW deficit, making a cascade of 107.5 kW deficit to SN(4). SN(4) has a 135 kW surplus. After accepting 107.5 kW deficit, it passes on 27.5 kW surplus to SN(5). SN(5) has a 82.5 kW deficit, hence after accepting 27.5 kW surplus, it passes on a 55 kW deficit to SN(6). Finally SN(6) passes on a 67.5 kW to the cold utility. It can be seen that SN (2), SN(3), SN(5) and SN(6) have negative heat flow, which is thermodynamically infeasible. To make it just feasible, 107.5 kW of heat from the hot utility must be added and cascaded right through the system. The net result of this

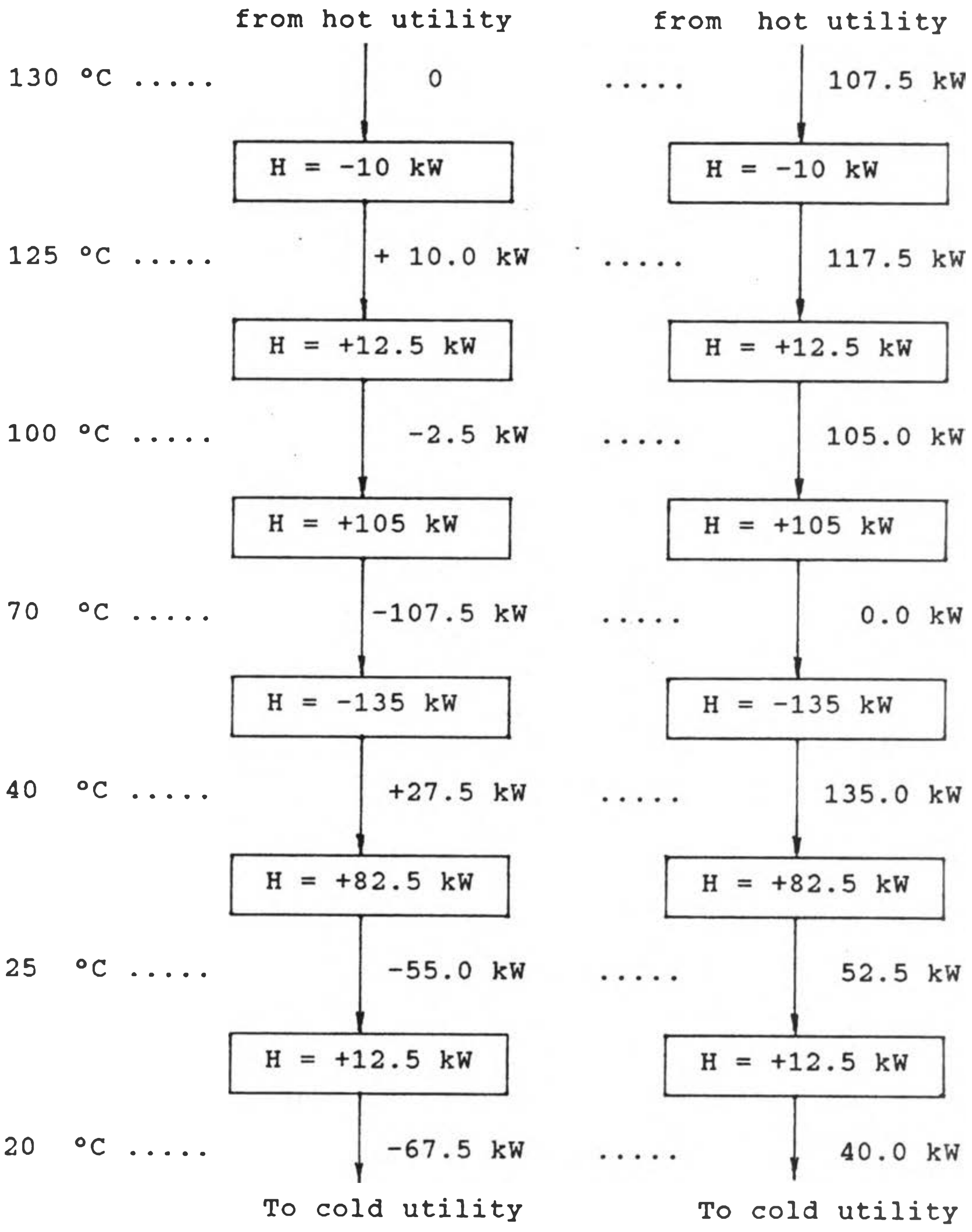


(a)

Subnetwork no.	Cold stream temp.interval (°C)	Ti-Ti+1 (°C)	ΣCPc-ΣCPh (kW/°C)	δHi (kW)	Surplus or deficit
	130				
1		5	-2.0	-10.0	surplus
	125				
2		25	0.5	12.5	deficit
	100				
3		30	3.5	105.0	deficit
	70				
4		30	-4.5	-135.0	surplus
	40				
5		15	5.5	82.5	deficit
	25				
6		5	2.5	12.5	deficit
	20				

(b)

Figure 2.5 Temperature interval analysis



(a) (b)

Figure 2.6 The heat cascade diagram

operation is that the minimum utility requirements have been predicted, i.e. 107.5 kW of hot utility and 40 kW of cold utility, as shown in Figure 2.6(b). Further more, the position of the pinch has been located. This is at the cold stream temperature of 70 °C where the heat flow is zero.

Compare the result obtained by this approach to the result from the composite curves. As shown in Figure 2.7 the same information is obtained, but the problem table provides a simple framework for numerical analysis.

2.1.4 Relation of minimum heating and cooling to the first-law requirement

The first-law analysis indicates that the difference between the heat available in the hot streams and that required by the cold streams is 67.5 kW. The second-law analysis with a 20 °C approach temperature indicates that we must supply a minimum of 107.5 kW and remove 40 kW. Hence, we see that any incremental heat that we put in from the hot utility must also be removed by the cold utility.

2.2 Pinch Design

The pinch represents the most constrained region of a design, because all δT_{min} exists between the hot and cold streams at the pinch. As a result the number of feasible matches in this region is severely restricted.

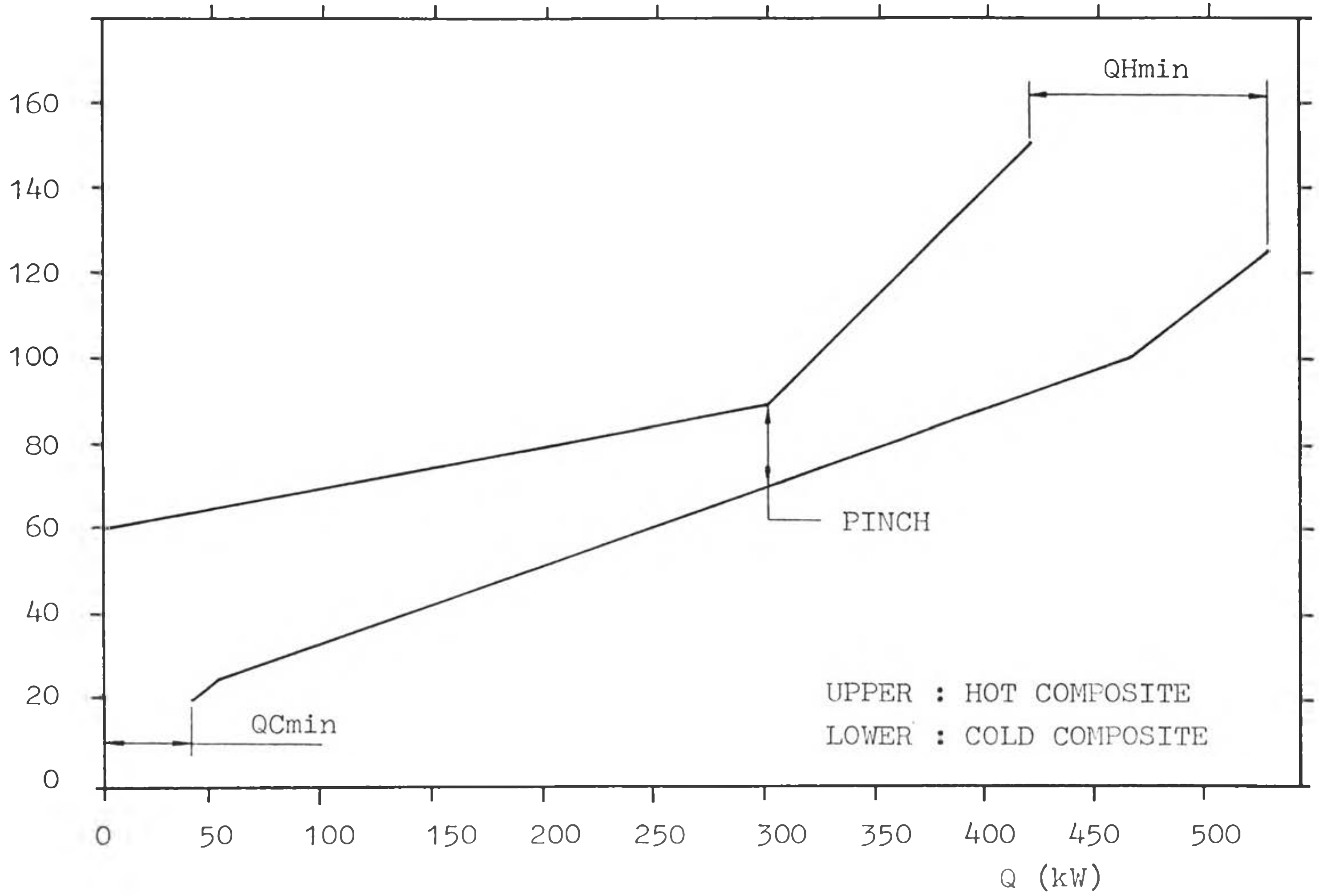


Figure 2.7 Composite curves of example problem

Once away from the pinch, the design task is no longer so constrained, hence the number of topological options usually increases. This increase in the number of options can be used to advantage by a designer.

2.2.1 Significance of pinch

The pinch decomposes the system into two parts, above and below it. The region above the pinch is referred to as a heat "sink", since only hot utility is required. The region below the pinch is referred to as heat "source", since only cold utility is required. This result was observed in the description of the problem table algorithm in the previous section.

First consider the effect of transferring heat across the pinch, (see Figure 2.8(a)). By enthalpy balance around the sink and the source, we see that the transfer of heat α across the pinch increases both hot and cold utility requirements by an amount α from their minimum requirements.

The effects of using cold utility above the pinch and hot utility below it are shown respectively in Figure 2.8 (b) and (c). A removal of heat α from the sink increases hot utility by α. A supply of heat α to the source has an analogous effect. Thus to achieve minimun utility usage, cold utility is not permitted above the pinch and hot utility is not permitted below the pinch.

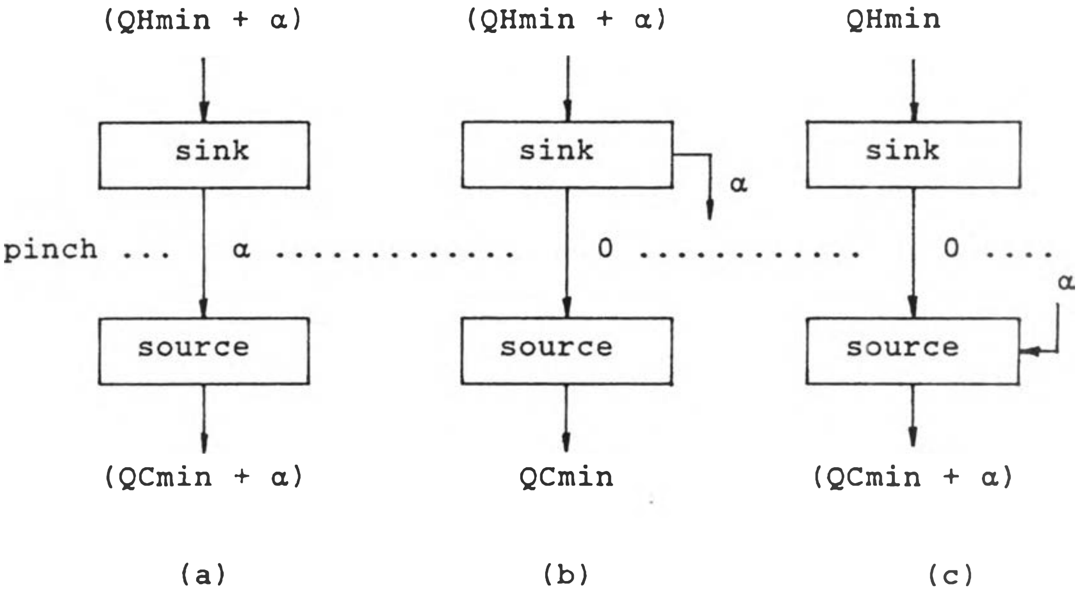
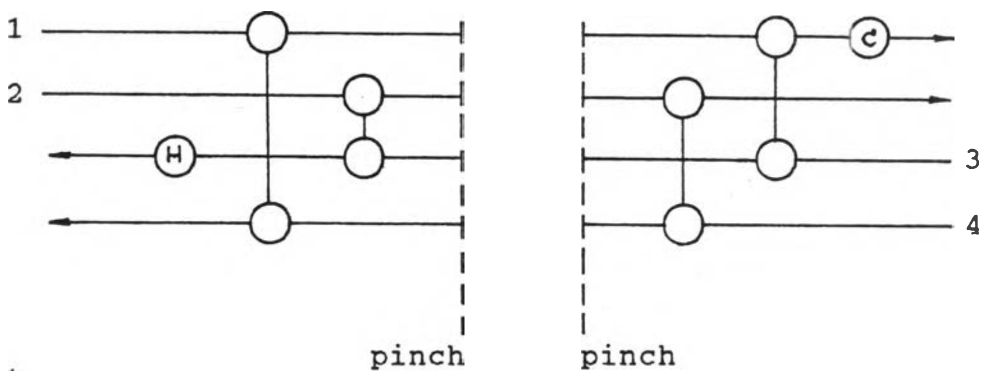


Figure 2.8 (a) Effect of heat transfer across the pinch
(b) Effect of utility cooling above the pinch
(c) Effect of utility heating below the pinch

2.2.2 Grid representation

Linnhoff and Flower [16:633] introduced the "grid" form to represent the heat exchanger network, as shown in Figure 2.9. Here the hot streams run from left to right across the top of diagram, and the cold streams from right to left at the bottom. A process interchanger is shown as two circles, connected by a vertical line. Also the grid represents the countercurrent nature of heat exchange, making it easier to check exchanger feasibility. The pinch is represented in the grid as a vertical dotted line. The left side of the pinch represents region above the pinch and the right side represents the region below the pinch.

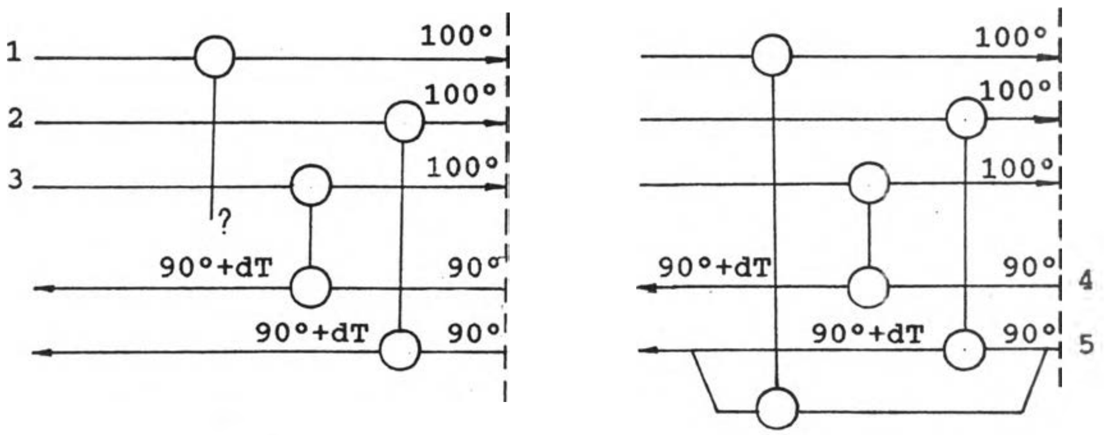


(a) above the pinch (b) below the pinch

Figure 2.9 Grid representation

2.2.3 Criteria for pinch matches

2.2.3.1. The number of process streams and branches. The significance of the population of hot and cold streams can be illustrated through Figures 2.10(a) and (b). Figure 2.10(a) shows an above-the-pinch stream set. For maximum energy recovery (M.E.R.) design, cold



(a) (b)

Figure 2.10 Above-the-pinch

utility must not be used above the pinch, which means that all hot streams must be cooled to their pinch temperature by interchange with cold streams. In Figure 2.10(a) regardless of streams' heat capacity flowrates, CP, it is attempted to place pinch matches between hot stream no.2 and cold stream no.5, and hot stream no.3 and cold stream no.4. Notice, however, that having made these matches, hot stream no.1 cannot be matched with either cold stream without violating the δTmin constraint. The only way out of this situation is to split a cold stream in two parallel branches as shown in Figure 2.10(b).

To summarize, the feasible criterion for the number of streams above the pinch is

$$NH <= NC \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2-4)$$

Here NH is number of hot streams or branches

NC is number of cold streams or branches.

The converse arguments apply below the pinch. That is

$$NH >= NC \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2-5)$$

Once again splitting of hot streams may be necessary to achieve the M.E.R. design.

2.2.3.2. The heat capacity flowrate for individual matches. The second feasibility criterion is concerned with temperature feasibility. As shown in Figure 2.11, the temperature driving force in a pinch match cannot decrease away from the pinch, since at the pinch it is already equal to the minimum allowable temperature difference for every match. For this condition to be fulfilled, the following CP condition must apply in every pinch match.

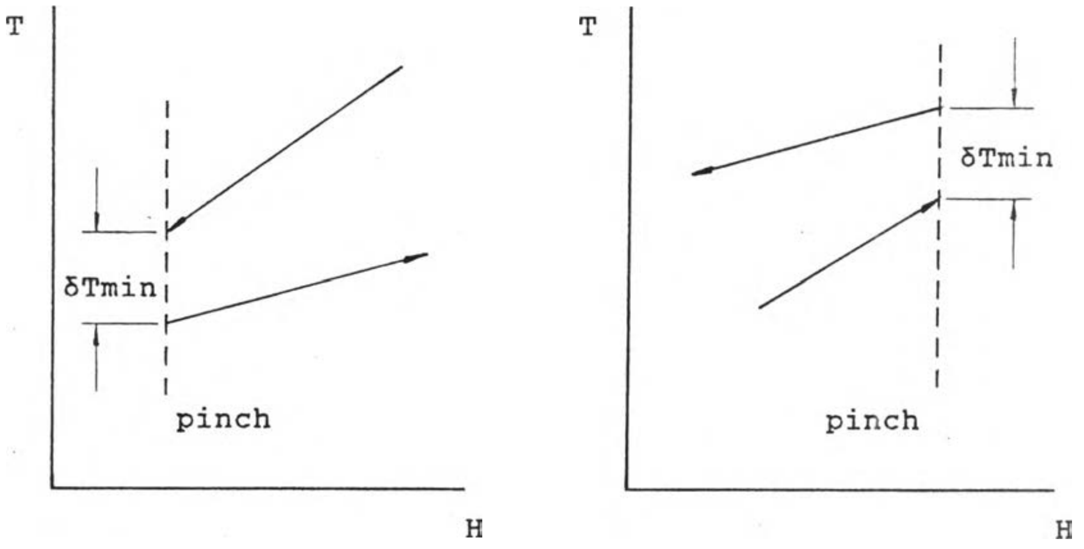
Above the pinch:

$$CP_H <= CP_C \quad \text{........................} \quad (2\text{-}6)$$

Below the pinch:

$$CP_H >= CP_C \quad \text{........................} \quad (2\text{-}7)$$

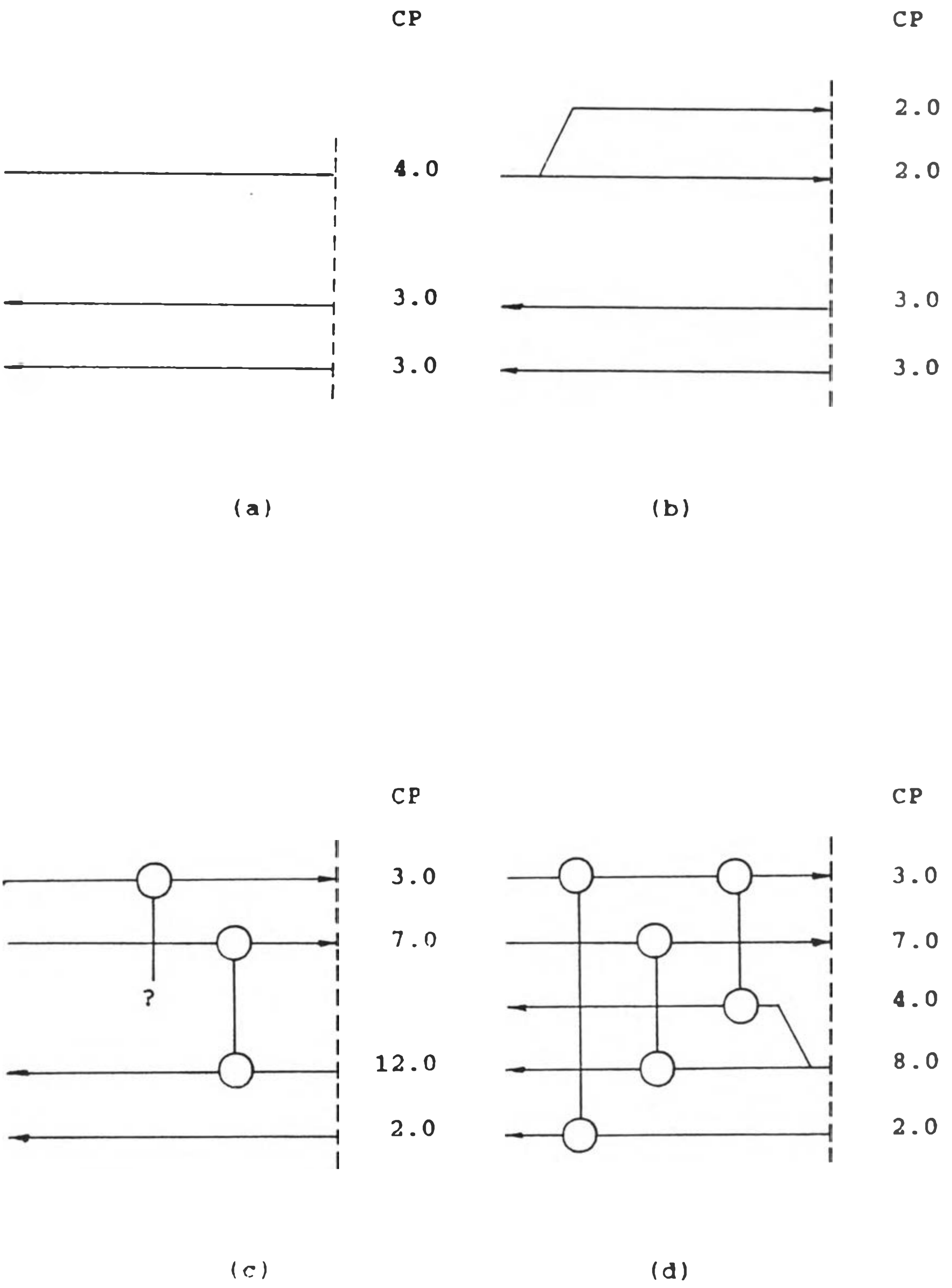
Here CP_H is the heat capacity flowrate of a hot stream or its branch, and CP_C is that of a cold stream or its branch.



(a) above the pinch (b) below the pinch

Figure 2.11 Feasible pinch match

Consider Figure 2.12(a). The number of stream criterion is satified (one hot stream against two cold stream) but the CP criterion, CPh <= CPc, is not met for either of the possible two matches. In this example one solution is to split a hot stream as shown in figure



(a) (b) (c) (d)

Figure 2.12 Stream splitting at the pinch

2.12(b). But sometimes it is better to split a cold stream as shown in Figure 2.12(c) and (d). In Figure 2.12(c) the number of stream criterion is met, but after the hot stream of CP = 7.0 is matched against the cold stream of CP = 12, the remaining hot stream of CP = 3.0 cannot match against the remaining cold stream of CP = 2.0. If a hot stream is now to be split, the number of stream criterion would not be satisfied, and the cold stream would then have to be split as well. It is better to split the large cold stream from the outset, as shown in Figure 2.12(d), producing a solution with only one split.

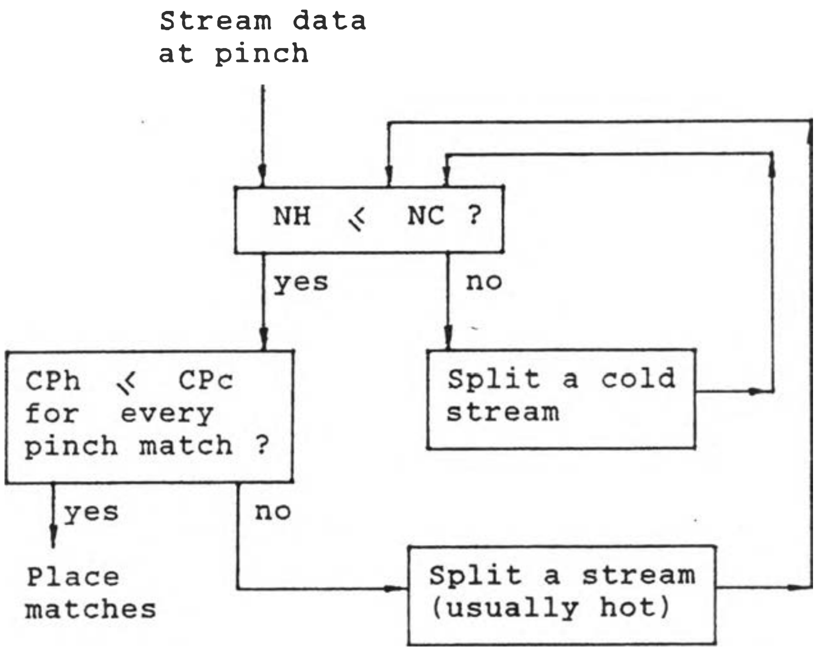
2.2.4 Algorithm for network design at the pinch

Figures 2.13(a) and (b) show the algorithms which apply the pinch design criteria to split streams for the case of above and below the pinch, respectively. The case for below pinch is the "mirror image" of that for above pinch.

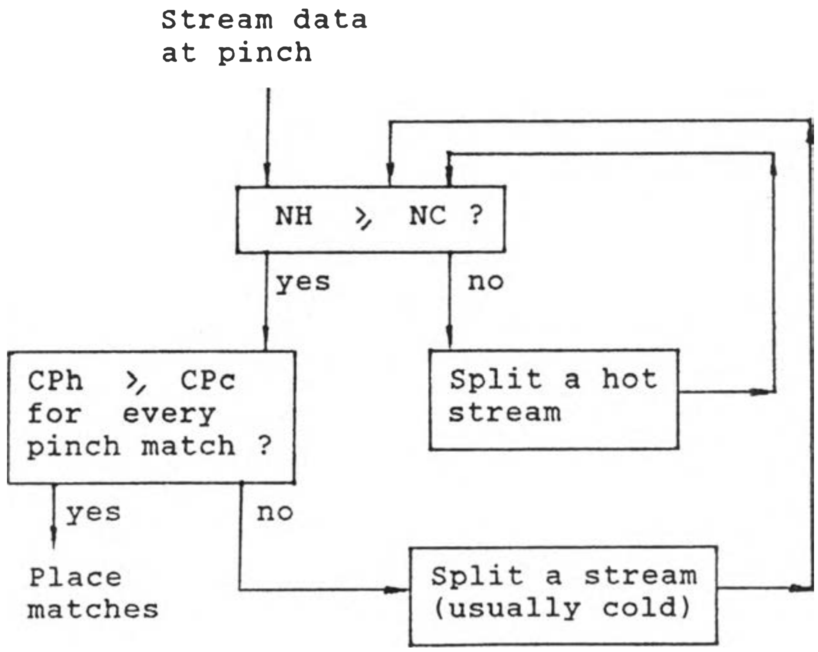
2.3 Heuristic Method for Network Design

After the pinch design has been carried out, some hot streams and some cold streams still have left heating and cooling load that may be exchanged. To accomplish the whole network design task, heuristic rules are introduced.

As mentioned previously, the pinch separates the system into two independent parts above the pinch and



(a) Above the pinch



(a) Below the pinch

Figure 2.13 Algorithm for design at the pinch below the pinch. Thus a network for each part can be constructed independently. Since the neighborhood of the pinch is the most temperature-constrained region, the design for each part is started at the pinch and gradually moves away from it.

2.3.1 Classification of heat exchanging streams

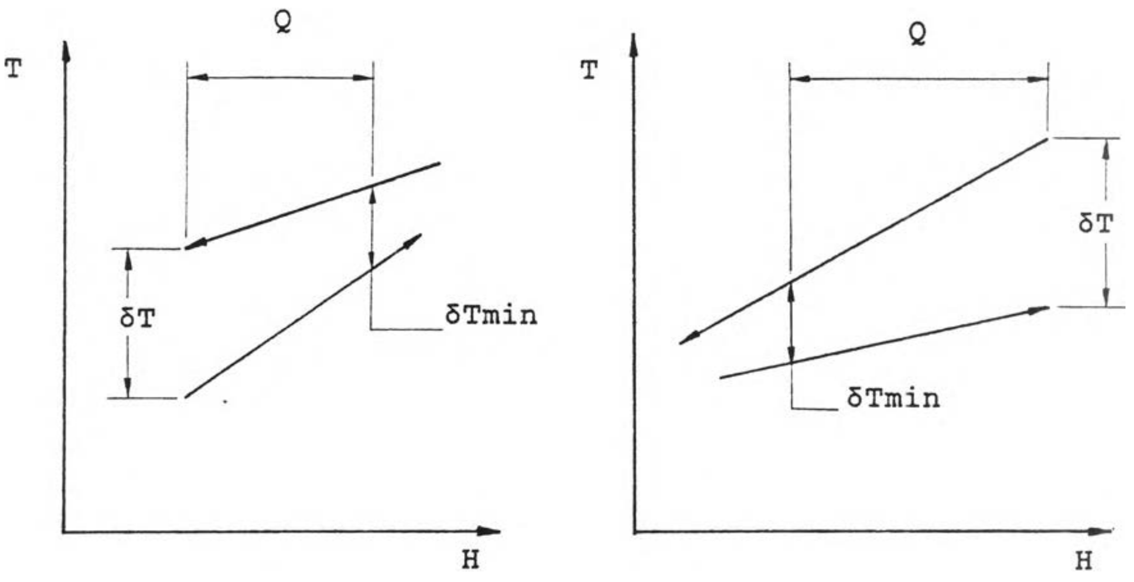
We can classify the heat transfer behavior of any stream pair into three categories as follows:

1. The hot stream completely transfers its heat load to the cold stream. Thus the hot stream is cooled down to its target temperature.
2. The cold stream is heated up to it target temperature.
3. Neither the hot stream nor the cold stream reaches its target temperature.

Figure 2.14(a) shows typical heat transfer features of the third category for above-the-pinch design. From the figure, the temperature difference is decreased from its maximum value to the minimum allowable value, δTmin, as it moves away from the pinch. This implies that the heat capacity flowrate of the hot stream is greater than that of the cold stream. The maximum possible heat exchange, Q, in this situation is

$$Q = \frac{(\delta T - \delta T\mathrm{min}) * CPc * CPh}{CPh - CPc} \quad \ldots\ldots\ldots\ldots \quad (2\text{-}8)$$

Here δT is the temperature difference at the cold end. If the temperature difference at the cold end equals



(a) above the pinch (b) below the pinch

Figure 2.14 Heat transfer in the third catagory for pinch design

δTmin, it is obvious that matching can not be performed without violating the desired δTmin at the hot end. Since such a violation is not allowed and since cold utility must not be used above the pinch in order to obtain the best performance, spliting of the hot stream is required, and the criterion of heat capacity flowrate for pinch design, CPh <= CPc, is applicable.

Below the pinch, the phenomenon is a mirror image of that above the pinch. In Figure 2.14(b), the stream system below the pinch is shown. Now the temperature difference at the cold end is constrained and the maximum possible heat exchange is

$$Q = \frac{(\delta T - \delta Tmin) * CPc * CPh}{CPc - CPh} \quad \ldots\ldots\ldots\ldots\ldots (2\text{-}9)$$

if the temperature difference at the hot end is equal to δTmin, and neither the use of hot utility below the pinch nor any violation of δTmin is allowed. Hence splitting of the cold stream is required and the criterion of heat capacity flowrate for pinch design, CPh >= CPc, is applicable.

2.3.2 Design strategy

Figure 2.15 shows the heuristic method adopted in this work to accomplish the above-pinch design task. The algorithm will be performed, if after the pinch design is finished, there is some uninterchanged hot stream load left. The residual hot stream with the lowest cold end temperature will receive the highest priority in matching. All previously splitted branches will first be recombined in order to avoid over-splitting. The priority of placing match with the cold streams is listed below.

(1) First choose a cold stream which has equal heat load to that of the hot stream (complete interchange), i.e. a cold stream in either the first or the second category.

(2) Choose a cold stream in the second category that will achieve maximum interchange load.

(3) Choose a cold stream in the first category, which will have a minimum new cold end temperature after interchange with the hot stream.

(4) Choose a cold steam in the third category which will achieve maximum interhange load.

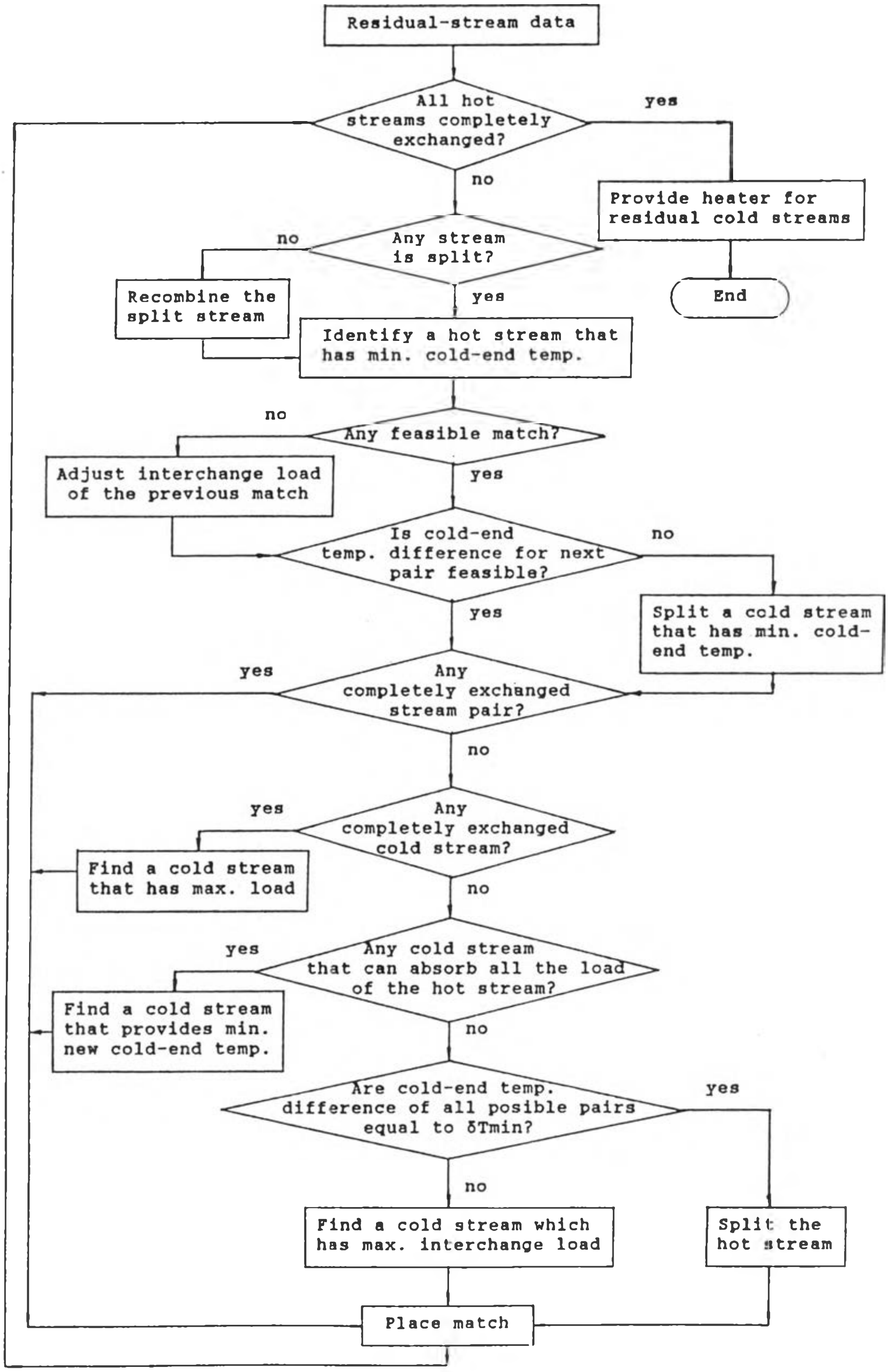


Figure 2.15 Heuristic procedure for above-the-pinch design

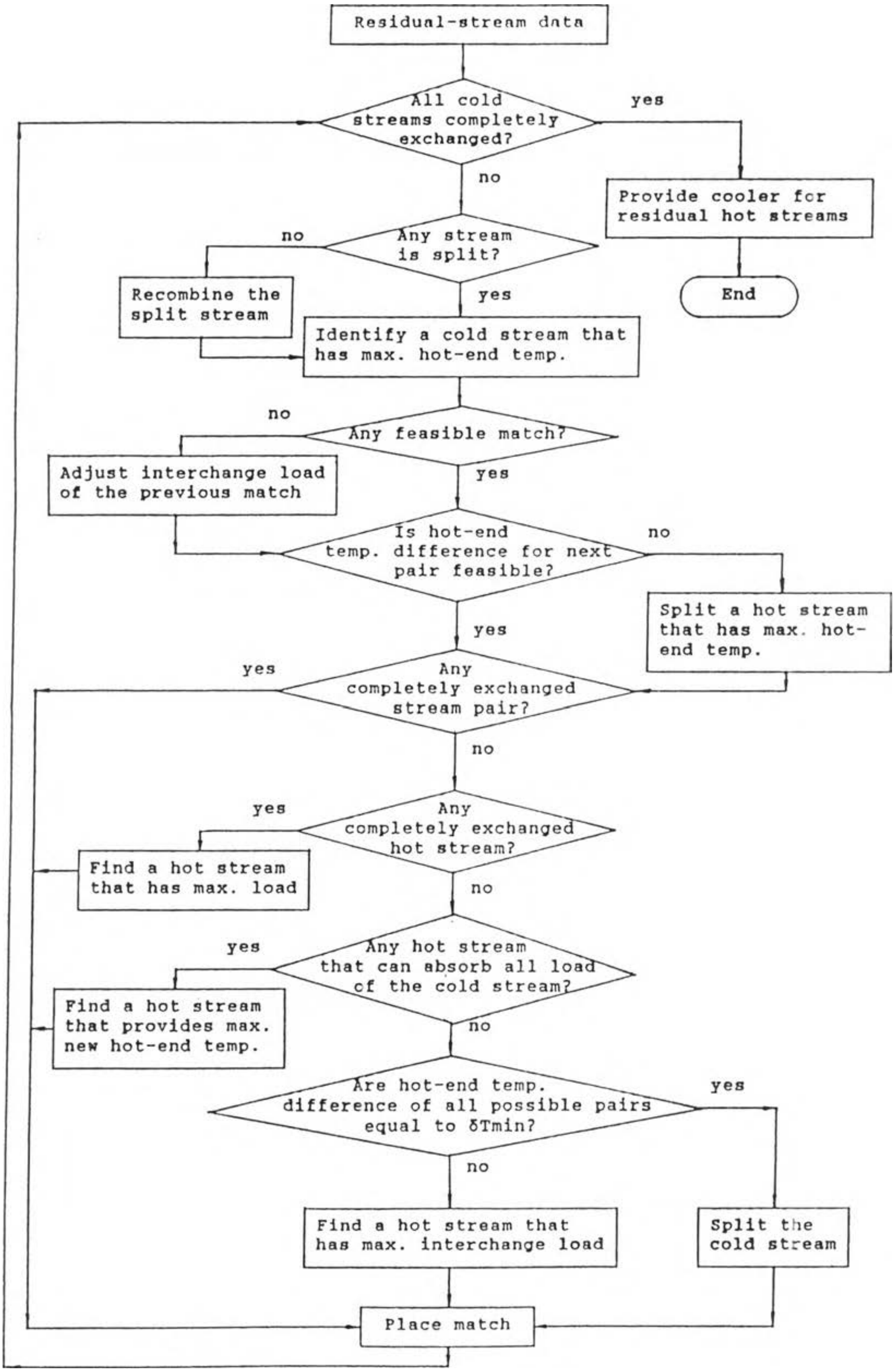


Figure 2.16 Heuristic procedure for below-the-pinch design

Similarly, the adopted heuristic method for below-pinch design is shown in Figure 2.16. The residual cold stream with highest hot end temperature will receive the highest priority in placing match with a suitable residual hot stream. The first in choosing the suitable hot stream is as follows:

(1) First choose a hot stream which has equal heat load to that of the cold stream (complete interchange), i.e. a hot stream in either the first or the second category.

(2) Choose a hot stream in the first category that will achieve maximum interchange load.

(3) Choose a hot stream in the second category that will have maximum new hot end temperature after interchange with the cold stream.

(4) Choose a hot steam in the third category which will achieve maximum interchange load.

2.4 Examples of Heat Exchanger Network Design

Example 2-1 [26: 745]

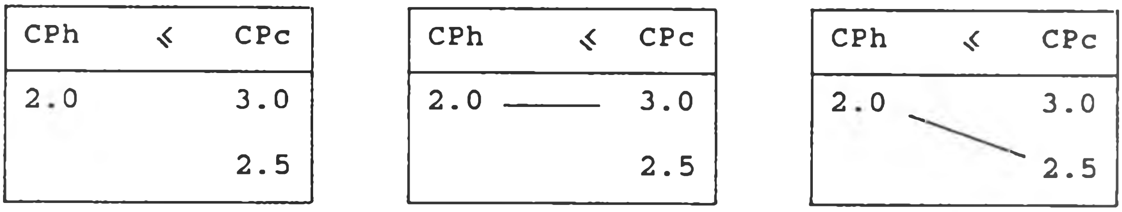
We shall use the stream data given in Table 2.1 as our example problem. The energy targets have been calculated using the problem table method in subsection 2.1.3 to be: the minimum utilities requirement are 117.5 kW hot and 40 kW cold. The pinch occurs where the hot streams are at 90 °C and the cold at 70 °C. The δTmin is 20 °C.

(a) Above-the-pinch design

The CP table for the streams lying above the pinch is given in Figure 2.17(a). A pinch topology will be identified in this table by applying the feasibility criterion mentioned in Figure 2.13(a). The first feasibility check shows that the number-of-stream criterion at the pinch is satisfied, namely, the number of hot streams is not more than that of the cold. Application of the second feasibilty requirement, the CP criterion, shows that there are two options as shown in Figure 2.17(b) and (c). The two correspoding design are shown in Figure 2.18(a) and (b).

In Figure 2.18(a), the interchange load of the pinch match identified in figure 2.17(b) has been maximised to tick off stream no. 1. Hence, the residual load of 17.5 kW on stream no. 3 and 90 kW on stream no. 4 can only be met by the placement of two heaters.

The other design option in Figure 2.17(c) is developed as shown in Figure 2.18(b). The pinch match now



(a) (b) (c)

Figure 2.17 The CP table for above-the-pinch design ticks off stream no. 4. This leaves a residual load on stream no.1 of 30 kW with only stream no.3 to match against. Thus the remaining problem is solved by the placement of one heat exchanger and one heater.

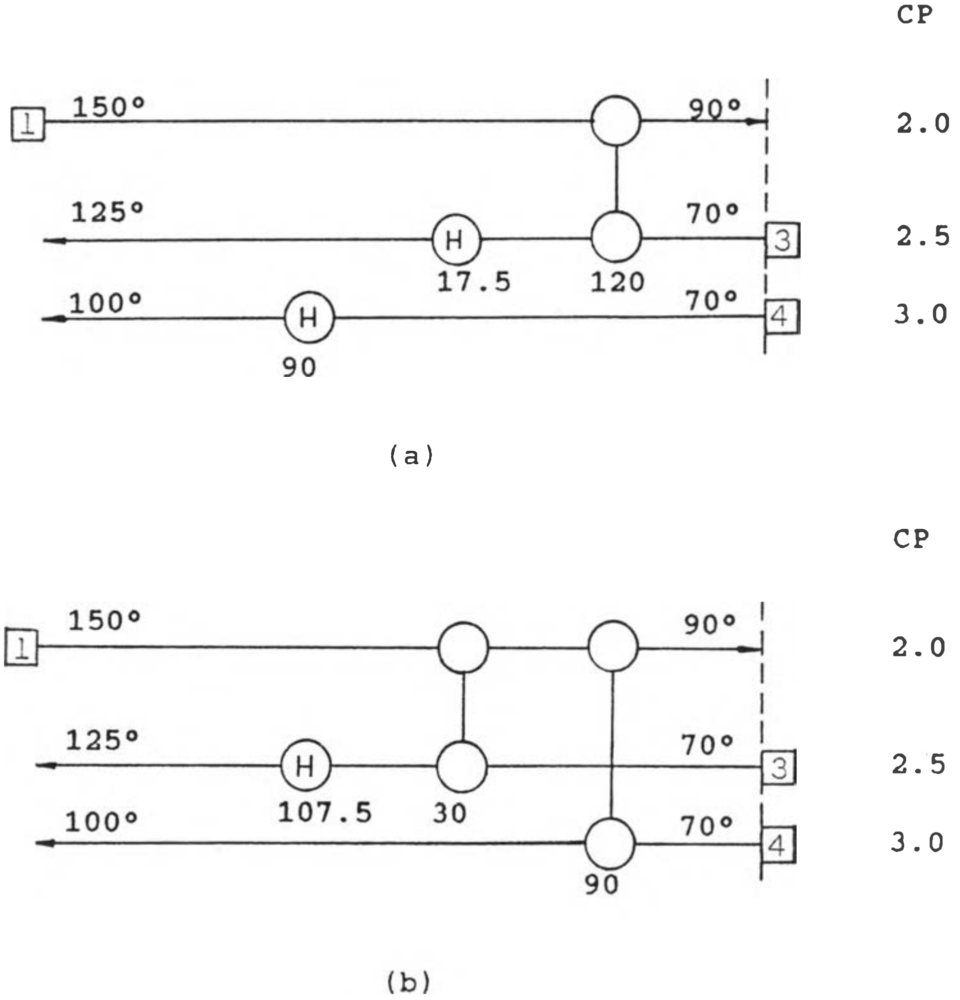
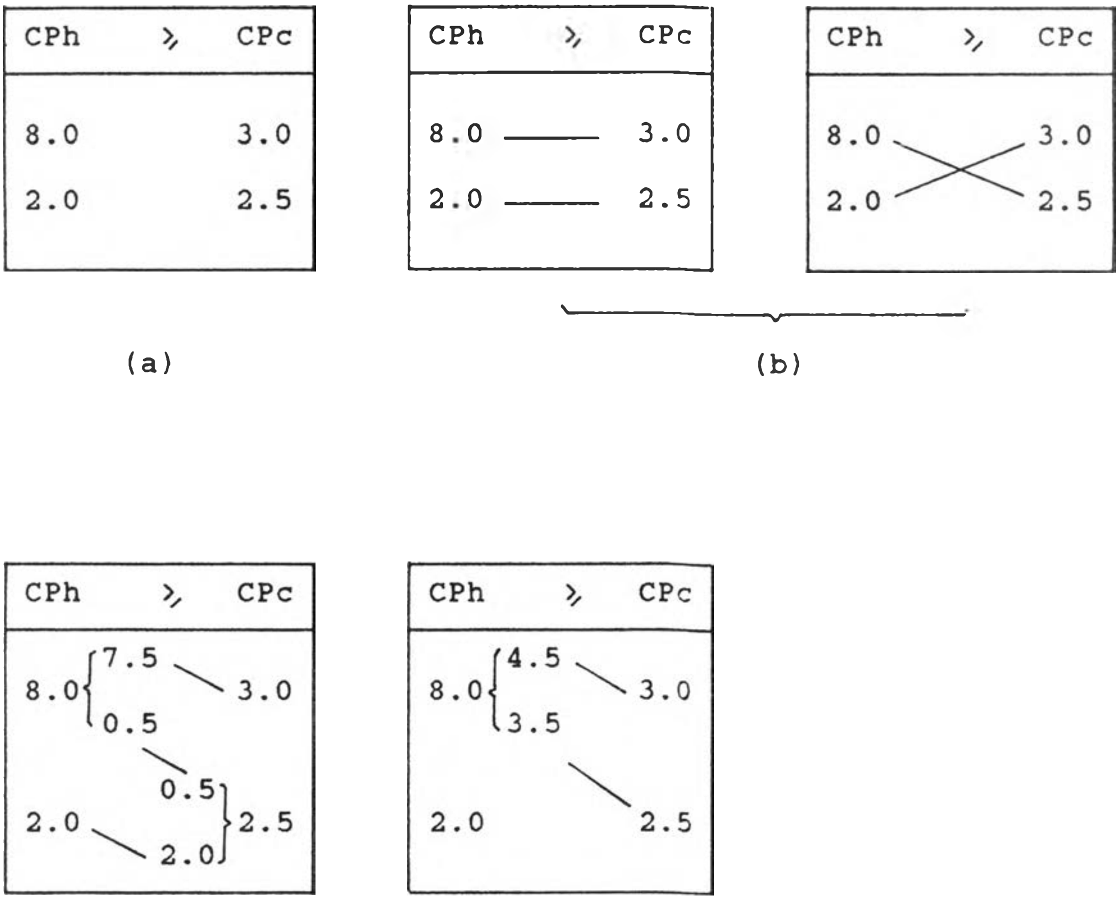


Figure 2.18 Above-the-pinch design structures

(b) Below-the-pinch design

The CP data for those streams lying below the pinch are shown in Figure 2.19(a). A pinch topology is will again be identified by applying the feasibility crieria according to Figure 2.13(b). The first feasibility requirement, number-of-stream criterion, is obeyed. However, placement of pinch matches cannot be performed since the CP criterion cannot be satisfied simultaneously by all possible pinch matches. In this situation, one



(a) (b)

(c) (d)

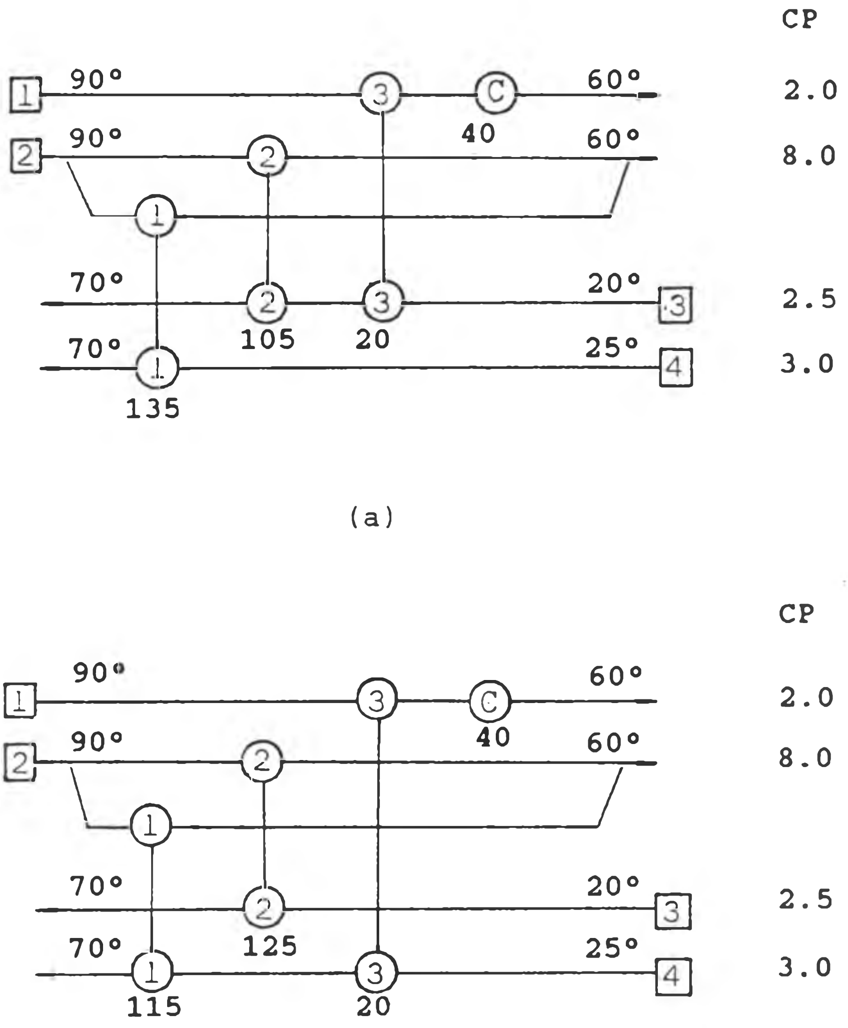
Figure 2.19 (a) CP table for below-the-pinch design.
(b) Infeasible pinch topology.
(c) Feasible pinch topology with two stream splits.
(d) Feasible pinch topology with one stream split.

might resort to stream splitting. Splitting of either a hot or cold stream is possible. In this problem the number of hot streams is equal to that of cold streams. Thus if we were to split a cold stream, we would have to split a hot stream as well to fulfill the number-of-stream criterion. Figure 2.19(c) shows a feasible pinch arrangement, in which the cold stream of CP 2.5 is split first, then the hot stream of CP 8 is split next. However, splitting of the hot stream should come first, since splitting of the cold stream would no longer be required as shown in Figure 2.17(d).

Two different networks can be developed using the pinch design criteria. This depends on how the heuristic tick-off rule is applied. In Figure 2.20(a) and (b), match no.1 and no.2 are essential pinch matches. The topology in Figure 2.18(a) results when the load on match 1 is chosen to tick off cold stream no.4. The topology in Figure 2.18(b) results when the load on match no.2 is chosen to tick off hot stream no.3.

It should be noted that there are numerous possible values of branch CP's that can be used in the calculation. The restrictions in an assigned branch CP are:

- It must obey the required CP criterion.
- Summation of branch CP's must equal to CP of the main stream.



(a)

(b)

Figure 2.20 Below-the-pinch design

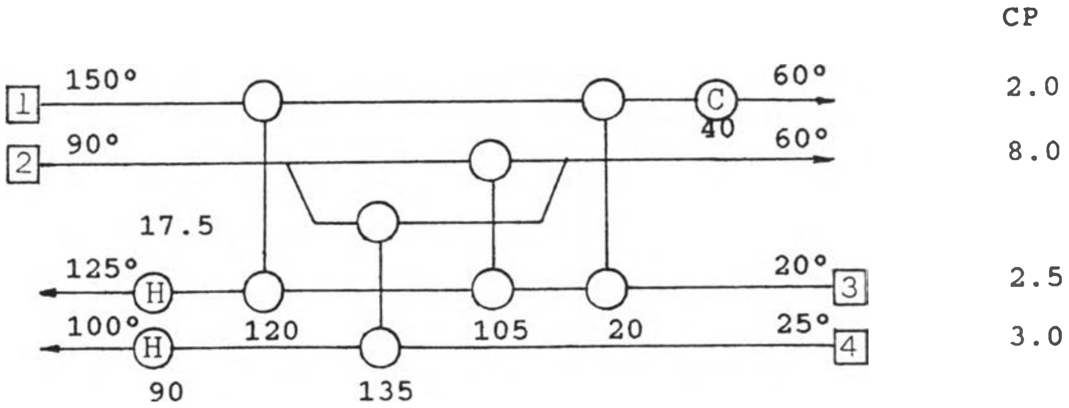


Figure 2.21 A minimum-utility designed network

A complete minimum utility network is obtained by combining above-the-pinch and below-the-pinch design stuctures. Figure 2.21 shows such a combination involving the above-pinch design from Figure 2.18(a) and the below-pinch design from Figure 2.20(a). The final overall design configuration has a total of seven exchanger and utility units.

It is obvious from this example that generally a minimum-utility network is not unique. That is there might exist several network configurations yielding the same minimum utilities. Furthermore, the complexity and the total number of exchanger units required might also differ. Thus other criteria, such as economic and operational considerations, are required to achieve the optimum minimum-utility network design.

Example 2-2

This example is given to illustrate the heuristic rules for away-from-the-pinch design. The energy targets based on stream data given in Table 2.2 are found by using the Problem Table method (see Table 2.3) to be 1100 kW hot utility and 40 kW cold utility. The pinch is located where the hot streams are at 70 °C and the cold streams at 60 °C. The δTmin is 10 °C.

(a) Above-the-pinch design

In Figure 2.22, there are only hot stream no.3 and

Table 2.2 Data for example 2-2

Stream no.	Type	Heat capacity flowrate(kw/°C)	Tsupply (°C)	Ttarget (°C)
1	hot	1.5	250	130
2	hot	3.0	320	150
3	hot	2.0	130	50
4	cold	2.5	60	200
5	cold	4.0	90	240
6	cold	3.0	80	400

Table 2.3 Problem table analysis

Subnetwork no.	Cold stream temp.interval (°C)	Deficit (kW)	Accumulative output (kW)	Heat flow (kW)
	400			1100
1		270	-270	
	310			830
2		0	-270	
	240			830
3		100	-370	
	200			730
4		300	-670	
	140			430
5		160	-830	
	120			270
6		225	-1055	
	90			45
7		35	-1090	
	80			10
8		10	-1100	
	60			0
9		-40	-1060	
	40			40

cold stream no.4 at the pinch, and the pinch design criteria for the present pair are obeyed. Match no.1 represents the pinch match in which hot stream no.3 is ticked off. The residual hot and cold streams are next to be matched according to the heuristic rules given in Figure 2.15. Hot stream no.1 which has the minimum cold-end temperature is selected for matching with one of the three residual cold streams. It can be observed that any one of the residual cold streams can tick off stream no.1, and the new cold-end temperature for the residual cold stream is either 180, 135 or 140 °C if stream no.1 is matched with either cold stream no.4, no.5 or no.6, respectively.

Since cold stream no.5 gives the minimum cold-end temperature, it is chosen to match with hot stream no.1, as represented by match no.2. At this moment, there leaves only hot stream no.2 for interchange. Either hot stream no.4 or no.5 can be ticked off by the residual cold stream. Since stream no.5 requires a larger load than stream no.4, cold stream no.5 is selected to be ticked off in match no.3. The residual load of 90 kW on hot stream no.2 can be ticked off by either stream no.4 or no.6. Stream no.6 is selected for match no.4 since it provide lower end temperature. The hot-stream heat loads are now completely interchanged and the residual cold streams are heated up to their target temperatures by two heaters.

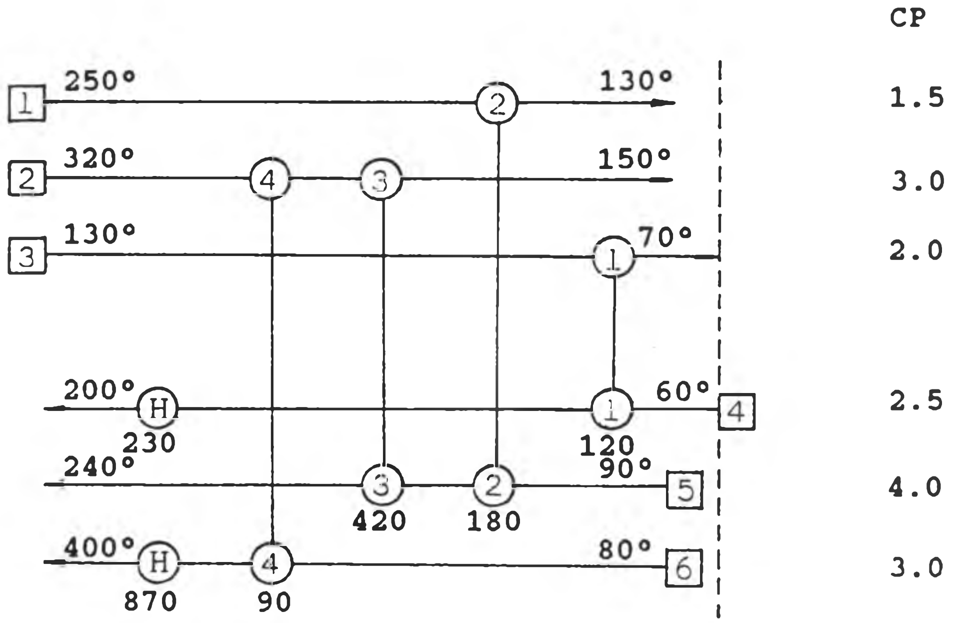


Figure 2.22 Above-the-pinch design

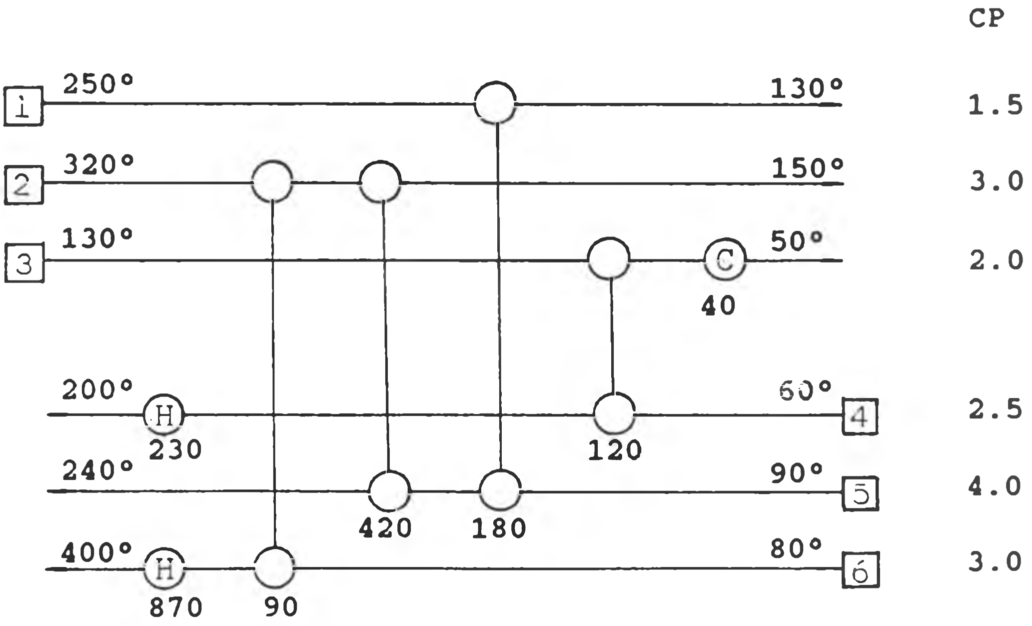


Figure 2.23 Final network structure

(b) Below-the-pinch design

Since there is only hot stream no.3 below the pinch, cold utility is required to cool it down to the target temperature.

The final network structure is as shown in Figure 2.23.