Chapter VIII

Examples of Applications to Heat Exchanger Network Design

This chapter consists of six examples which are selected to illustrate the network design procedure aided by the developed software. The procedure for economic analysis of both new and retrofit processes is illustrated via examples (8-1) and (8-5). The loop breaking procedure is illustrated via examples (8-2) to (8-5). Example (8-4) is an application to the threshold-type problem, while example (8-6) illustrates a case of restricted matching composed of seven streams.

Example 8-1

This example consists of two hot streams and two cold streams, the data of which are given in Table 8-1. The minimum allowable temperature difference is 20 °F.

Table 8-1. Data for example 8-1 [source 13: 1132].

Stream no.	Starting temp. (°F)	Target temp. (°F)	Heat capacity flowrate (b.t.u./hr.°F)
H1	320	200	16670
H2	480	280	20000
C1	140	320	14450
C2	240	500	11530

Network design procedure

Step 1. Enter numbers of streams.

NO. OF HOT STREAMS ? 2

NO. OF COLD STREAMS? 2

Step 2. Enter units of temperature and heat load.

UNIT OF TEMPERATURE (°)? F

UNIT OF HEAT LOAD ? b.t.u./hr

Step 3. Enter minimum allowable temperature difference.

MINIMUM ALLOWABLE TEMPERATURE DIFFERENCE (°F) ? 20

Step 4. Enter hot-stream data.

HOT STREAM NO.	STARTING TEMP. (°F)	TARGET TEMP. (°F)	HEAT CAPACITY FLOWRATE (b.t.u./hr.°F)
1	320	200	16670
2	480	280	20000

Step 5. Enter cold-stream data.

HOT STREAM NO.	STARTING TEMP. (°F)	TARGET TEMP. (°F)	HEAT CAPACITY FLOWRATE (b.t.u./hr.°F)
1	140	320	14450
2	240	500	11530

Step 6. Enter restricted stream pairs (if any).

ARE THERE ANY RESTRICTED STREAM/STREAM MATCHES (Y/N)? N or ENTER

Result:

1. Problem table analysis

SUBNETWORK	COLD STREAM TEMP.INTERVAL (°F)	DEFICIT (b.t.u. /hr)	ACCUMULATIVE OUTPUT (b.t.u./hr)	HEAT FLOW (b.t.u./hr)
	500			461200
1		461200	-461200	
	460			0
2		-1185800	724600	
	320			1185800
3		119600	605000	
	300			1066200
4		-427600	1032600	
	260			1493800
5		186200	846400	
	240			1307600
6		-133200	979600	
	180			1440800
7		578000	401600	
	140			862800

2. Pinch location and utility requirements.

PINCH IS LOCATED AT COLD STREAM TEMPERATURE (°F) = 460

MINIMUM HOT UTILITY (b.t.u./hr) = 461200

MINIMUM COLD UTILITY (b.t.u./hr) = 862800

3. Composite curve (as shown in Figure 8-1).

4. Above-the-pinch design.

Match no. 1 Hot utility required = 461200

Cold stream no. 2 Th = 500 Tc = 460 CP = 11530

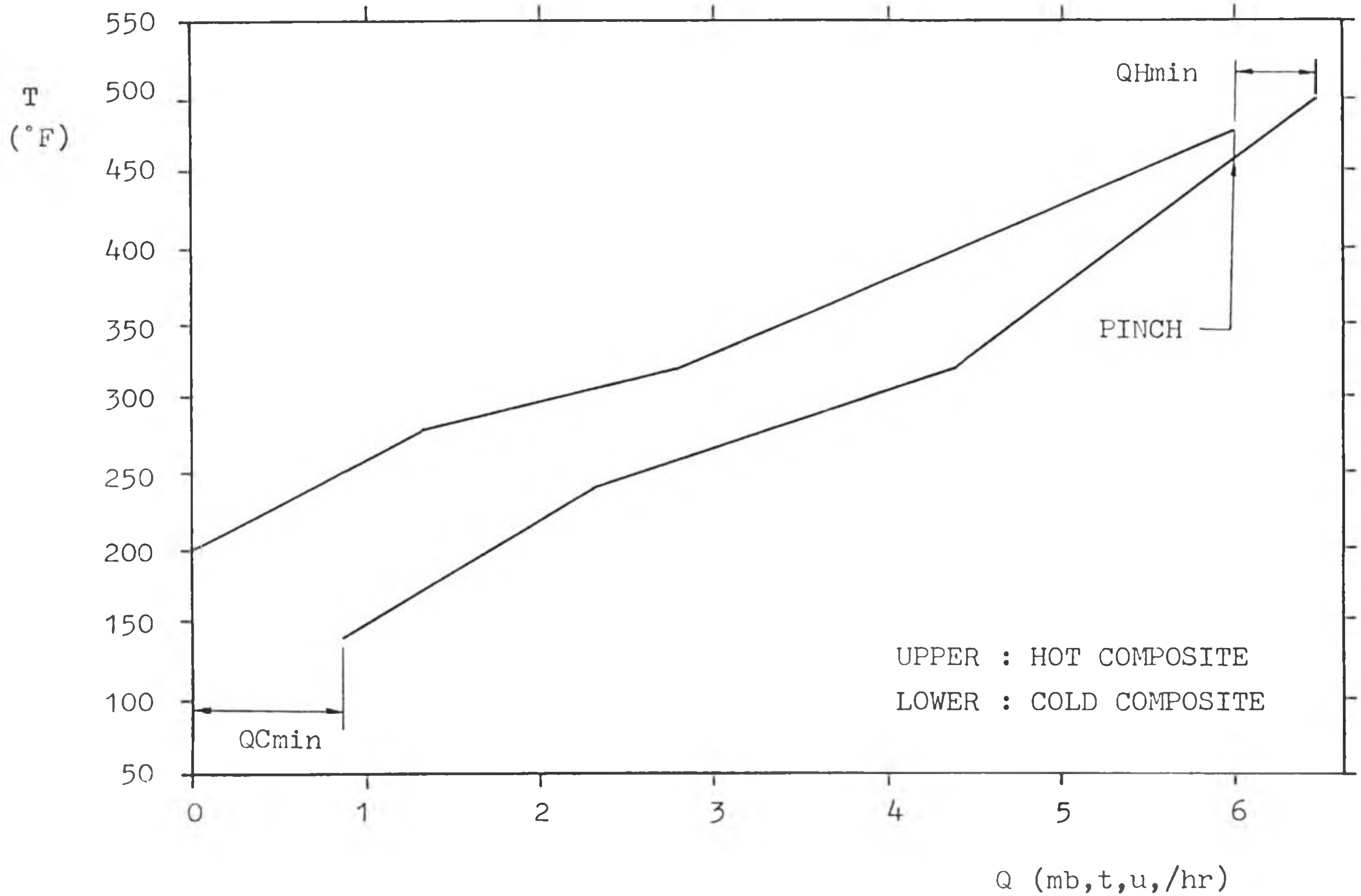


Figure 8-1 Composite curves for example 8-1

5. Below-the-pinch design.

Match no. 2		Heat load = 2536600		
Hot stream no.	2	Th = 480	Tc = 353.17	CP = 20000
Cold stream no.	2	Th = 460	Tc = 240	CP = 11530
Match no. 3		Heat load = 1463400		
Hot stream no.	2	Th = 353.17	Tc = 280	CP = 20000
Cold stream no.	1	Th = 320	Tc = 218.73	CP = 14450
Match no. 4		Heat load = 1137600		
Hot stream no.	1	Th = 320	Tc = 251.76	CP = 16670
Cold stream no.	1	Th = 218.73	Tc = 140	CP = 14450
Match no. 5		cold utility required = 862800		
Hot stream no. 1		Th = 251.76	Tc = 200	CP = 16670

6. Grid representation of the designed maximum-energy-recovery (M.E.R.) network is shown below.

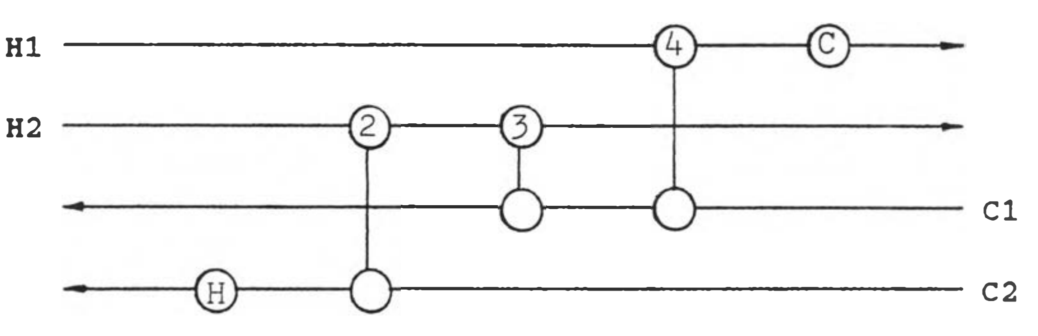


Figure 8-2. Grid representation for M.E.R. network of example 8-1

After the initial M.E.R. network structure has been generated, the user must select one of the following options:

A. SEARCH AND BREAK LOOP

B. MERGE HEAT LOAD FOR THE SELECTED PATH

C. DRAW THE RESULTING NETWORK CONFIGURATION

D. ECONOMIC ANALYSIS

X. TERMINATE THE PROGRAM

The function of each option are as follows:

A. Search and break loop. In this option primary loops in the designed network is automatically searched for and attempts are made to break them up to the second-level.

B. Merge heat load for the selected path. This option is provided for interactive loop breaking. That is, the user has to identify a loop himself and enter the number of exchangers in the loop interactively. However, the loop breaking step is computerized.

C. Draw the resulting network configuration. This option is used to display the grid represention of the latest network structure.

D. Economic analysis. This option is used to carry out economic evaluation of the network structure.

Since it is obvious that example 8-1 has no loop in the designed network, it is meaningless to select option 'A' or "B". Hence we proceed on to economic analysis through the following procedure.

<u>Procedure for economic analysis of new process</u>

Step 1. Select option "D"

ENTER YOUR SELECTION ? <u>d</u>

Step 2. Enter "n" for new plant condition.

NEW OR RETROFIT PLANT (N/R)? n

Step 3. Enter the following data

PRESENT HEAT EXCHANGER COST INDEX	? 350
WORKING LIFE OF HEAT EXCHANGER (YEARS)	? 10
INTEREST RATE (%)	? 10
UNIT: HEAT EXCHANGER AREA	? ft^2
CURRENCY (press ENTER for US$)	? (enter)

Step 4. Enter hot utility data

H/E NO.	HEAT LOAD (b.t.u. /hr)	Tin (°F)	Tout (°F)	COST PER UNIT (US$/b.t.u.yr)	COST TOTAL (US$)
1	461200	540	540	.03	13836

Step 5. Enter cold utility data

H/E NO.	HEAT LOAD (b.t.u. /hr)	Tin (°F)	Tout (°F)	COST PER UNIT (US$/b.t.u.yr)	COST TOTAL (US$)
5	862800	100	180	.003	2588.4

Step 6. Enter the value of the overall heat transfer coefficient, U, for each unit. The cursor will wait for the data in the third column. The required heat transfer area will be calculated and shown in the last column.

H/E NO.	STREAM PAIR	U (B.t.u./ hr.ft^2.°F)	THin (°F)	THout (°F)	TCin (°F)	TCout (°F)	REQUIRED AREA (ft^2)
1	H 0 - C 2	200	540	540	460	500	39.96
2	H 2 - C 2	150	480	353.17	240	460	314.57
3	H 2 - C 1	150	353.17	280	218.73	320	213.04
4	H 1 - C 1	150	320	251.76	140	218.73	71.26
5	H 1 - C 0	150	251.76	200	100	180	67.59

Result:

1. Cost of new heat exchangers.

Exchanger costs in 1959 will be calculated according to equation (6-2) to (6-4), then it will be converted to the present costs according to equation (6-1). The results are shown below.

H/E NO.	AREA (ft^2)	COST IN 1958 (US$)	PRESENT COST (US$)
1	39.96	30.51	106.80
2	314.57	2186.32	7652.14
3	213.04	1878.77	6575.72
4	71.26	32.83	114.91
5	67.59	32.62	114.17
TOTAL	706.43		14563.74

2. Annual expenditures.

To evaluate the annual expenditure of the designed network, the user will be asked to provide installation cost, piping cost and contigency. These data can be input either as percentages of the total heat exchanger cost or as absolute amounts. First the program will ask for data in percents. If zero is entered, it will then ask for the absolute cost of the specific item. In this example such costs are assumed to be 20, 20 and 5 percent of the total heat exchanger cost, respectively. The breakdown of costs and calculation results are shown below:

DESCRIPTION	COST	
	% OF H/E COST	TOTAL (US$)
TOTAL HEAT EXCHANGER COST		14563.74
INSTALLATION , RELOCATION COST	20	2912.75
PIPING COST	20	2912.75
OTHERS	5	728.19
TOTAL CAPITAL		21117.43
WORKING LIFE OF HEAT EXCHANGER (YEARS)		10
INTEREST RATE (%)		10
ANNUALISED : CAPITAL		3436.67
UTILITY		16424.40
ANNUAL EXPENDITURE		19861.17

The present solution of example 8-1 provides a network configuration which achieves maximum energy recovery and a minimum number of units, with an annual cost of 19861.17 US$. In fact the designed network structure is identical to the optimum network structure achieved using Tree Searching Algorithms [13: 1182].

Example 8-2

This example consists of two hot streams and four cold streams the data of which are given in Table 8-2, and the minimum temperature approach is 20 °C.

Table 8-2. Data for example 8-2 [source 30: 577]

STREAM NO.	STARTING TEMP. (°C)	TARGET TEMP. (°C)	HEAT CAPACITY FLOWRATE (kW/°C)
H1	120	95	8
H2	88	70	19
C1	90	110	4
C2	65	85	8
C3	50	68	10
C4	50	76	1

Network design procedure

Step 1. Enter numbers of streams.

NO. OF HOT STREAMS ? 2

NO. OF COLD STREAMS? 4

Step 2. Enter units of temperature and heat load.

UNIT OF TEMPERATURE (°)? C

UNIT OF HEAT LOAD ? kW

Step 3. Enter minimum allowable temperature difference.

MINIMUM ALLOWABLE TEMPERATURE DIFFERENCE (°C) ? 20

Step 4. Enter hot-stream data.

HOT STREAM NO.	STARTING TEMP. (°C)	TARGET TEMP. (°C)	HEAT CAPACITY FLOWRATE (kW/°C)
1	120	95	8
2	88	70	19

Step 5. Enter cold-stream data.

COLD STREAM NO.	STARTING TEMP. (°C)	TARGET TEMP. (°C)	HEAT CAPACITY FLOWRATE (kW/°C)
1	90	110	4
2	65	85	8
3	50	68	10
4	50	76	1

Step 6. Enter restricted stream pairs (if any).

ARE THERE ANY RESTRICTED STREAM/STREAM MATCHES (Y/N)? N or ENTER

Result:

1. Problem table analysis

SUBNETWORK NO.	COLD STREAM TEMP.INTERVAL (°C)	DEFICIT (kW)	ACCUMULATE OUTPUT (kW)	HEAT FLOW (kW)
	110			40
1		40	-40	
	100			0
2		-40	0	
	90			40
3		-40	40	
	85			80
4		0	40	
	76			80
5		1	39	
	75			79
6		63	-24	
	68			16
7		0	-24	
	65			16
8		-120	96	
	50			136

2. Pinch point and utility requirements

PINCH IS LOCATED AT COLD STREAM TEMPERATURE (°C) = 100

MINIMUM HOT UTILITY (kW) = 40

MINIMUM COLD UTILITY (kW) = 136

3. Composite curve (as shown in Figure 8-3)

4. Above-the-pinch design.

MATCH NO. 1 HOT UTILITY = 40

COLD STREAM NO. 1 Th = 110 Tc = 100 CP = 4

5. Below-the-pinch design

SPLIT HOT STREAM NO.2 TO STREAM NO.3 AND STREAM NO.4

SPLIT TEMP. = 88 RECOMBINED TEMP. = 77.16

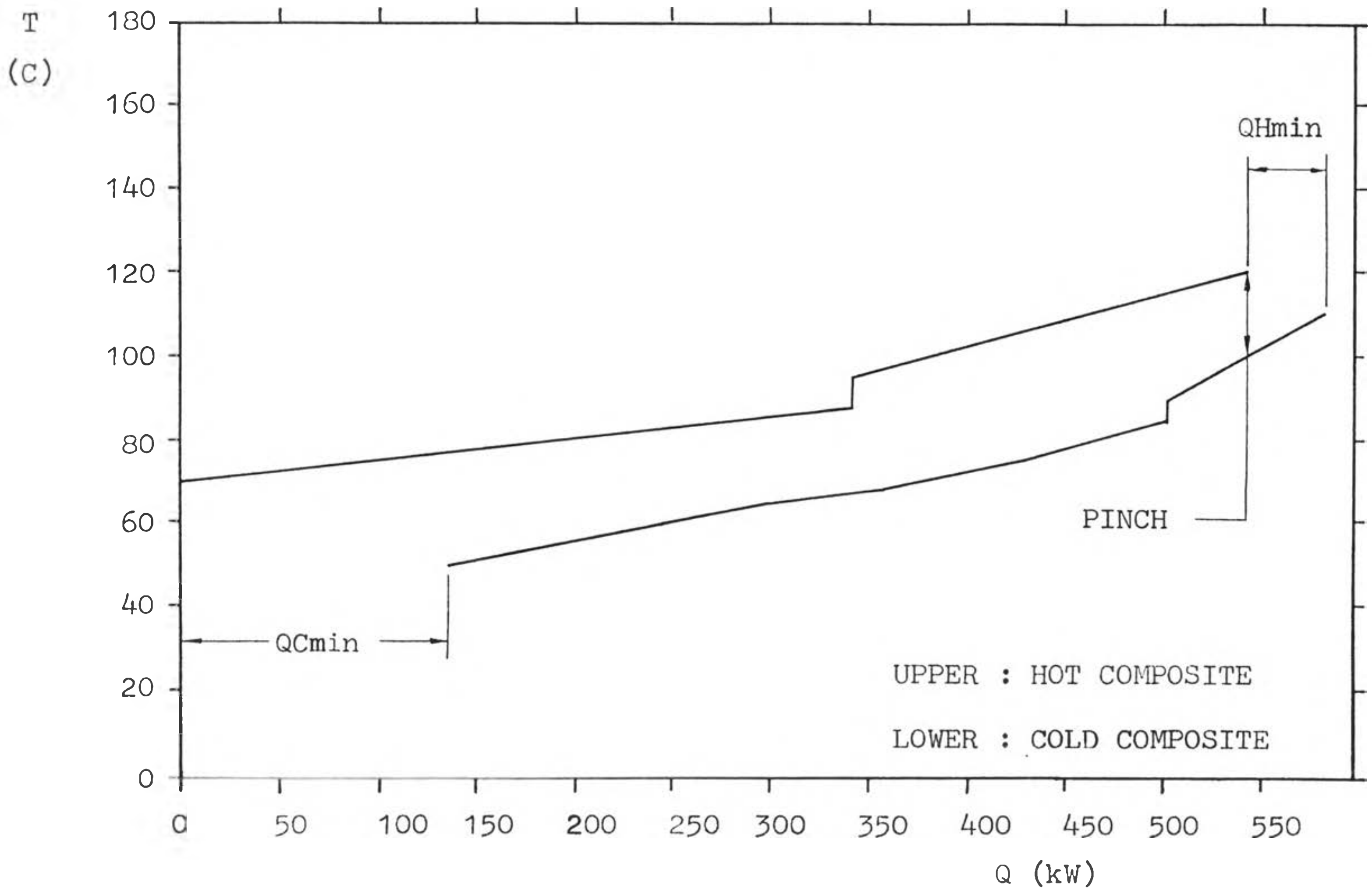


Figure 8-3 Composite curves for example 8-2

TSH(3) = 88		TTH(3) = 85.11		CPH(3) = 9
TSH(4) = 88		TTH(4) = 70		CPH(4) = 10
MATCH NO. 2		HEAT LOAD = 40		
HOT STREAM NO.	1	Th = 120	Tc = 115	CP = 8
COLD STREAM NO.	1	Th = 100	Tc = 90	CP = 4
MATCH NO. 3		HEAT LOAD = 152		
HOT STREAM NO.	1	Th = 115	Tc = 96	CP = 8
COLD STREAM NO.	2	Th = 85	Tc = 66	CP = 8
MATCH NO. 4		HEAT LOAD = 8		
HOT STREAM NO.	1	Th = 96	Tc = 95	CP = 8
COLD STREAM NO.	4	Th = 76	Tc = 68	CP = 1
MATCH NO. 5		HEAT LOAD = 180		
HOT STREAM NO.	4	Th = 88	Tc = 70	CP = 10
COLD STREAM NO.	3	Th = 68	Tc = 50	CP = 10
MATCH NO. 6		HEAT LOAD = 18		
HOT STREAM NO.	3	Th = 88	Tc = 86	CP = 9
COLD STREAM NO.	4	Th = 68	Tc = 50	CP = 1
MATCH NO. 7		HEAT LOAD = 8		
HOT STREAM NO.	3	Th = 86	Tc = 85.11	CP = 9
COLD STREAM NO.	2	Th = 66	Tc = 65	CP = 8
MATCH NO. 8		COLD UTILITY = 136		
HOT STREAM NO.	2	Th = 77.16	Tc = 70	CP = 19

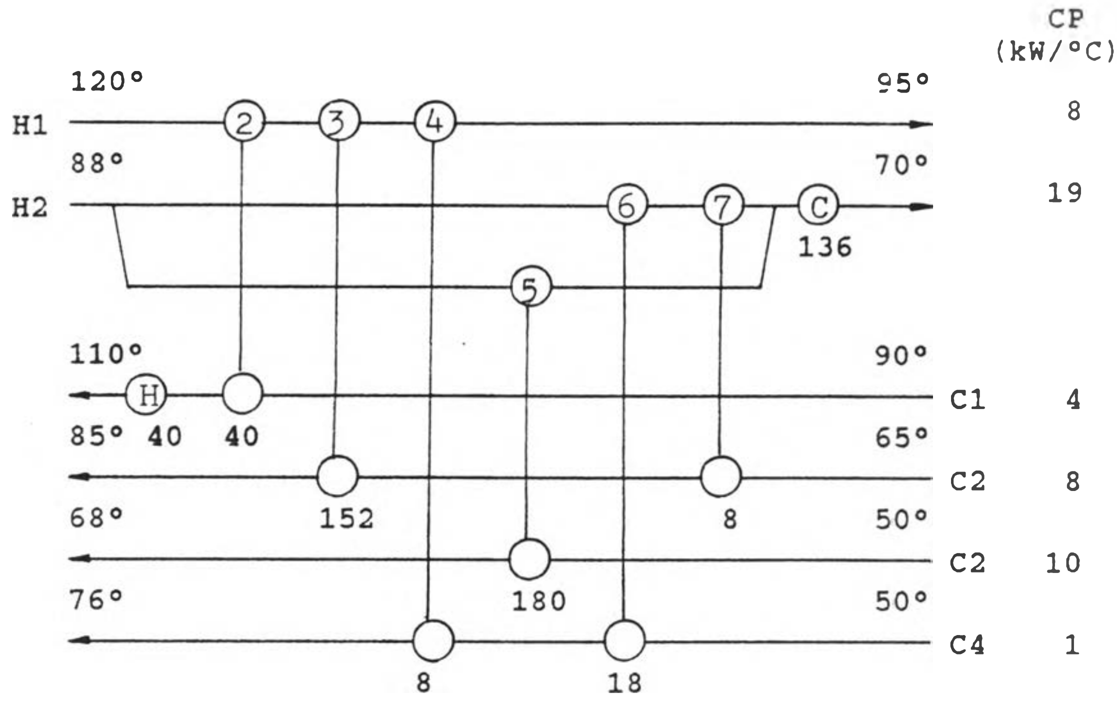
6. Grid representation of M.E.R. design (shown in Figure 8-4(a))

OPTION :

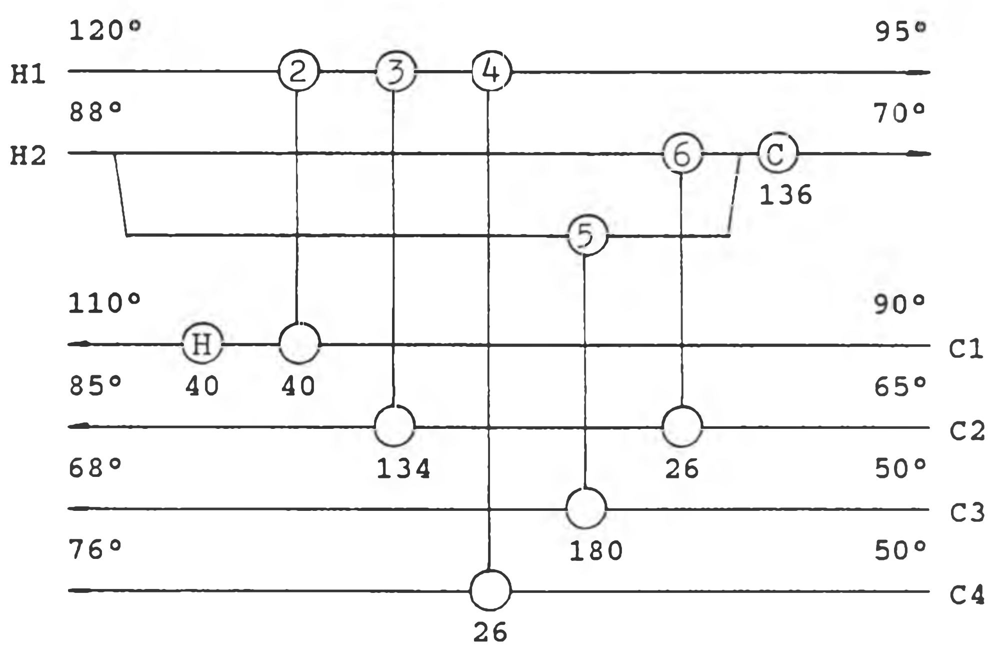
A. SEARCH AND BREAK LOOP

B. MERGE HEAT LOAD FOR THE SELECTED PATH

C. DRAW THE RESULTING NETWORK CONFIGURATION



(a) Initial structure



(b) Final structure

Figure 8-4 Grid representation for M.E.R. and final networks of example 8-2.

D. ECONOMIC ANALYSIS

X. TERMINATE THE PROGRAM

Since the total number of exchanger units is greater than the predicted minimum of 7, there must be some loops incorporated in the designed M.E.R. network. Hence they should be searched out and broken up. We next accomplish the loop-searching and loop-breaking task through the following procedure.

Step 1. Select option "A".

ENTER YOUR SELECTION ? a

Step 2. Enter the permissible δTmin violation range.

DO YOU ALLOW δTmin TO BE VIOLATED WITHIN A SPECIFIC RANGE (Y/N)? y

MAXIMUM VIOLATION (°C)? 2

If the minimum allowable temperature difference, δTmin, is violated within the specified value (2°C for this example), the user will be asked to decide whether to accept it or not.

Result:

SEARCH FOR FIRST LEVEL LOOP

No first level loop is found.

SEARCH FOR SECOND LEVEL LOOP

MERGING TARGET : 3

LOOP :(3 , 7 , 6 , 4)

MERGE : infeasible, negative heat load appears on match no. 6

MERGING TARGET : 7

LOOP :(7 , 6 , 4 , 3)

MERGE : feasible, no negative heat load

TEMP.DIFFERENCE : violate the given δTmin on match no. 6

(δT = 12)

MERGING TARGET : 6

LOOP :(6 , 4 , 3 , 7)

MERGE : feasible, no negative heat load

TEMP.DIFFERENCE : violate the given δTmin on match no. 6

(δT = 19.75)

CAN YOU ACCEPT (Y/N)? y

The evolved network structure is shown in Figure 8-4(b) and data of the resulting matches are listed below.

MATCH NO. 1		HOT UTILITY = 40		
COLD STREAM NO.	1	Th = 110	Tc = 100	CP = 4
MATCH NO. 2		HEAT LOAD = 40		
HOT STREAM NO.	1	Th = 120	Tc = 115	CP = 8
COLD STREAM NO.	1	Th = 100	Tc = 90	CP = 4
MATCH NO. 3		HEAT LOAD = 134		
HOT STREAM NO.	1	Th = 115	Tc = 98.25	CP = 8
COLD STREAM NO.	2	Th = 85	Tc = 68.25	CP = 8
MATCH NO. 4		HEAT LOAD = 26		
HOT STREAM NO.	1	Th = 98.25	Tc = 95	CP = 8
COLD STREAM NO.	4	Th = 76	Tc = 50	CP = 1
MATCH NO. 5		HEAT LOAD = 180		
HOT STREAM NO.	4	Th = 88	Tc = 70.51	CP = 10.29
COLD STREAM NO.	3	Th = 68	Tc = 50	CP = 10

MATCH NO. 6		HEAT LOAD = 26		
HOT STREAM NO.	3	Th = 88	Tc = 85.01	CP = 8.708
COLD STREAM NO.	2	Th = 68.25	Tc = 65	CP = 8
MATCH NO. 7		COLD UTILITY = 136.0001		
HOT STREAM NO.	2	Th = 77.16	Tc = 70	CP = 19

The loop searching is then restarted at the first level. However, no loop is found. The program next displays the previous five options. Since we want to terminate the program, option "X" is selected.

In conclusion, the final network of example 8-2 satisfies both the M.E.R. and the minimum number of units simualtaneously. In comparison, the network designed by Saboo and Morari [30: 577] achieved the same minimum number of units by consuming an additional 8 kW of both hot and cold utilities.

Example 8-3 [8: 898]

Figure 8-5 shows the flow diagram of the ABCDE process. A gas mixture of A, B and C, at 320 K and 16 bar, is compressed and mixed with a recycle stream before entering a high pressure reactor. The reaction, A + B ---> D + E, is exothermic at 600 K and 100 bar. The reactcr products, at 600 K and 100 bar, are cooled to 310 K and 98 bar and sent to a flash separator where unreacted A, B, and C are recovered. The vapor stream is scrubbed with water to recover D and E. Two percent of the lean vapcr is purged, to remove C, and the remainder is recirculated to the

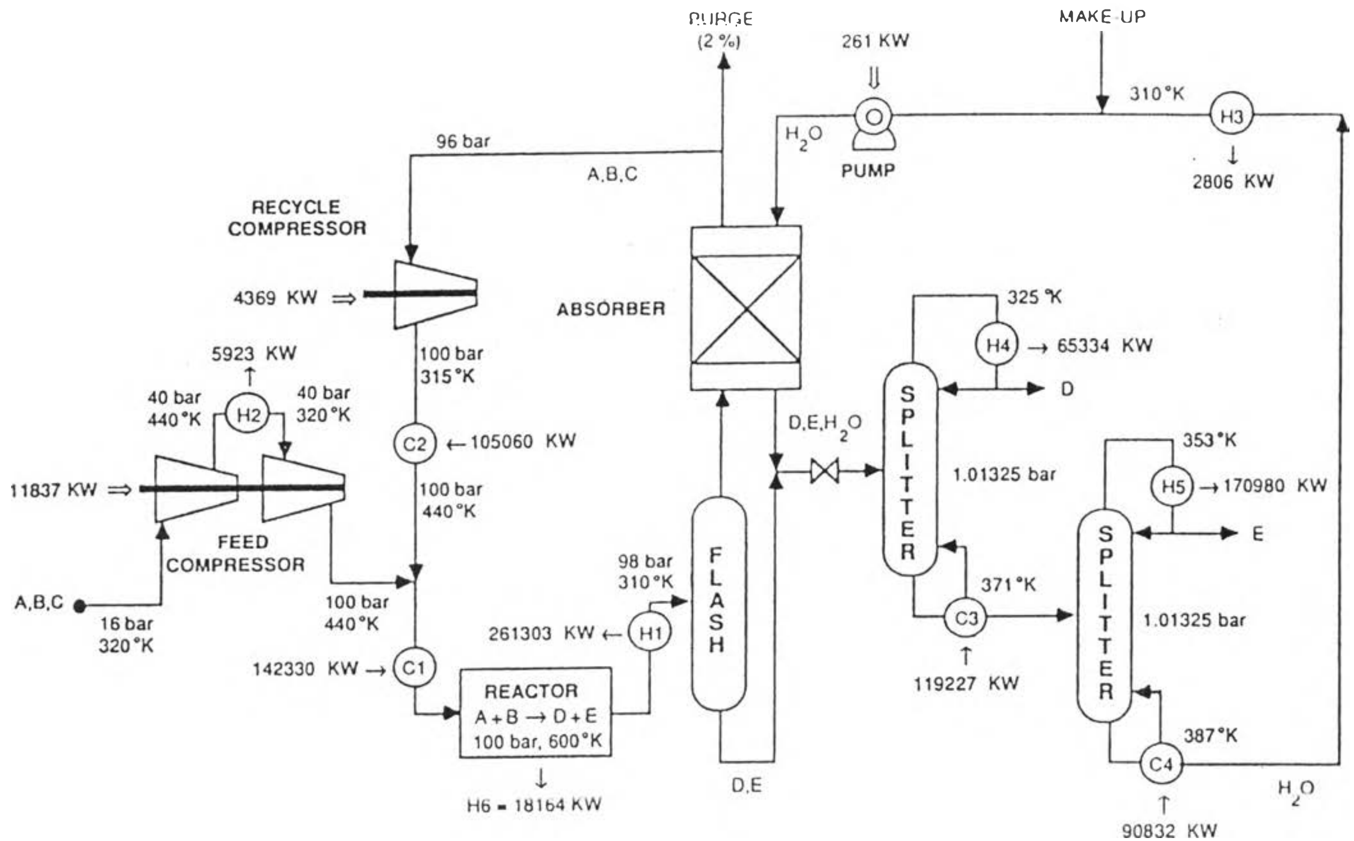


Figure 8-5 Flow diagram of the ABCDE process

reactor. The rich water is mixed with liquid from the flash separator and sent to the first of two atmospheric distillation columns. In the first column, D is removed in the distillate, and the bottom stream is sent to the second column , where E is recovered in the distillate. The bottom stream, mainly water, is pumped back to the absorber. Cold streams to be heated are labeled C# and hot streams to be cooled are labeled H#, with heat duties and heat capacity flow rates given in table 8-3. The minimum allowable temperature approach is 10 °K.

Table 8-3 Heating and cooling demands for ABCDE process [source 8: 898]

STREAM NO.	Ts (°K)	Tt (°K)	Q (kW)	HEAT CAPACITY FLOWRATE (kW/°K)
H1	600	310	261303	901.045
H2	440	320	5923	49.358
H3	387	310	2806	36.422
H4	325	325	65334	-
H5	353	353	170980	-
H6	600	600	18164	-
C1	440	600	142330	889.563
C2	315	440	105060	840.480
C3	371	371	119227	-
C4	387	387	90832	-

From the given data, there are three hot streams and two cold streams that encounter change of phase during interchange of heat load. Since the developed software does not provide for phase change, the above given data will be modified by assuming that those streams with phase change are accompanied by a small temperature difference of 0.1 K. Therefore, their heat capacity flow rates are ten times their expected heat duties.

Network design procedure

Step 1. Enter numbers of streams.

NO. OF HOT STREAMS ? 6

NO. OF COLD STREAMS? 4

Step 2. Enter units of temperature and heat load.

UNIT OF TEMPERATURE (°)? K

UNIT OF HEAT LOAD ? kW

Step 3. Enter minimum allowable temperature difference.

MINIMUM ALLOWABLE TEMPERATURE DIFFERENCE (°K) ? 10

Step 4. Enter hot-stream data.

HOT STREAM NO.	STARTING TEMP. (°K)	TARGET TEMP. (°K)	HEAT CAPACITY FLOWRATE (kW/°K)
1	600	310	901.045
2	440	320	49.358
3	387	310	36.422
4	325.05	324.95	653340.000
5	353.05	352.95	1709800.000
6	600.05	599.95	181640.000

Step 5. Enter cold-stream data.

COLD STREAM NO.	STARTING TEMP. (°K)	TARGET TEMP. (°K)	HEAT CAPACITY FLOWRATE (kW/°K)
1	440	600	889.563
2	315	440	840.480
3	370.95	371.05	1192270.000
4	386.95	387.05	908320.000

Step 6. Enter restricted stream pair (if any).

ARE THERE ANY RESTRICTED STREAM/STREAM MATCHES

(Y/N) ? n or enter

RESULT:

1. Problem table analysis

SUBNETWORK NO.	COLD STREAM TEMP. INTERVAL (°K)	DEFICIT (kW)	ACCUMULATIVE OUTPUT (kW)	HEAT FLOW (kW)
	600			191704.5
1		8851.16	-8851.16	
	590.05			182853.4
2		-9035.31	184.15	
	590			191888.7
3		-9080.35	9264.51	
	589.95			200969.0
4		-1721.72	10986.23	
	440			202690.8
5		-605.65	11591.88	
	430			203296.4
6		-4721.19	16313.07	
	387.05			208017.6
7		90798.84	-74485.77	
	386.95			117218.8

SUBNETWORK NO.	COLD STREAM TEMP.INTERVAL (°K)	DEFICIT (kW)	ACCUMULATIVE OUTPUT (kW)	HEAT FLOW (kW)
8		-1093.73	-73392.03	
	377			118312.5
9		-870.75	-72521.27	
	371.05			119183.3
10		119183.30	-191704.50	
	370.95			0
11		-4083.03	-187621.50	
	343.05			4083.0
12		-170952.90	-16668.63	
	342.95			175035.9
13		-4083.03	-12585.60	
	315.05			179118.9
14		-32666.34	20080.75	
	315			211785.3
15		-32708.36	52789.10	
	314.95			244493.6
16		-4884.79	57673.90	
	310			249378.4
17		-9374.67	67048.57	
	300			258753.1

2. Pinch point and utility requirements.

PINCH IS LOCATED AT COLD STREAM TEMPERATURE (°K) = 370.95

MINIMUM HOT UTILITY (kW) = 191704.5

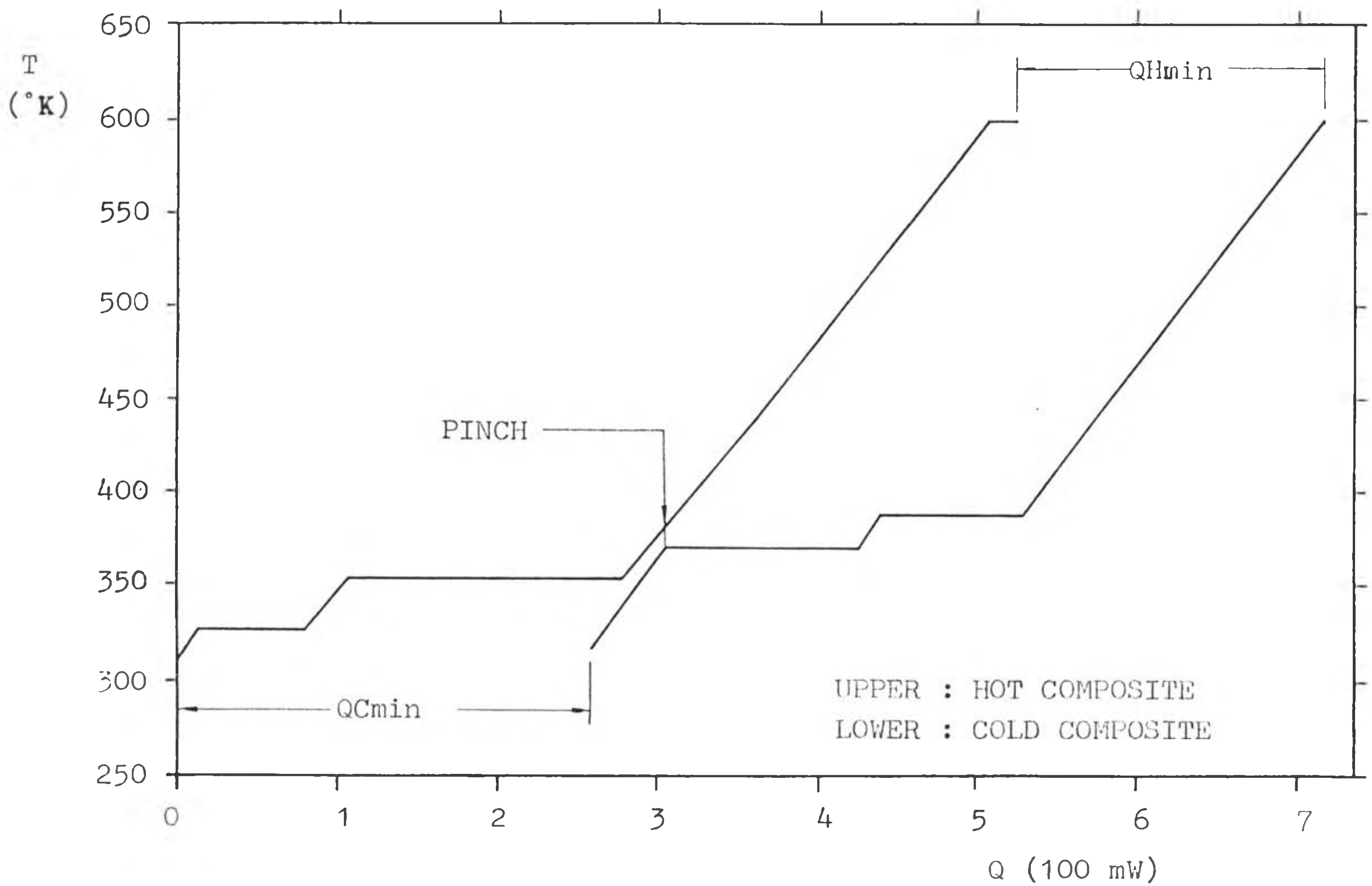
MINIMUM COLD UTILITY (kW) = 258753.1

3. Composite curve (as shown in Figure 8-6).

4. Above-the-pinch design

SPLIT COLD STREAM NO.3 TO STREAM NO.5 AND STREAM NO.6

SPLITTED TEMP. = 370.95 RECOMBINED TEMP. = 371.05



Figute 8-6 Composite curves for example 8-3

TSC(5) = 370.95 TTC(5) = 371.05 CPC(5) = 1411.66

TSC(6) = 370.95 TTC(6) = 371.05 CPC(6) = 1190858

MATCH NO. 1 HEAT LOAD = 119056.8

HOT STREAM NO. 1 Th = 513.08 Tc = 380.95 CP = 901.045

COLD STREAM NO.6 Th = 371.05 Tc = 370.95 CP = 11908581

MATCH NO. 2 HEAT LOAD = 141.1316

HOT STREAM NO. 2 Th = 383.81 Tc = 380.95 CP = 49.358

COLD STREAM NO.5 Th = 371.05 Tc = 370.95 CP = 1411.66

MATCH NO. 3 HEAT LOAD = 220.3527

HOT STREAM NO. 3 Th = 387 Tc = 380.95 CP = 36.422

COLD STREAM NO.2 Th = 371.21 Tc = 370.95 CP = 840.48

MATCH NO. 4 HEAT LOAD = 2773.458

HOT STREAM NO. 2 Th = 440 Tc = 383.81 CP = 49.358

COLD STREAM NO.2 Th = 374.51 Tc = 371.21 CP = 840.48

MATCH NO. 5 HEAT LOAD = 78317.13

HOT STREAM NO. 1 Th = 600 Tc = 513.08 CP = 901.045

COLD STREAM NO.4 Th = 387.04 Tc = 386.95 CP = 908320

MATCH NO. 6 HEAT LOAD = 18159.57

HOT STREAM NO. 6 Th = 600.05 Tc = 599.95 CP = 181640

COLD STREAM NO.2 Th = 396.12 Tc = 374.51 CP = 840.48

MATCH NO. 7 HOT UTILITY = 142330.1

COLD STREAM NO.1 Th = 600 Tc = 440 CP = 889.563

MATCH NO. 8 HOT UTILITY = 36881.76

COLD STREAM NO.2 Th = 440 Tc = 396.12 CP = 840.48

MATCH NO. 9 HOT UTILITY = 12492.7

COLD STREAM NO.4 Th = 387.05 Tc = 387.04 CP = 908320

5 Below-the-pinch design

MATCH NO. 10 HEAT LOAD = 47024.86

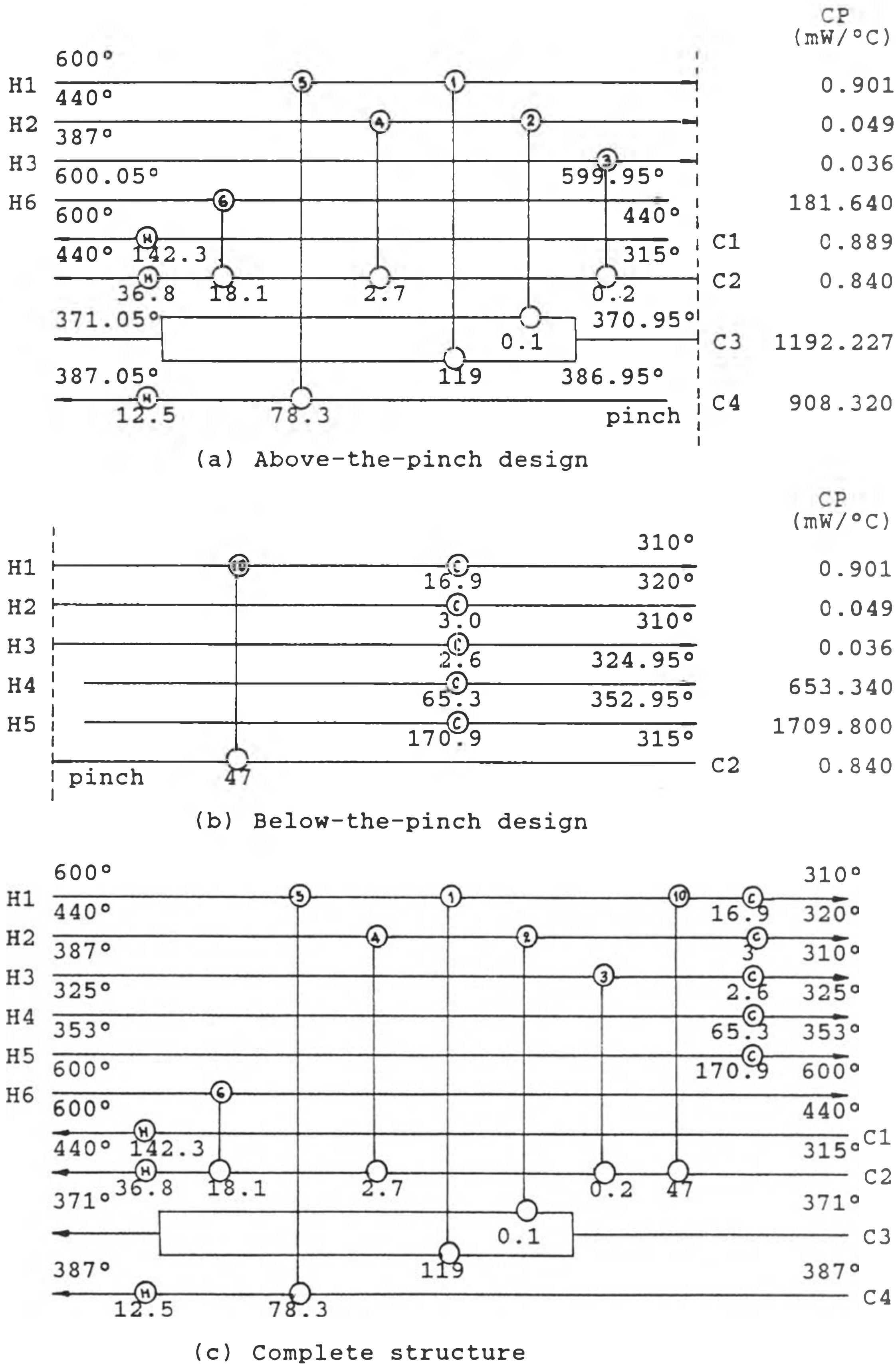


Figure 8-7 Grid representation for M.E.R. network of example 8-3.

HOT STREAM NO. 1   Th = 380.95   Tc = 328.76   CP = 901.045

COLD STREAM NO.2   Th = 370.95   Tc = 315   CP = 840.48

MATCH NO. 11   COLD UTILITY = 16904.29

HOT STREAM NO. 1   Th = 328.76   Tc = 310   CP = 901.045

MATCH NO. 12   COLD UTILITY = 3008.371

HOT STREAM NO. 2   Th = 380.95   Tc = 320   CP = 49.358

MATCH NO. 13   COLD UTILITY = 2584.141

HOT STREAM NO. 3   Th = 380.95   Tc = 310   CP = 36.422

MATCH NO. 14   COLD UTILITY = 65318.05

HOT STREAM NO. 4   Th = 325.05   Tc = 324.95   CP = 653340

MATCH NO. 15   COLD UTILITY = 170938.3

HOT STREAM NO. 5   Th = 353.05   Tc = 352.95   CP = 1709800

6. Grid representation of the M.E.R. design (shown in figure 8-7)

OPTION :

A. SEARCH AND BREAK LOOP

B. MERGE HEAT LOAD FOR THE SELECTED PATH

C. DRAW THE RESULTING NETWORK CONFIGURATICN

D. ECONOMIC ANALYSIS

X. TERMINATE THE PROGRAM

Loop breaking procedure

Step 1. Select option "A".

ENTER YOUR SELECTION ? a

Step 2. Enter the permissible δTmin violation range.

DO YOU ALLOW δTmin TO BE VIOLATED WITHIN A SPECIFIC RANGE (Y/N)? y

MAXIMUM VIOLATION (°K)? 2

Result:

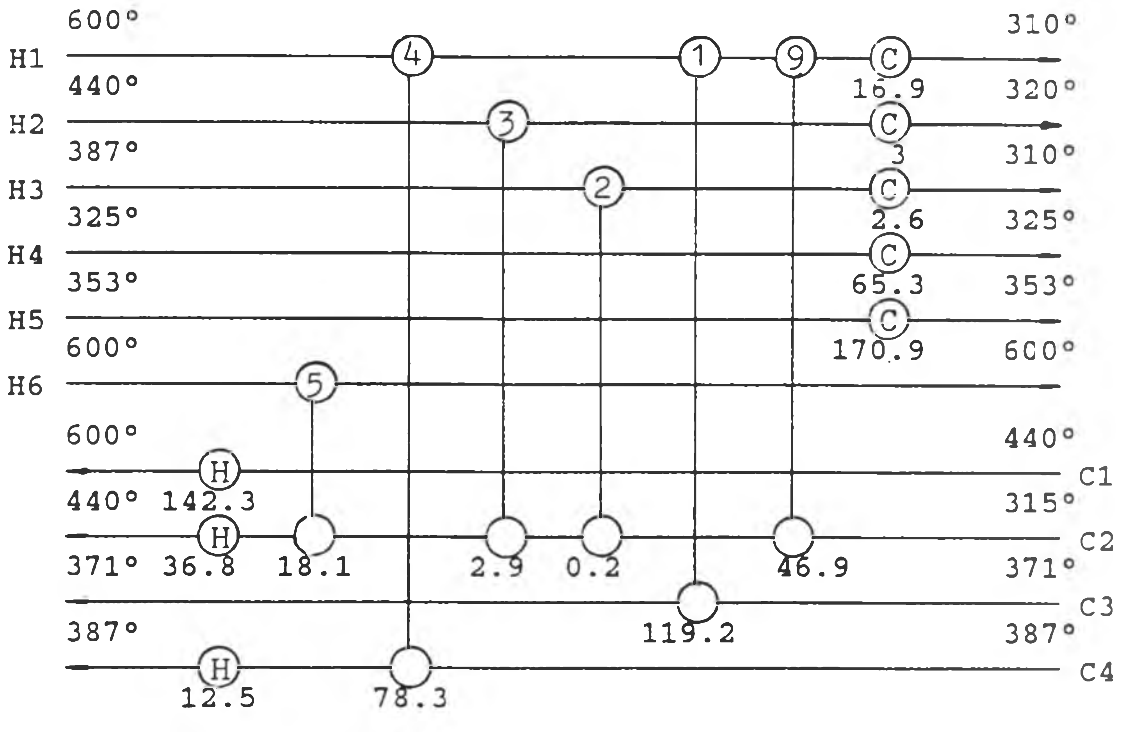
The first-level loops are first searched out. If no loop is found, it will continue to search for second-level loops. Whenever a loop is broken, the program will automatically restart search at the first level. After numerous manipulations only two loops, (2,4,10,1) and (2,12,10,9), have been broken. The evolved structures are shown in Figure 8-8 and the evolved match results are listed below.

SEARCH FOR FIRST-LEVEL LOOP

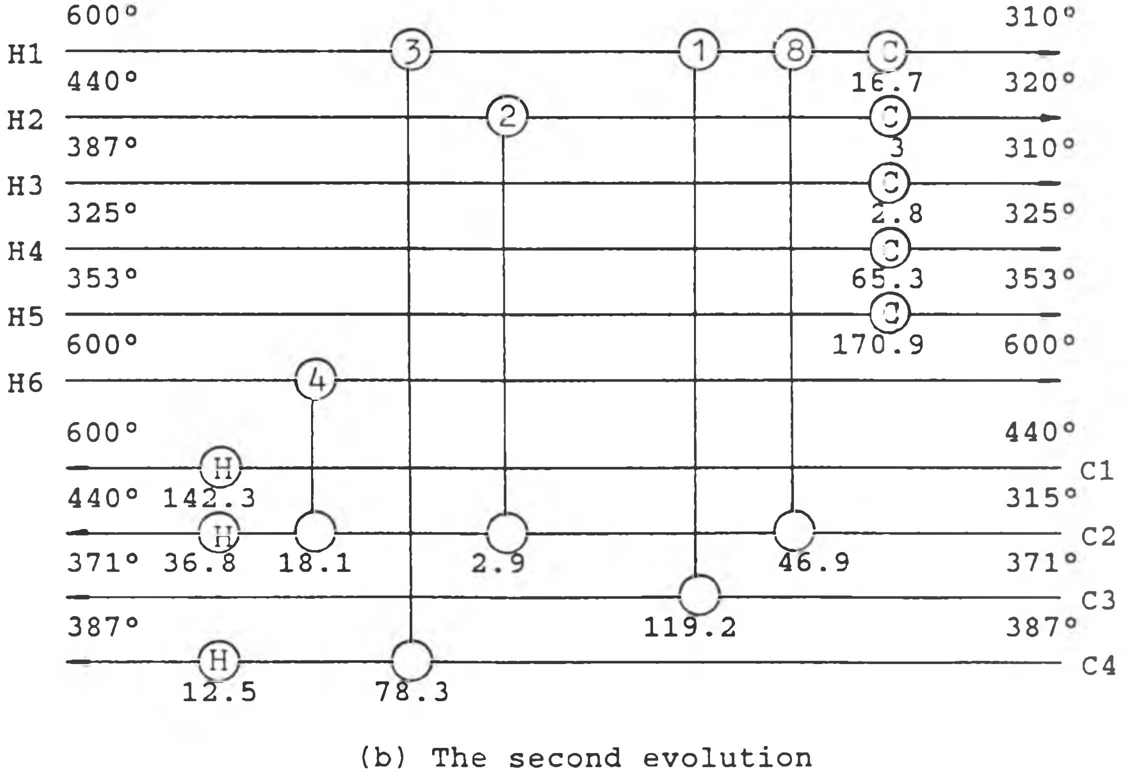
No first level loop is found.

SEARCH FOR SECOND-LEVEL LOOP

```
 MERGING TARGET : 2
           LOOP :( 2 , 4 , 10 , 1 )
          MERGE : feasible, no negative heat load
TEMP.DIFFERENCE : violate the given δTmin on match no. 1
                  (δT = 9.84 )
TEMP.DIFFERENCE : violate the given δTmin on match no. 3
                  (δT = 9.91 )
CAN YOU ACCEPT (Y/N)? y
    MATCH NO. 1    HEAT LOAD = 119197.9
HOT STREAM NO. 1   Th = 513.08   Tc = 380.79  CP = 901.045
COLD STREAM NO.3   Th = 371.05   Tc = 370.95  CP = 1192270
    MATCH NO. 2    HEAT LOAD = 220.3527
HOT STREAM NO. 3   Th = 387      Tc = 380.95  CP = 36.422
COLD STREAM NO.2   Th = 371.04   Tc = 370.78  CP = 840.48
    MATCH NO. 3    HEAT LOAD = 2914.59
```



(a) The first evolution



(b) The second evolution

Figure 8-8 Evolved network structures of example 8-3

HOT STREAM NO. 2	Th = 440	Tc = 380.95	CP = 49.358
COLD STREAM NO.2	Th = 374.51	Tc = 371.04	CP = 840.48
MATCH NO. 4	HEAT LOAD = 78317.13		
HOT STREAM NO. 1	Th = 600	Tc = 513.08	CP = 901.045
COLD STREAM NO.4	Th = 387.04	Tc = 386.95	CP = 908320
MATCH NO. 5	HEAT LOAD = 18159.57		
HOT STREAM NO. 6	Th = 600.05	Tc = 599.95	CP = 181640
COLD STREAM NO.2	Th = 396.12	Tc = 374.51	CP = 840.48
MATCH NO. 6	HOT UTILITY = 142330.1		
COLD STREAM NO.1	Th = 600	Tc = 440	CP = 889.563
MATCH NO. 7	HOT UTILITY = 36881.76		
COLD STREAM NO.2	Th = 440	Tc = 396.12	CP = 840.48
MATCH NO. 8	HOT UTILITY = 12492.7		
COLD STREAM NO.4	Th = 387.05	Tc = 387.04	CP = 908320
MATCH NO. 9	HEAT LOAD = 46883.73		
HOT STREAM NO. 1	Th = 380.79	Tc = 328.76	CP = 901.045
COLD STREAM NO.2	Th = 370.78	Tc = 315	CP = 840.48
MATCH NO. 10	COLD UTILITY = 16904.29		
HOT STREAM NO. 1	Th = 328.76	Tc = 310	CP = 901.045
MATCH NO. 11	COLD UTILITY = 3008.371		
HOT STREAM NO. 2	Th = 380.95	Tc = 320	CP = 49.358
MATCH NO. 12	COLD UTILITY = 2584.141		
HOT STREAM NO. 3	Th = 380.95	Tc = 310	CP = 36.422
MATCH NO. 13	COLD UTILITY = 65318.05		
HOT STREAM NO. 4	Th = 325.05	Tc = 324.95	CP = 653340
MATCH NO. 14	COLD UTILITY = 170938.3		
HOT STREAM NO. 5	Th = 353.05	Tc = 352.95	CP = 1709800

SEARCH FOR FIRST LEVEL LOOP

No first level loop is found.

SEARCH FOR SECOND LEVEL LOOP

MERGING TARGET : 2

LOOP :(2 , 12 , 10 , 9)

MERGE : feasible, no negative heat load

TEMP.DIFFERENCE : violate the given δTmin on match no. 1

(δT = 9.84)

TEMP.DIFFERENCE : violate the given δTmin on match no. 2

(δT = 9.91)

TEMP.DIFFERENCE : violate the given δTmin on match no. 8

(δT = 9.75)

CAN YOU ACCEPT (Y/N)? y

MATCH NO. 1	HEAT LOAD = 119197.9		
HOT STREAM NO. 1	Th = 513.08	Tc = 380.79	CP = 901.045
COLD STREAM NO.3	Th = 371.05	Tc = 370.95	CP = 1192270
MATCH NO. 2	HEAT LOAD = 2914.59		
HOT STREAM NO. 2	Th = 440	Tc = 380.95	CP = 49.358
COLD STREAM NO.2	Th = 374.51	Tc = 371.04	CP = 840.48
MATCH NO. 3	HEAT LOAD = 78317.13		
HOT STREAM NO. 1	Th = 600	Tc = 513.08	CP = 901.045
COLD STREAM NO.4	Th = 387.04	Tc = 386.95	CP = 908320
MATCH NO. 4	HEAT LOAD = 18159.57		
HOT STREAM NO. 6	Th = 600.05	Tc = 599.95	CP = 181640
COLD STREAM NO.2	Th = 396.12	Tc = 374.51	CP = 840.48
MATCH NO. 5	HOT UTILITY = 142330.1		
COLD STREAM NO.1	Th = 600	Tc = 440	CP = 889.563
MATCH NO. 6	HOT UTILITY = 36881.76		

COLD STREAM NO.2 Th = 440 Tc = 396.12 CP = 840.48

MATCH NO. 7 HOT UTILITY = 12492.7

COLD STREAM NO.4 Th = 387.05 Tc = 387.04 CP = 908320

MATCH NO. 8 HEAT LOAD = 47104.08

HOT STREAM NO. 1 Th = 380.79 Tc = 328.52 CP = 901.045

COLD STREAM NO.2 Th = 371.04 Tc = 315 CP = 840.48

MATCH NO. 9 COLD UTILITY = 16683.94

HOT STREAM NO. 1 Th = 328.52 Tc = 310 CP = 901.045

MATCH NO. 10 COLD UTILITY = 3008.371

HOT STREAM NO. 2 Th = 380.95 Tc = 320 CP = 49.358

MATCH NO. 11 COLD UTILITY = 2804.494

HOT STREAM NO. 3 Th = 387 Tc = 310 CP = 36.422

MATCH NO. 12 COLD UTILITY = 65318.05

HOT STREAM NO. 4 Th = 325.05 Tc = 324.95 CP = 653340

MATCH NO. 13 COLD UTILITY = 170938.3

HOT STREAM NO. 5 Th = 353.05 Tc = 352.95 CP = 1709800

C	H						
	0	1	2	3	4	5	6
0		9	10	11	12	13	
1	5						
2	6	8	2				4
3		1					
4	7	3					

NOTE:

0 REPRESENT HOT OR COLD UTILITY

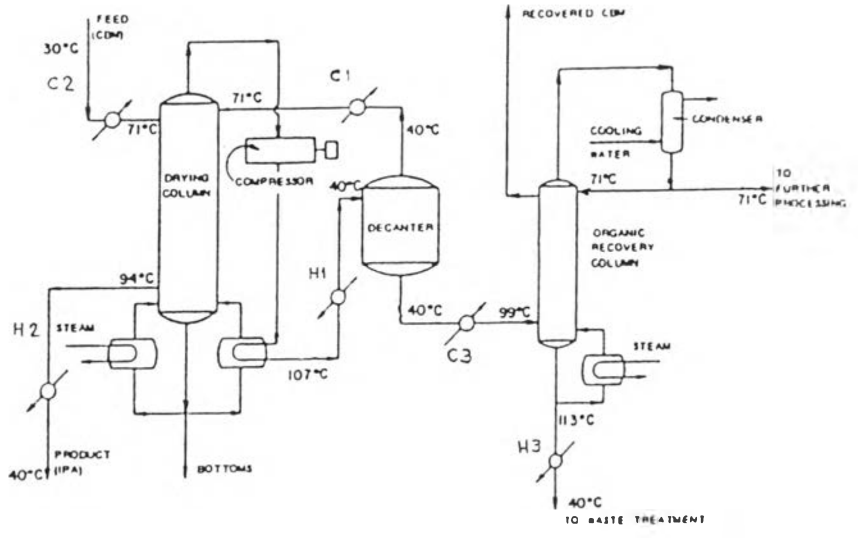
When no breakable first-level and second-level loops are left a table which lists the match numbers on each stream (as shown above) will be generated. If desired, the user might search for any higher level loop from this table, then input the unit numbers belonging to the loop interactively. The loop breaking procedure is computerized, and if the loop cannot be broken the program will automatically change the merging target. For example, from the above table a third level loop, (9,3,7,6,2,10), is found; however, it cannot be broken.

In this example the initial M.E.R. configuration requires cold stream splitting, however, the splitting is eliminated after the first evolution. The required utilities of the final configuration are the minima predicted, but it has two units more than the minimum possible. Anyway, the final configuration obtained here requires one units less than the network designed by using mixed-integer programming [24: 723].

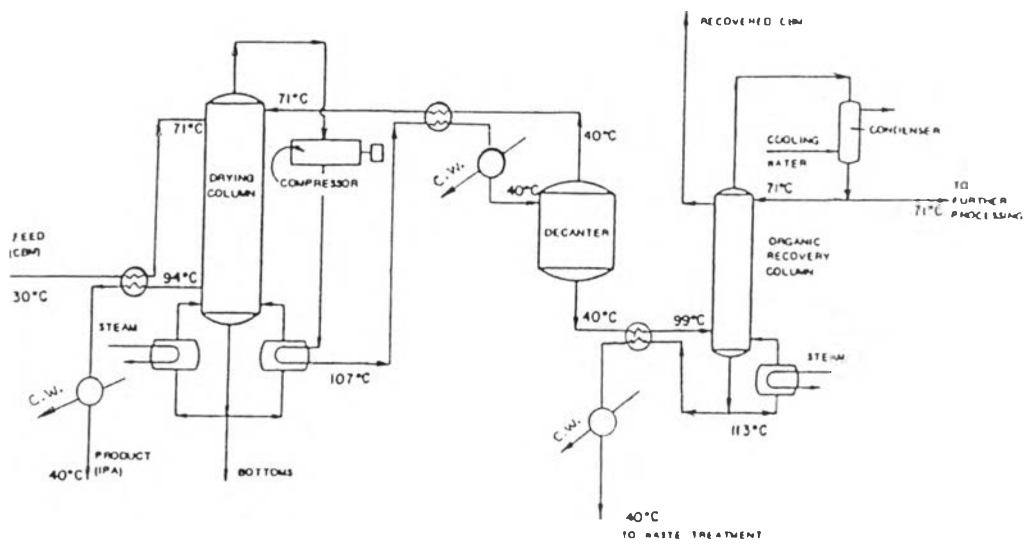
Example 8-4

Figure 8-9(a) shows a process flowsheet for the dehydration of isopropanol with isopropyl ether. Data of the problem with three hot streams and three cold streams are shown in Table 8-4. It is desired to design a maximum energy recovery network for a temperature approach of 10 °C.

Network design procedure



(a) Initial flowsheet



(b) Final flowsheet

Figure 8-9 Flowsheet for the dehydration of isopropanol with isopropyl ether (example8-4).

Table 8-4 Data for example 8-4.

STREAM NO.	STARTING TEMP. (°C)	TARGET TEMP. (°C)	HEAT CAPACITY FLOWRATE (kJ/hr.°C)
H1	107	40	145000
H2	94	40	36400
H3	113	40	7350
C1	40	71	137000
C2	30	71	45300
C3	40	99	8060

Step 1. Enter numbers of streams.

NO. OF HOT STREAM ? 3

NO. OF COLD STREAM ? 3

Step 2. Enter units of temperature and heat load.

UNIT OF TEMPERATURE (°)? C

UNIT OF HEAT LOAD ? kJ/hr

Step 3. Enter minimum allowable temperature difference.

MINIMUM ALLOWABLE TEMPERATURE DIFFERENCE (°C) ? 10

Step 4. Enter hot-stream data.

HOT STREAM NO.	STARTING TEMP. (°C)	TARGET TEMP. (°C)	HEAT CAPACITY FLOWRATE (kJ/hr.°C)
1	107	40	145000
2	94	40	36400
3	113	40	7350

Step 5. Enter cold-stream data.

COLD STREAM NO.	STARTING TEMP. (°C)	TARGET TEMP. (°C)	HEAT CAPACITY FLOWRATE (kJ/hr.°C)
1	40	71	137000
2	30	71	45300
3	40	99	8060

Step 6. Enter restricted stream pairs (if any).

ARE THERE ANY RESTRICTED STREAM/STREAM MATCHES (Y/N)? N or ENTER

Result:

1. Problem table analysis

SUBNETWORK NO.	COLD STREAM TEMP.INTERVAL (°C)	DEFICIT (kJ/hr)	ACCUMULATIVE OUTPUT (kJ/hr)	HEAT FLOW (kJ/hr)
	103			0
1		-29400	29400	
	99			29400
2		1420	27980	
	97			27980
3		-1875770	1903750	
	84			1903750
4		-2348970	4252720	
	71			4252720
5		49910	4202810	
	40			4202810
6		-1434500	5637310	
	30			5637310

2. Pinch point and utility requirements

PINCH IS LOCATED AT COLD STREAM TEMPERATURE (°C) = 103

MINIMUM HOT UTILITY (kJ/hr) = 0

MINIMUM COLD UTILITY (kJ/hr) = 5637310

3. Composite curve (as shown in Figure 8-10)

Obviously this example is a threshold type problem.

4. Below-the-pinch design

MATCH NO. 1	HEAT LOAD = 333752.1		
HOT STREAM NO. 3	Th = 113	Tc = 67.59	CP = 7350
COLD STREAM NO.3	Th = 99	Tc = 57.59	CP = 8060
MATCH NO. 2	HEAT LOAD = 4247000		
HOT STREAM NO. 1	Th = 107	Tc = 77.71	CP = 145000
COLD STREAM NO.1	Th = 71	Tc = 40	CP = 137000
MATCH NO. 3	HEAT LOAD = 1857300		
HOT STREAM NO. 2	Th = 94	Tc = 42.98	CP = 36400
COLD STREAM NO.2	Th = 71	Tc = 30	CP = 45300
MATCH NO. 4	HEAT LOAD = 141787.9		
HOT STREAM NO. 1	Th = 77.71	Tc = 76.73	CP = 145000
COLD STREAM NO.3	Th = 57.59	Tc = 40	CP = 8060
MATCH NO. 5	COLD UTILITY = 5326212		
HOT STREAM NO. 1	Th = 76.73	Tc = 40	CP = 145000
MATCH NO. 6	COLD UTILITY = 108300		
HOT STREAM NO. 2	Th = 42.98	Tc = 40	CP = 36400
MATCH NO. 7	COLD UTILITY = 202797.9		
HOT STREAM NO. 3	Th = 67.59	Tc = 40	CP = 7350

5. Grid representation of M.E.R. design (shown in figure 8-11(a))

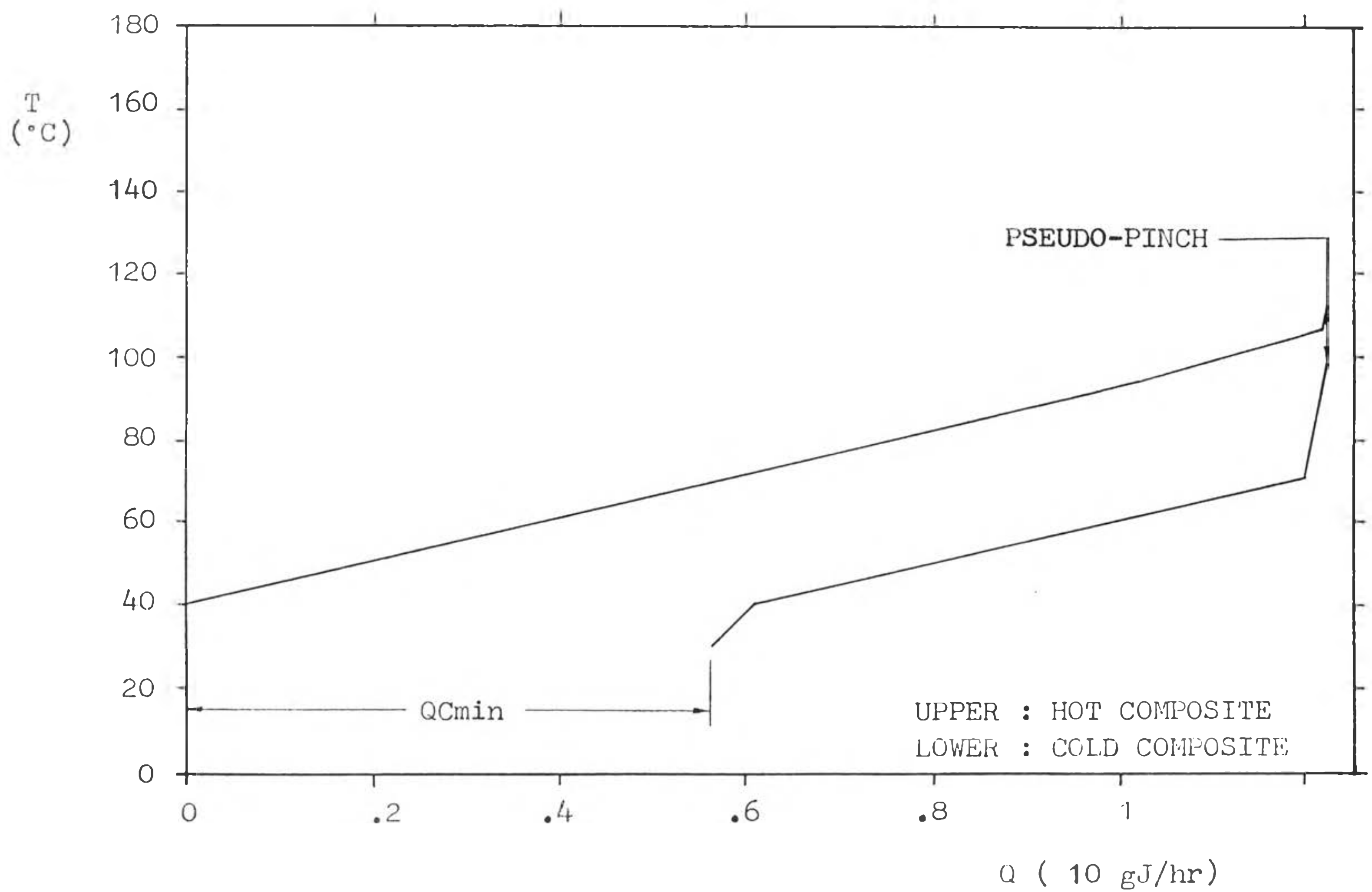


Figure 8-10 Composite curves for example 8-4

OPTION :

A. SEARCH AND BREAK LOOP

B. MERGE HEAT LOAD FOR THE SELECTED PATH

C. DRAW THE RESULTING NETWORK CONFIGURATION

D. ECONOMIC ANALYSIS

X. TERMINATE THE PROGRAM

Loop breaking procedure

Step 1. Select option "A"

ENTER YOUR SELECTION ? a

Step 2. Enter the permissible δTmin violation range.

DO YOU ALLOW δTmin TO BE VIOLATED WITHIN A SPECIFIC RANGE (Y/N)? y

MAXIMUM VIOLATION (°C)? 5

Result:

Only one loop in the initial network structure can be broken. The evolved grid representation and flowsheet are shown in Figure 8-11(b) and 8-9(b), resectively. The evolved match results are listed below.

SEARCH FOR FIRST LEVEL LOOP

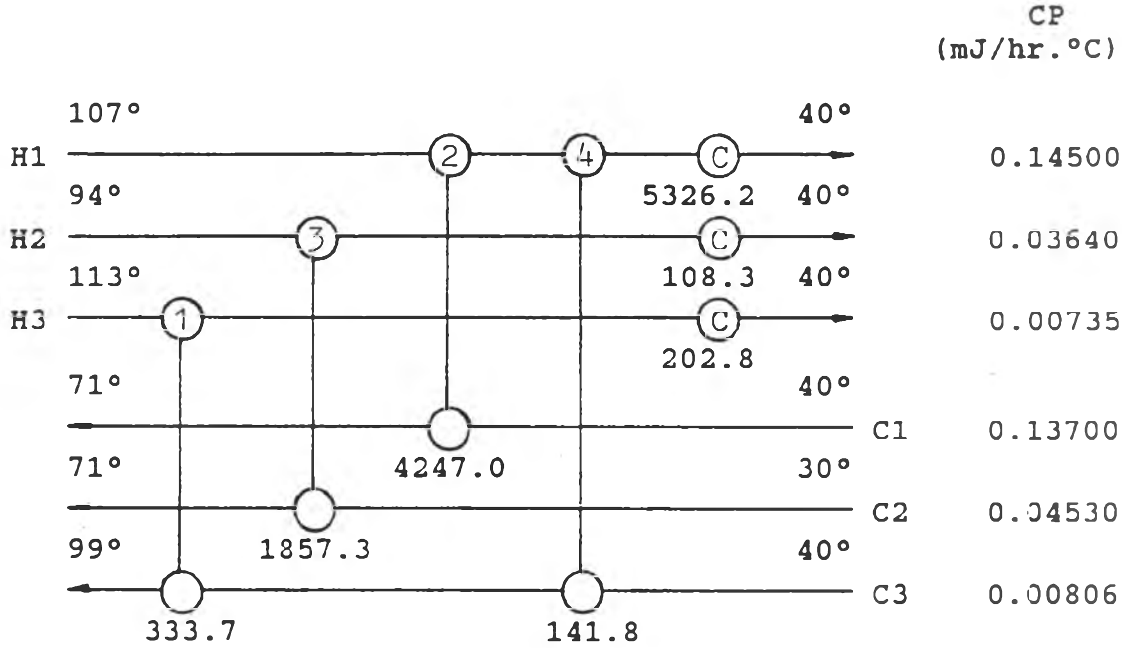
No first level loop is found.

SEARCH FOR SECOND LEVEL LOOP

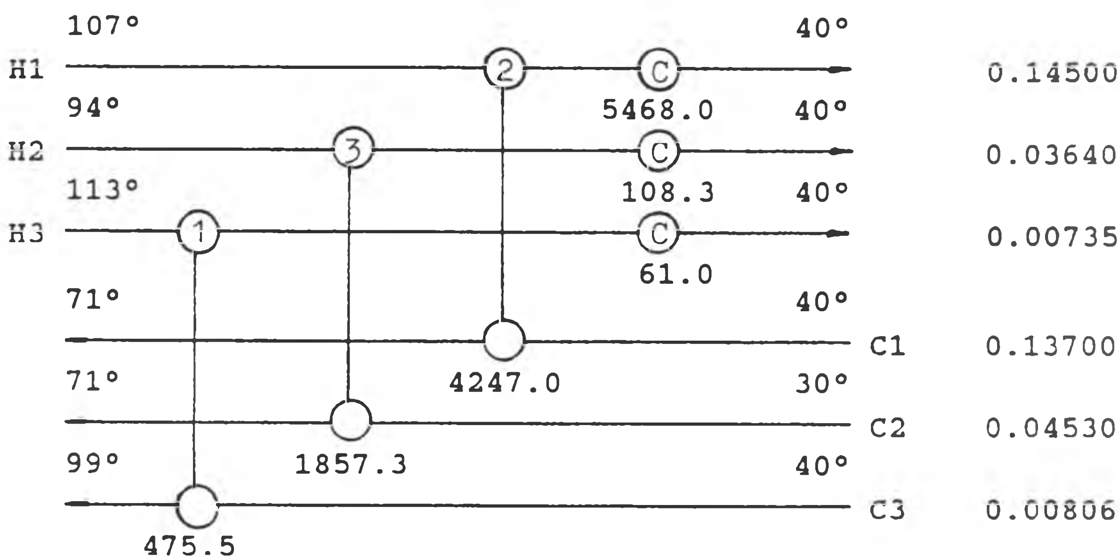
MERGING TARGET : 4

LOOP :(4 , 1 , 7 , 5)

MERGE : feasible, no negative heat load



(a) Initial structure



(b) Final structure

Figure 8-11 Designed network configuration for example 8-4

TEMP.DIFFERENCE : violate the given δTmin on match no. 1

(δT = 8.3)

CAN YOU ACCEPT (Y/N)? y

TEMP.DIFFERENCE : feasible

MATCH NO. 1	HEAT LOAD = 475540		
HOT STREAM NO. 3	Th = 113	Tc = 48.3	CP = 7350
COLD STREAM NO.3	Th = 99	Tc = 40	CP = 8060
MATCH NO. 2	HEAT LOAD = 4247000		
HOT STREAM NO. 1	Th = 107	Tc = 77.71	CP = 145000
COLD STREAM NO.1	Th = 71	Tc = 40	CP = 137000
MATCH NO. 3	HEAT LOAD = 1857300		
HOT STREAM NO. 2	Th = 94	Tc = 42.98	CP = 36400
COLD STREAM NO.2	Th = 71	Tc = 30	CP = 45300
MATCH NO. 4	COLD UTILITY = 5468000		
HOT STREAM NO. 1	Th = 77.71	Tc = 40	CP = 145000
MATCH NO. 5	COLD UTILITY = 108300		
HOT STREAM NO. 2	Th = 42.98	Tc = 40	CP = 36400
MATCH NO. 6	COLD UTILITY = 61010		
HOT STREAM NO. 3	Th = 48.3	Tc = 40	CP = 7350

In the above results, an M.E.R. network with the minimum number of units has been obtained. It proves that the developed software is applicable for the threshold-type problem.

Example 8-5 [source 3: 1]

Figure 8-12 shows the grid representation of a conventionally designed heat-exchanger network. Its heat transfer areas are summarized in Table 8-5. It is desired to expore the possibility for retrofitting this network under the assumptions that δTmin = 35 °C and overall heat transfer coefficient for each exchange unit is equal to 0.85 kW/M^2°C. Hot and cold utility costs are 100 and 6 US$/kW.yr, respectively.

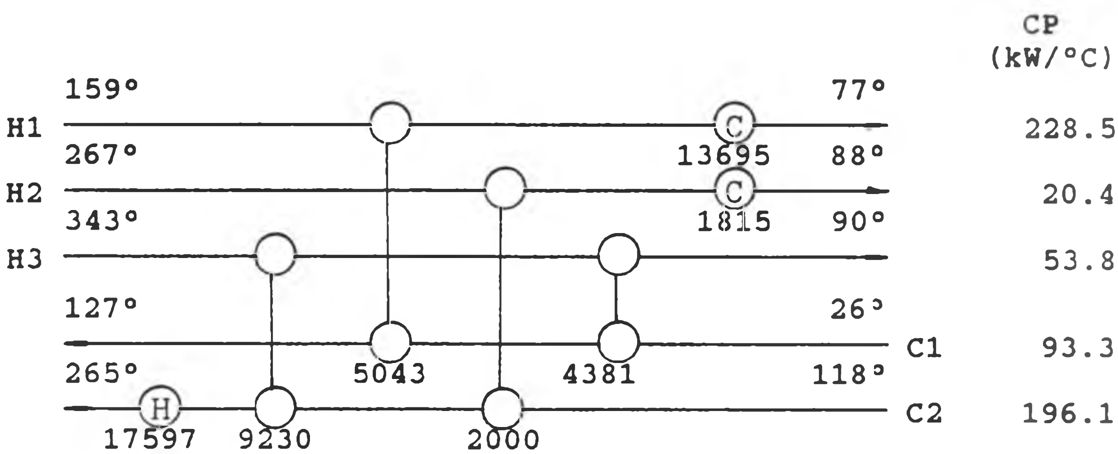


Figure 8-12 The grid diagram for an existing network (example 8-5)

Table 8-5 Heat transfer areas of the existing exchangers in example 8-5

H/E no.	E-1	E-2	E-3	E-4	H-1	C-1	C-2
Area (M^2)	119	65	129	27	293	311	30

<u>Network design procedure</u>

Step 1. Enter numbers of streams.

NO. OF HOT STREAM ? <u>3</u>

NO. OF COLD STREAM ? <u>2</u>

Step 2. Enter units of temperature and heat load.

UNIT OF TEMPERATURE (°)? C

UNIT OF HEAT LOAD ? kW

Step 3. Enter minimum allowable temperature difference.

MINIMUM ALLOWABLE TEMPERATURE DIFFERENCE (°C) ? 10

Step 4. Enter hot-stream data.

HOT STREAM NO.	STARTING TEMP. (°C)	TARGET TEMP. (°C)	HEAT CAPACITY FLOWRATE (kW/°C)
1	159	77	228.5
2	267	88	20.4
3	343	90	53.8

Step 5. Enter cold-stream data

COLD STREAM NO.	STARTING TEMP. (°C)	TARGET TEMP. (°C)	HEAT CAPACITY FLOWRATE (kW/°C)
1	26	127	93.3
2	118	265	196.1

Step 6. Enter restricted stream pairs (if any).

ARE THERE ANY RESTRICTED STREAM/STREAM MATCHES (Y/N)? N or ENTER

Result:

1. Problem table analysis

SUBNETWORK NO.	COLD STREAM TEMP.INTERVAL (°C)	DEFICIT (kW)	ACCUMULATIVE OUTPUT (kW)	HEAT FLOW (kW)
	308			15827.6
1		-2313.4	2313.4	
	265			18141.0
2		4695.9	-2382.5	
	232			13445.1
3		12799.5	-15182.0	
	127			645.6
4		645.6	-15827.6	
	124			0
5		-79.8	-15747.8	
	118			79.8
6		-13192.2	-2555.6	
	55			13272.0
7		-311.2	-2244.4	
	53			13583.2
8		-1487.2	-757.2	
	42			15070.4
9		1492.8	-2250.0	
	26			13577.6

2. Pinch point and utility requirements

PINCH IS LOCATED AT COLD STREAM TEMPERATURE (°C) = 124

MINIMUM HOT UTILITY (kW) = 15827.6

MINIMUM COLD UTILITY (kW) = 13577.6

3. Composite curve (as shown in Figure 8-13)

4. Above-the-pinch design

MATCH NO. 1 HEAT LOAD = 2690.609

HOT STREAM NO. 3 Th = 209.01 Tc = 159 CP = 53.8

COLD STREAM NO. 2 Th = 137.72 Tc = 124 CP = 196.1

MATCH NO. 2 HEAT LOAD = 279.9

HOT STREAM NO. 2 Th = 172.72 Tc = 159 CP = 20.4

COLD STREAM NO. 1 Th = 127 Tc = 124 CP = 93.3

MATCH NO. 3 HEAT LOAD = 1923.3

HOT STREAM NO. 2 Th = 267 Tc = 172.72 CP = 20.4

COLD STREAM NO. 2 Th = 147.53 Tc = 137.72 CP = 196.1

MATCH NO. 4 HEAT LOAD = 7208.591

HOT STREAM NO. 3 Th = 343 Tc = 209.01 CP = 53.8

COLD STREAM NO. 2 Th = 184.29 Tc = 147.53 CP = 196.1

MATCH NO. 5 HOT UTILITY = 15827.6

COLD STREAM NO. 2 Th = 265 Tc = 184.29 CP = 196.1

5. Below-the-pinch design

SPLIT COLD STREAM NO.1 TO STREAM NO.3, NO.4 AND NO.5

TSC(3) = 26.16 TTC(3) = 124 CPC(3) = 50.21261

TSC(4) = 26.16 TTC(4) = 124 CPC(4) = 19.63031

TSC(5) = 26.16 TTC(5) = 124 CPC(5) = 23.45708

SPLIT HOT STREAM NO.1 TO STREAM NO.4 AND NO.5

TSH(4) = 159 TTH(4) = 77 CPH(4) = 200.5129

TSH(5) = 159 TTH(5) = 77 CPH(5) = 27.98708

MATCH NO. 6 HEAT LOAD = 1176.6

HOT STREAM NO. 4 Th = 159 Tc = 153.13 CP = 200.5129

COLD STREAM NO.2 Th = 124 Tc = 118 CP = 196.1

MATCH NO. 7 HEAT LOAD = 3712.2

HOT STREAM NO. 3 Th = 159 Tc = 90 CP = 53.8

COLD STREAM NO.3 Th = 124 Tc = 50.07 CP = 50.21261

MATCH NO. 8 HEAT LOAD = 2294.94

HOT STREAM NO. 5 Th = 159 Tc = 77 CP = 27.98708

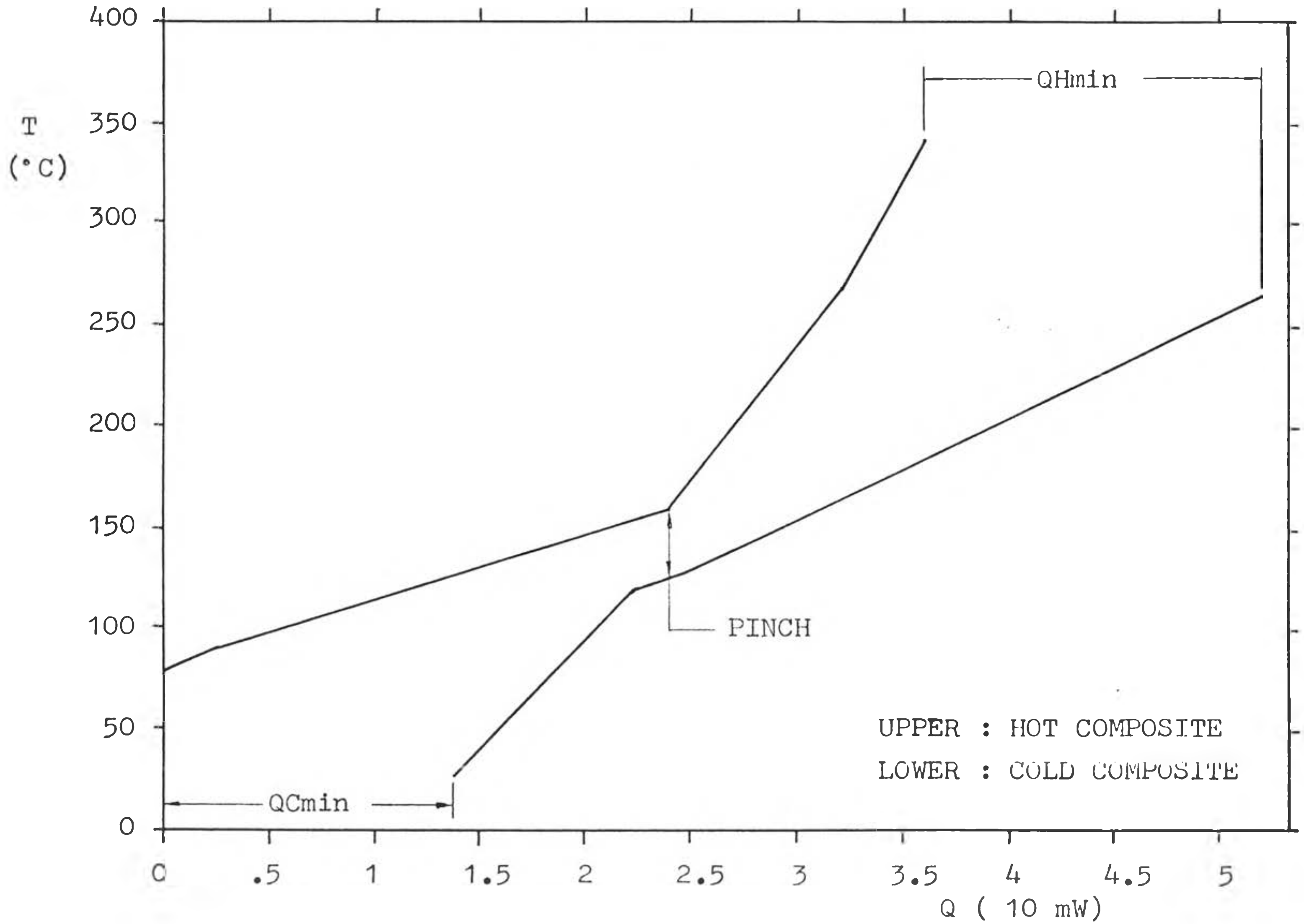
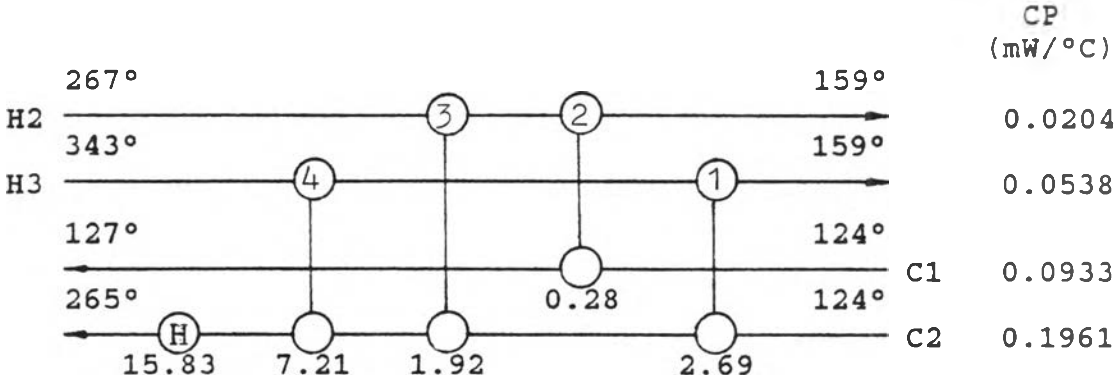
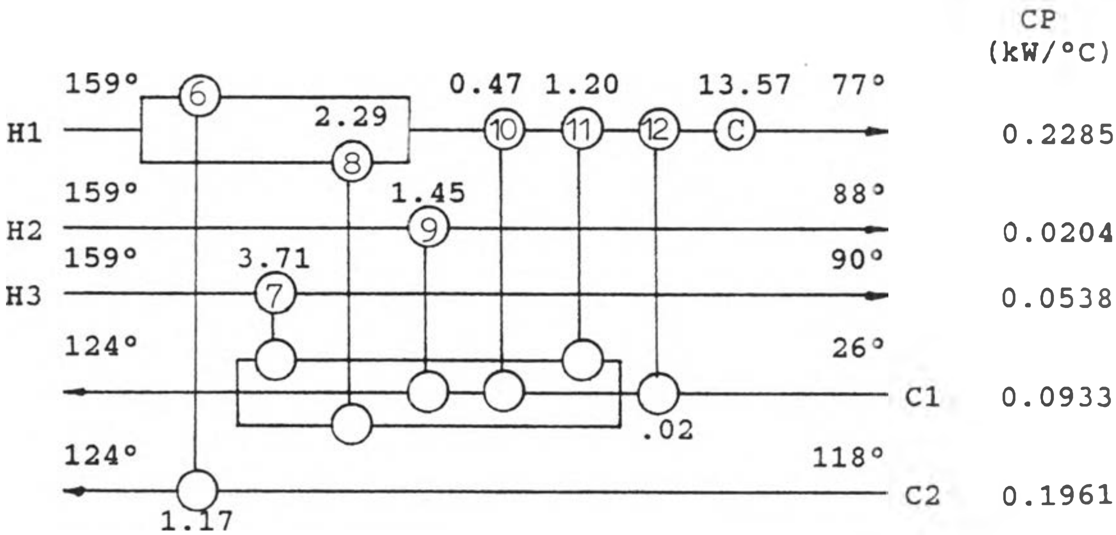


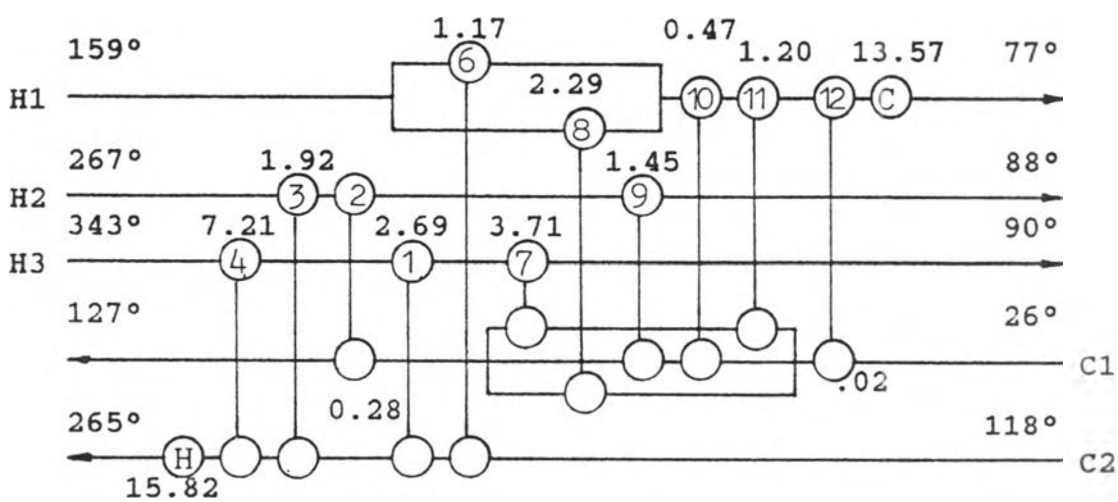
Figure 8-13 Composite curves for example 8-5



(a) Above-the-pinch design



(b) Below-the-pinch design



(c) Complete network

Figure 8-14 Initial M.E.R. design for example 8-5

COLD STREAM NO.5	Th = 124	Tc = 26.16	CP = 23.45708
MATCH NO. 9	HEAT LOAD = 1448.4		
HOT STREAM NO. 2	Th = 159	Tc = 88	CP = 20.4
COLD STREAM NO.4	Th = 124	Tc = 50.22	CP = 19.63031
MATCH NO. 10	HEAT LOAD = 472.146		
HOT STREAM NO. 1	Th = 143.81	Tc = 141.74	CP = 228.5
COLD STREAM NO.4	Th = 50.22	Tc = 26.16	CP = 19.63031
MATCH NO. 11	HEAT LOAD = 1200.387		
HOT STREAM NO. 1	Th = 141.74	Tc = 136.49	CP = 228.5
COLD STREAM NO.3	Th = 50.07	Tc = 26.16	CP = 50.21261
MATCH NO. 12	HEAT LOAD = 15.32696		
HOT STREAM NO. 1	Th = 136.49	Tc = 136.42	CP = 228.5
COLD STREAM NO.1	Th = 26.16	Tc = 26	CP = 93.3
MATCH NO. 13	COLD UTILITY = 13577.6		
HOT STREAM NO. 1	Th = 136.42	Tc = 77	CP = 228.5

OPTION :

A. SEARCH AND BREAK LOOP

B. MERGE HEAT LOAD FOR THE SELECTED PATH

C. DRAW THE RESULTING NETWORK CONFIGURATION

D. ECONOMIC ANALYSIS

X. TERMINATE THE PROGRAM

Loop breaking procedure

Step 1. Select option "A"

ENTER YOUR SELECTION ? a

Step 2. Enter the permissible δTmin violation range.

DO YOU ALLOW δTmin TO BE VIOLATED WITHIN A SPECIFIC

RANGE (Y/N)? y

MAXIMUM VIOLATION (°C)? 5

Result:

Several loops have been found and attempt to break them. However, only three loops are broken. The evolved structures are shown in Figure 8-14 and the match results are listed below.

MERGING TARGET : 10

LOOP : (10 , 8)

MERGE : feasible, no negative heat load

TEMP.DIFFERENCE : feasible

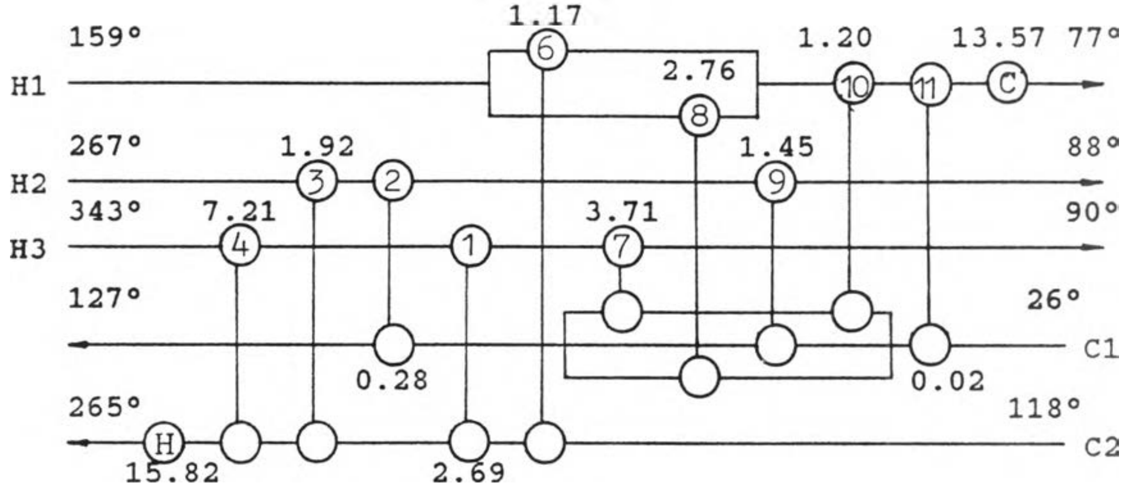
SPLIT COLD STREAM NO.1 TO STREAM NO.3, NO.4 AND NO.5

SPLIT TEMP. = 124		RECOMBINE TEMP. = 26.16
TSC(3) = 26.16	TTC(3) = 124	CPC(3) = 50.21261
TSC(4) = 26.16	TTC(4) = 124	CPC(4) = 14.80441
TSC(5) = 26.16	TTC(5) = 124	CPC(5) = 28.28298

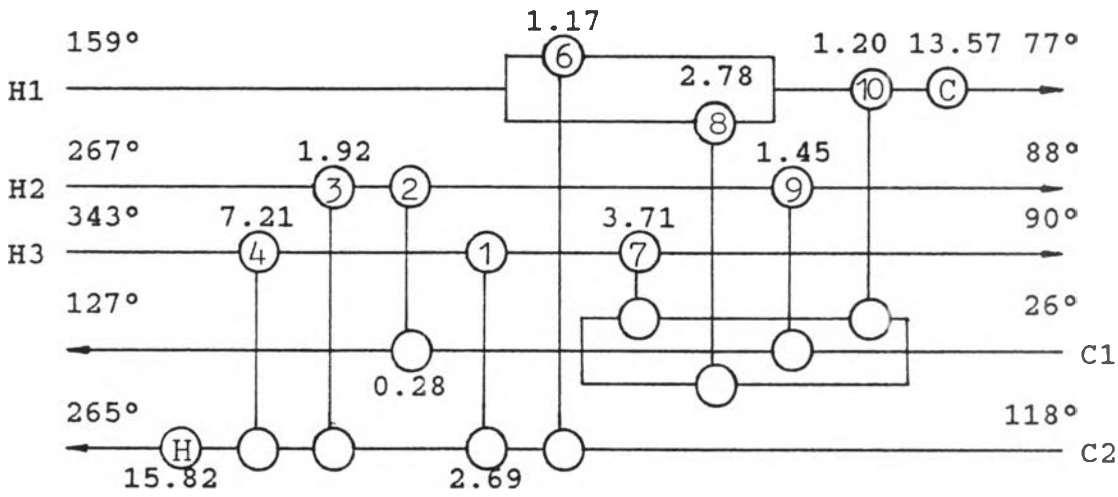
SPLIT HOT STREAM NO.1 TO STREAM NO.4 AND NO.5

SPLIT TEMP. = 159		RECOMBINE TEMP. = 141.74
TSH(4) = 159	TTH(4) = 77	CPH(4) = 197.3283
TSH(5) = 159	TTH(5) = 77	CPH(5) = 31.17167

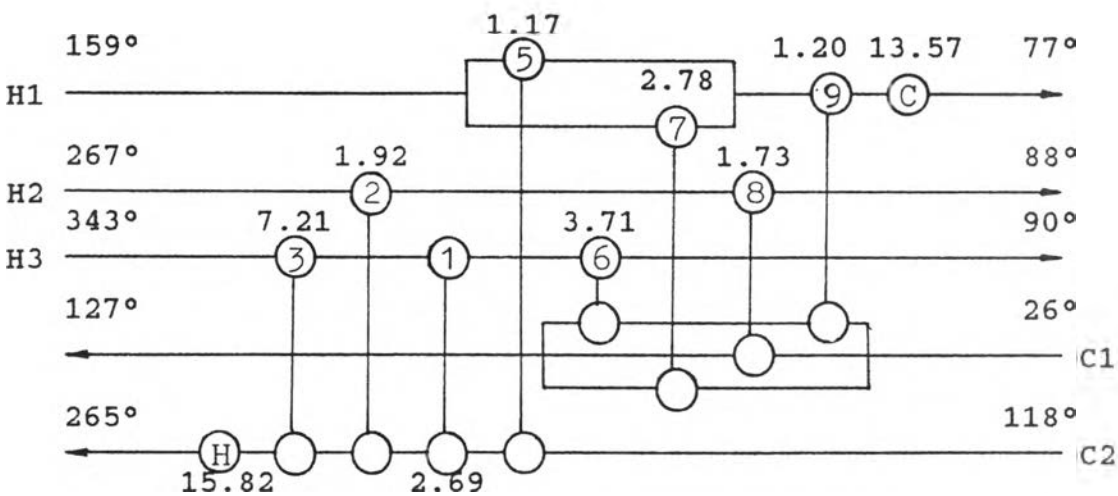
MATCH NO. 1	HEAT LOAD = 2690.609		
HOT STREAM NO. 3	Th = 209.01	Tc = 159	CP = 53.8
COLD STREAM NO.2	Th = 137.72	Tc = 124	CP = 196.1
MATCH NO. 2	HEAT LOAD = 279.9		
HOT STREAM NO. 2	Th = 172.72	Tc = 159	CP = 20.4
COLD STREAM NO.1	Th = 127	Tc = 124	CP = 93.3



(a) The first evolved structure



(b) The second evolved structure



(c) Final structure

Figure 8-15 Designed network for example 8-5

MATCH NO. 3	HEAT LOAD = 1923.3		
HOT STREAM NO. 2	Th = 267	Tc = 172.72	CP = 20.4
COLD STREAM NO.2	Th = 147.53	Tc = 137.72	CP = 196.1
MATCH NO. 4	HEAT LOAD = 7208.591		
HOT STREAM NO. 3	Th = 343	Tc = 209.01	CP = 53.8
COLD STREAM NO.2	Th = 184.29	Tc = 147.53	CP = 196.1
MATCH NO. 5	HOT UTILITY = 15827.6		
COLD STREAM NO.2	Th = 265	Tc = 184.29	CP = 196.1
MATCH NO. 6	HEAT LOAD = 1176.6		
HOT STREAM NO. 4	Th = 159	Tc = 153.04	CP = 197.3283
COLD STREAM NO.2	Th = 124	Tc = 118	CP = 196.1
MATCH NO. 7	HEAT LOAD = 3712.2		
HOT STREAM NO. 3	Th = 159	Tc = 90	CP = 53.8
COLD STREAM NO.3	Th = 124	Tc = 50.07	CP = 50.21261
MATCH NO. 8	HEAT LOAD = 2767.086		
HOT STREAM NO. 5	Th = 159	Tc = 70.23	CP = 31.17167
COLD STREAM NO.5	Th = 124	Tc = 26.16	CP = 28.28298
MATCH NO. 9	HEAT LOAD = 1448.4		
HOT STREAM NO. 2	Th = 159	Tc = 88	CP = 20.4
COLD STREAM NO.4	Th = 124	Tc = 26.16	CP = 14.80441
MATCH NO. 10	HEAT LOAD = 1200.387		
HOT STREAM NO. 1	Th = 141.74	Tc = 136.49	CP = 228.5
COLD STREAM NO.3	Th = 50.07	Tc = 26.16	CP = 50.21261
MATCH NO. 11	HEAT LOAD = 15.32696		
HOT STREAM NO. 1	Th = 136.49	Tc = 136.42	CP = 228.5
COLD STREAM NO.1	Th = 26.16	Tc = 26	CP = 93.3
MATCH NO. 12	COLD UTILITY = 13577.6		
HOT STREAM NO. 1	Th = 136.42	Tc = 77	CP = 228.5

```
 MERGING TARGET : 11
           LOOP : ( 11 , 8 )
          MERGE : feasible, no negative heat load
TEMP.DIFFERENCE : feasible
SPLIT COLD STREAM NO.1 TO STREAM NO.3, NO.4 AND NO.5
SPLIT TEMP. = 124           RECOMBINE TEMP. = 26
TSC(3) = 26       TTC(3) = 124      CPC(3) = 50.12844
TSC(4) = 26       TTC(4) = 124      CPC(4) = 14.77959
TSC(5) = 26       TTC(5) = 124      CPC(5) = 28.39197
SPLIT HOT STREAM NO.1 TO STREAM NO.4 AND NO.5
SPLIT TEMP. = 159           RECOMBINE TEMP. = 141.67
TSH(4) = 159      TTH(4) = 153.04   CPH(4) = 197.277
TSH(5) = 159      TTH(5) = 69.89    CPH(5) = 31.22298
    MATCH NO. 1    HEAT LOAD = 2690.609
HOT STREAM NO. 3   Th = 209.01  Tc = 159     CP = 53.8
COLD STREAM NO.2   Th = 137.72  Tc = 124     CP = 196.1
    MATCH NO. 2    HEAT LOAD = 279.9
HOT STREAM NO. 2   Th = 172.72  Tc = 159     CP = 20.4
COLD STREAM NO.1   Th = 127     Tc = 124     CP = 93.3
    MATCH NO. 3    HEAT LOAD = 1923.3
HOT STREAM NO. 2   Th = 267     Tc = 172.72  CP = 20.4
COLD STREAM NO.2   Th = 147.53  Tc = 137.72  CP = 196.1
    MATCH NO. 4    HEAT LOAD = 7208.591
HOT STREAM NO. 3   Th = 343     Tc = 209.01  CP = 53.8
COLD STREAM NO.2   Th = 184.29  Tc = 147.53  CP = 196.1
    MATCH NO. 5    HOT UTILITY  = 15827.6
COLD STREAM NO.2   Th = 265     Tc = 184.29  CP = 196.1
    MATCH NO. 6    HEAT LOAD = 1176.6
```

```
HOT STREAM NO. 4    Th = 159      Tc = 153.04   CP = 197.277
COLD STREAM NO.2    Th = 124      Tc = 118      CP = 196.1
    MATCH NO. 7     HEAT LOAD = 3712.2
HOT STREAM NO. 3    Th = 159      Tc = 90       CP = 53.8
COLD STREAM NO.3    Th = 124      Tc = 49.95    CP = 50.12844
    MATCH NO. 8     HEAT LOAD = 2782.413
HOT STREAM NO. 5    Th = 159      Tc = 69.89    CP = 31.22298
COLD STREAM NO.5    Th = 124      Tc = 26       CP = 28.39197
    MATCH NO. 9     HEAT LOAD = 1448.4
HOT STREAM NO. 2    Th = 159      Tc = 88       CP = 20.4
COLD STREAM NO.4    Th = 124      Tc = 26       CP = 14.77959
    MATCH NO. 10    HEAT LOAD = 1200.387
HOT STREAM NO. 1    Th = 141.67   Tc = 136.42   CP = 228.5
COLD STREAM NO.3    Th = 49.95    Tc = 26       CP = 50.12844
    MATCH NO. 11    COLD UTILITY = 13577.6
HOT STREAM NO. 1    Th = 136.42   Tc = 77       CP = 228.5


 MERGING TARGET : 2
           LOOP : ( 2 , 9 )
          MERGE : feasible, no negative heat load
TEMP.DIFFERENCE : violate the given δTmin on match no.  7
                  (δT = 32 )
TEMP.DIFFERENCE : violate the given δTmin on match no.  8
                  (δT = 32 )
CAN YOU ACCEPT (Y/N)? y
SPLIT COLD STREAM NO.1 TO STREAM NO.3, NO.4 AND NO.5
SPLIT TEMP. = 127           RECOMBINE TEMP. = 26
TSC(3) = 26        TTC(3) = 127      CPC(3) = 48.63948
```

TSC(4) = 26   TTC(4) = 127   CPC(4) = 17.11188

TSC(5) = 26   TTC(5) = 127   CPC(5) = 27.54865

SPLIT HOT STREAM NO.1 TO STREAM NO.4 AND NO.5

SPLIT TEMP. = 159   RECOMBINE TEMP. = 141.67

TSH(4) = 159   TTH(4) = 153.04   CPH(4) = 197.277

TSH(5) = 159   TTH(5) = 69.89   CPH(5) = 31.223

MATCH NO. 1   HEAT LOAD = 2690.609

HOT STREAM NO. 3   Th = 209.01   Tc = 159   CP = 53.8

COLD STREAM NO.2   Th = 137.72   Tc = 124   CP = 196.1

MATCH NO. 2   HEAT LOAD = 1923.3

HOT STREAM NO. 2   Th = 267   Tc = 172.72   CP = 20.4

COLD STREAM NO.2   Th = 147.53   Tc = 137.72   CP = 196.1

MATCH NO. 3   HEAT LOAD = 7208.591

HOT STREAM NO. 3   Th = 343   Tc = 209.01   CP = 53.8

COLD STREAM NO.2   Th = 184.29   Tc = 147.53   CP = 196.1

MATCH NO. 4   HOT UTILITY = 15827.6

COLD STREAM NO.2   Th = 265   Tc = 184.29   CP = 196.1

MATCH NO. 5   HEAT LOAD = 1176.6

HOT STREAM NO. 4   Th = 159   Tc = 153.04   CP = 197.277

COLD STREAM NO.2   Th = 124   Tc = 118   CP = 196.1

MATCH NO. 6   HEAT LOAD = 3712.2

HOT STREAM NO. 3   Th = 159   Tc = 90   CP = 53.8

COLD STREAM NO.3   Th = 127   Tc = 50.68   CP = 48.63948

MATCH NO. 7   HEAT LOAD = 2782.413

HOT STREAM NO. 5   Th = 159   Tc = 69.89   CP = 31.223

COLD STREAM NO.5   Th = 127   Tc = 26   CP = 27.54865

MATCH NO. 8   HEAT LOAD = 1728.3

HOT STREAM NO. 2   Th = 172.72   Tc = 88   CP = 20.4

COLD STREAM NO.4   Th = 127   Tc = 26   CP = 17.11188

MATCH NO. 9   HEAT LOAD = 1200.387

HOT STREAM NO. 1   Th = 141.67   Tc = 136.42   CP = 228.5

COLD STREAM NO.3   Th = 50.68   Tc = 26   CP = 48.63948

MATCH NO. 10   COLD UTILITY = 13577.6

HOT STREAM NO. 1   Th = 136.42   Tc = 77   CP = 228.5

Economic analysis for the retrofit project

Step 1. Enter "r" for retrofit.

NEW OR RETROFIT PLANT (N/R)? r

Step 2. Enter cost index, units of area and currency.

PRESENT COST INDEX ? 350

INTEREST RATE (%) ? 15

UNIT: AREA ? m^2

CURRENCY (press ENTER for US$) ? (enter)

Step 3. Enter hot utility data.

H/E NO.	HEAT LOAD (kW)	Tin (°C)	Tout (°C)	COST PER UNIT (US$/kW)	COST TOTAL (US$)
4	15827.6	300	300	100	1582760

Step 4. Enter cold utility data.

H/E NO.	HEAT LOAD (kW)	Tin (°C)	Tout (°C)	COST PER UNIT (US$/kW)	COST TOTAL (US$)
10	13577.6	30	50	6	81465.59

Step 5. Enter heat transfer coefficient, U (kW/m^2.°C).

H/E NO.	STREAM PAIR	U	THin (°C)	THout (°C)	TCin (°C)	TCout (°C)	AREA (m^2)
1	H 3 - C 2	.85	209.0	159.0	124.0	137.7	317.74
2	H 2 - C 2	.85	267.0	172.7	137.7	147.5	149.49
3	H 3 - C 2	.85	343.0	209.0	147.5	134.3	423.55
4	H 0 - C 2	.85	300.0	300.0	184.3	265.0	937.95
5	H 4 - C 2	.85	159.0	153.0	118.0	124.0	151.35
6	H 3 - C 3	.85	159.0	90.0	50.7	127.0	1111.35
7	H 5 - C 5	.85	159.0	69.9	26.0	127.0	678.35
8	H 2 - C 4	.85	172.7	88.0	26.0	127.0	323.36
9	H 1 - C 3	.85	141.6	136.4	26.0	50.7	109.69
10	H 1 - C 0	.85	136.4	77.0	30.0	50.0	1048.92

Step 6. Enter existing plant's utility data

DESCRIPTION	QUANTITY (kW)	COST PER UNIT (US$/kW)	COST TOTAL (US$)
HOT UTILITY	17597	100	1759700
COLD UTILITY	15510	6	93060

TOTAL UTILITY COST :

EXISTING PLANT (US$) 1852760

NEW DESIGN (US$) 1664226

Step 7. Enter the numbers and heat transfer areas of reusable heat exchangers (if any).

ARE THERE ANY REUSEABLE HEAT EXCHANGERS (Y/N)? y or enter

TOTAL NUMBER OF REUSABLE HEAT EXCHANGER? 7

EXISTING H/E NO.	AREA (M^2)
E-1	119
E-2	65
E-3	129
E-4	27
H-1	293
C-1	311
C-2	30

Result:

1. Reused exchangers

H/E NO.	REQUIRED AREA (m^2)	AVAILABLE AREA (m^2)	EXISTING H/E NO.
1	62.05	65	E-2
4	275.86	311	C-1
6	122.90	129	E-3
7	86.99	119	E-1
9	14.06	30	E-2
10	248.80	293	H-1

DO YOU ACCEPT THE REUSE OF THE EXISTING H/E AS TABULATED ABOVE (Y/N)? Y

2. Costs of new heat exchangers.

H/E NO.	AREA (m^2)	COST IN 1958 (US$)	PRESENT COST (US$)
2	32.89	2289.06	8011.72
3	82.72	4562.07	15967.23
5	39.53	3178.44	11124.56
8	38.04	3130.80	10957.79
TOTAL	1667.50		46061.30

3. Pay back period

DESCRIPTION	COST	
	% OF H/E COST	AMOUNT (US$)
TOTAL HEAT EXCHANGER COST		46061.3
INSTALLATION , RELOCATION COST	20	13818.4
PIPING COST	50	13818.4
OTHER	2	4606.1
TOTAL COST		78304.2
INTEREST RATE (%)		15.0
ANNUAL SAVING		188534.4
PAY BACK PERIOD (YEAR)		.46

The above results reveal that the present software is able to achieve an M.E.R. network, which reduces the energy consumptions for both the hot and cold utility by 1769.4 kW each. This amounts to savings of 188,534 $/yr with a quick payback of 6 months for an investment of 78,304 $.

Example 8-6

This problem comprises 4 hot streams and 3 cold streams, data of which are given in Table 8-6. Figure 8-15 is the initial unrestricted match network obtained by using the developed software. It is desired here to redesign the network under the restriction that hot stream no.4 and cold stream no.3 cannot be paired together.

Table 8-6 Data for example 8-6 [33: 153].

Stream no.	Starting temp. (°C)	Target temp. (°C)	Heat capacity flowrate (kW/°C)
H1	160	110	10.548
H2	249	138	12.660
H3	227	106	17.724
H4	271	146	8.400
C1	96	160	6.096
C2	116	217	4.864
C3	140	250	12.000

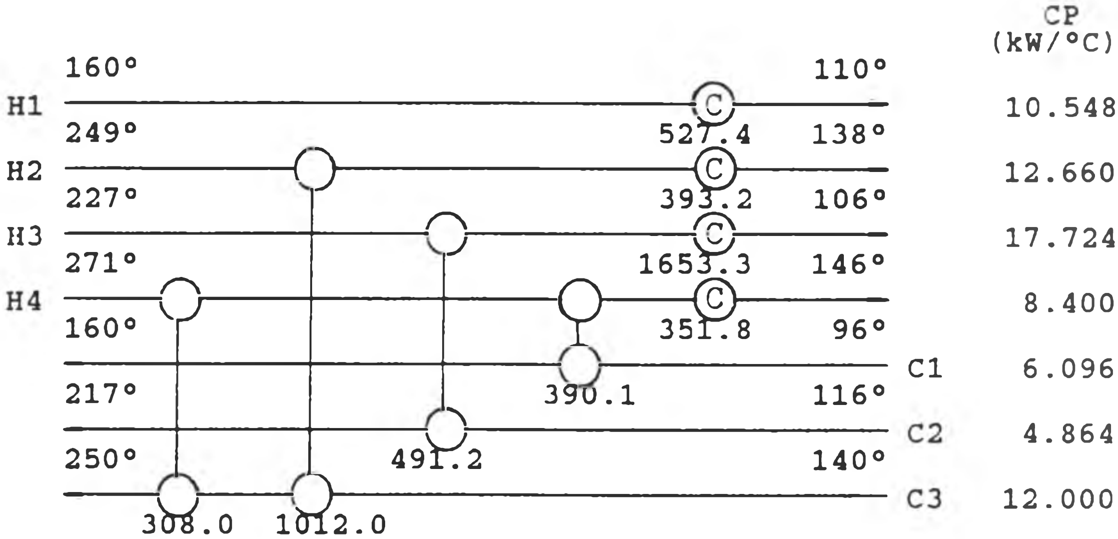


Figure 8-16 Network obtained under unrestricted conditions for example 8-6

Network designing procdure

Step 1. Enter numbers of streams.

NO. OF HOT STREAMS ? 4

NO. OF COLD STREAMS? 3

Step 2. Enter units of temperature and heat load.

UNIT OF TEMPERATURE (°)? C

UNIT OF HEAT LOAD ? kW

Step 3. Enter minimum allowable temperature difference.

MINIMUM ALLOWABLE TEMPERATURE DIFFERENCE (°C)? 10

Step 4. Enter hot-stream data.

HOT STREAM NO.	STARTING TEMP. (°C)	TARGET TEMP. (°C)	HEAT CAPACITY FLOWRATE (kW/°C)
1	160	110	10.548
2	249	138	12.660
3	227	106	17.724
4	271	146	8.400

Step 5. Enter cold-stream data.

COLD STREAM NO.	STARTING TEMP. (°C)	TARGET TEMP. (°C)	HEAT CAPACITY FLOWRATE (kW/°C)
1	96	160	6.096
2	116	217	4.864
3	140	250	12.000

Step 6. Enter restricted stream pairs (if any).

ARE THERE ANY RESTRICTED STREAM/STREAM MATCHES (Y/N)? Y

HOT STREAM No.?4 CANNOT MATCH with COLD STREAM NO.?3 ?ENTER

HOT STREAM No.?ENTER

Result:

1. PROBLEM TABLE ANALYSIS (FOR UNRESTRICTED CONDITION)

SUBNETWORK	COLD STREAM TEMP.INTERVAL (°C)	DEFICIT (kW)	ACCUMULATIVE OUTPUT (kW)	HEAT FLOW (kW)
	261			0
1		-92.40	92.40	
	250			92.40
2		39.60	52.80	
	239			52.80
3		-199.32	252.12	
	217			252.12
4		-1249.44	1501.56	
	160			1501.56
5		-158.24	1659.80	
	150			1659.80

SUBNETWORK	COLD STREAM TEMP.INTERVAL (°C)	DEFICIT (kW)	ACCUMULATIVE OUTPUT (kW)	HEAT FLOW (kW)
6		-263.72	1923.52	
	140			1923.52
7		-153.488	2077.01	
	136			2077.01
8		-239.776	2316.78	
	128			2316.78
9		-207.744	2524.53	
	116			2524.53
10		-354.816	2879.34	
	100			2879.34
11		-46.512	2925.85	
	96			2925.85

2. Pinch piont and minimum utility requirements

PINCH IS LOCATED AT COLD STREAM TEMPERATURE (°C) = 261

MINIMUM HOT UTILITY (kW) = 0

MINIMUM COLD UTILITY (kW) = 2925.856

MIMINUM SURPLUS OF BOTH HOT AND COLD UTILITIES (kW) = 132

3. Composite curve (as shown in Figure 8-16)

4. Below-the-pinch design

MATCH NO. 1 HOT UTILITY = 132

COLD STREAM NO. 3 Th = 250 Tc = 239 CP = 12

MATCH NO. 2 HEAT LOAD = 278.52

HOT STREAM NO. 2 Th = 249 Tc = 227 CP = 12.66

COLD STREAM NO. 3 Th = 239 Tc = 215.79 CP = 12

MATCH NO. 3 HEAT LOAD = 491.264

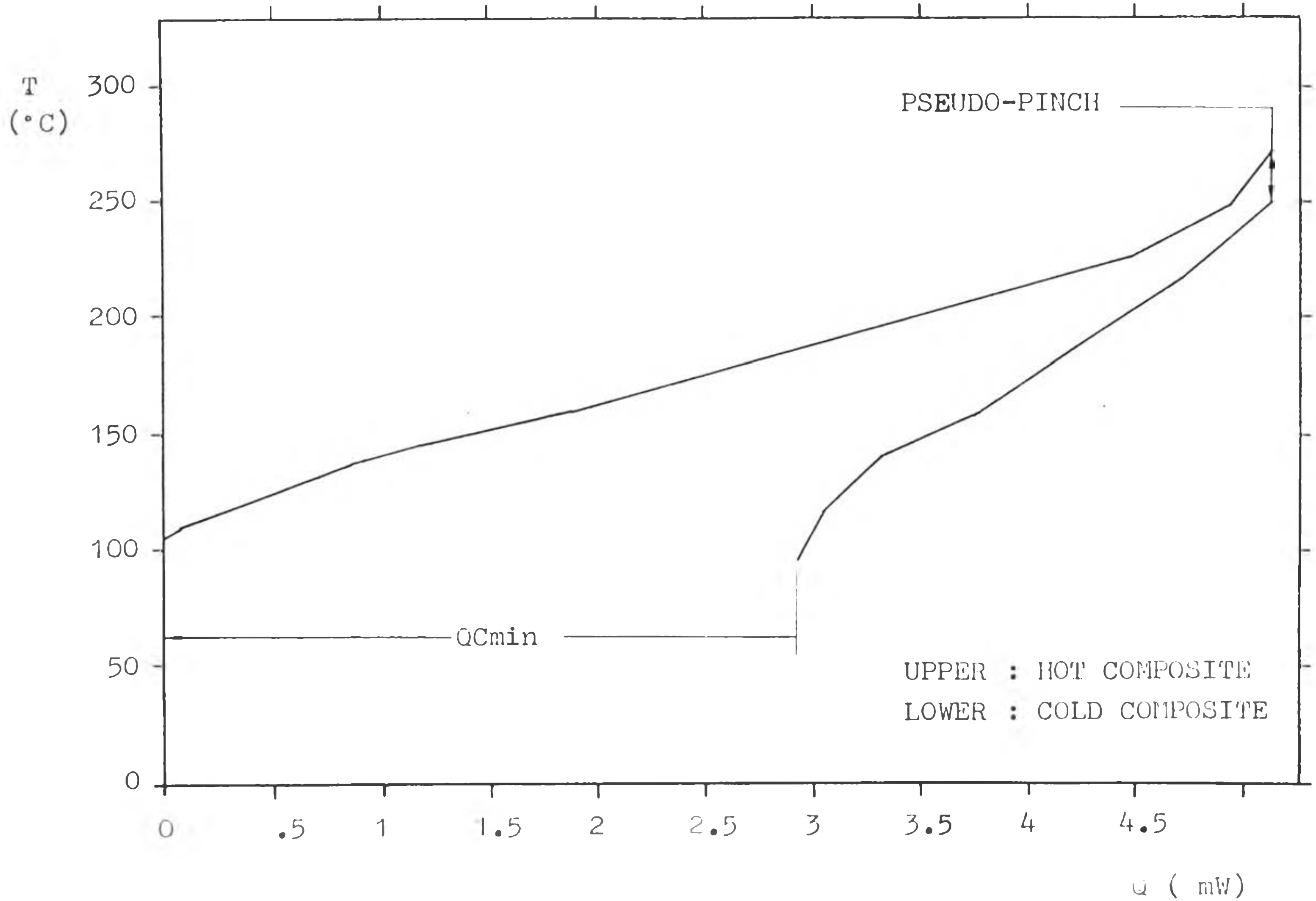


Figure 8-17 Composite curves for example 8-6 (unrestricted condition)

```
HOT STREAM NO.   4   Th = 271      Tc = 212.52   CP = 8.4
COLD STREAM NO.  2   Th = 217      Tc = 116      CP = 4.864
    MATCH NO. 4      HEAT LOAD = 909.480
HOT STREAM NO.   3   Th = 227      Tc = 175.69   CP = 17.724
COLD STREAM NO.  3   Th = 215.79   Tc = 140      CP = 12
    MATCH NO. 5      HEAT LOAD = 390.144
HOT STREAM NO.   2   Th = 227      Tc = 196.18   CP = 12.66
COLD STREAM NO.  1   Th = 160      Tc = 96       CP = 6.096
    MATCH NO. 6      COLD UTILITY =  527.4
HOT STREAM NO. 1     Th = 160      Tc =  110     CP = 10.548
    MATCH NO. 7      COLD UTILITY =  736.5959
HOT STREAM NO. 2     Th = 196.18   Tc =  138     CP = 12.66
    MATCH NO. 8      COLD UTILITY =  1235.124
HOT STREAM NO. 3     Th = 175.69   Tc =  106     CP = 17.724
    MATCH NO. 9      COLD UTILITY =  558.736
HOT STREAM NO. 4     Th =  212.52  Tc =  146     CP = 8.4
```

5. Grid representation for restricted matching (shown in Figure 8-17(a))

OPTION:

A. SEARCH AND BREAK LOOP

B. MERGE HEAT LOAD FOR THE SELECTED PATH

C. DRAW THE RESULTING NETWORK CONFIGURATION

D. ECONOMIC ANALYSIS

X. TERMINATE THE PROGRAM

<u>Loop breaking procedure</u>

Step 1. Select option "A"

ENTER YOUR SELECT ? a

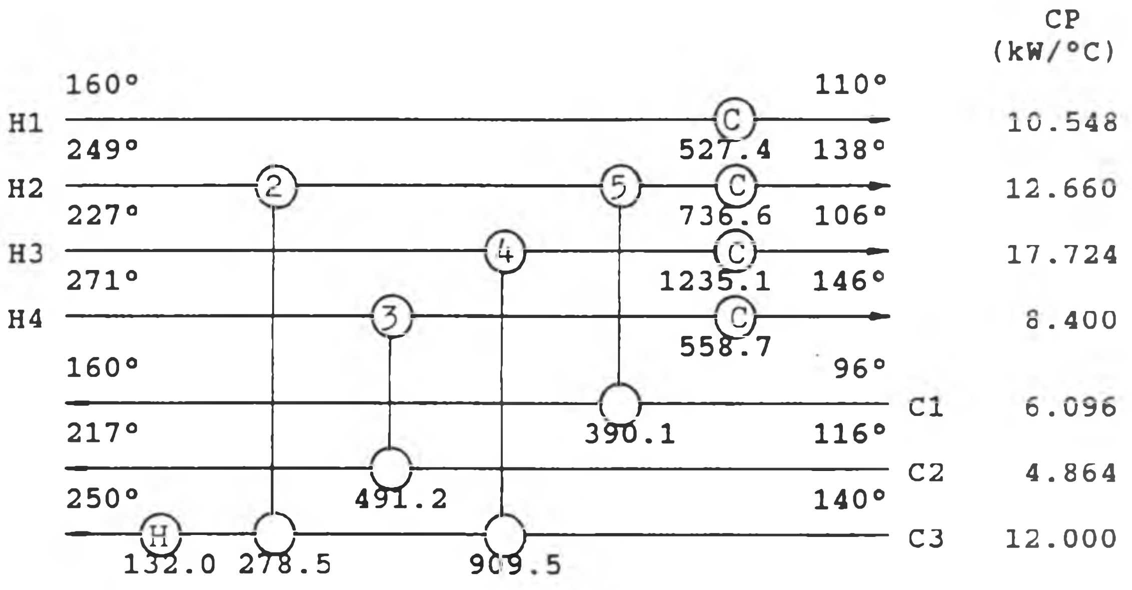
Step 2. Enter permissible δTmin violation range (if any).

DO YOU ALLOW δTmin TO BE VIOLATED WITHIN A SPECIFY RANGE (Y/N) ? y

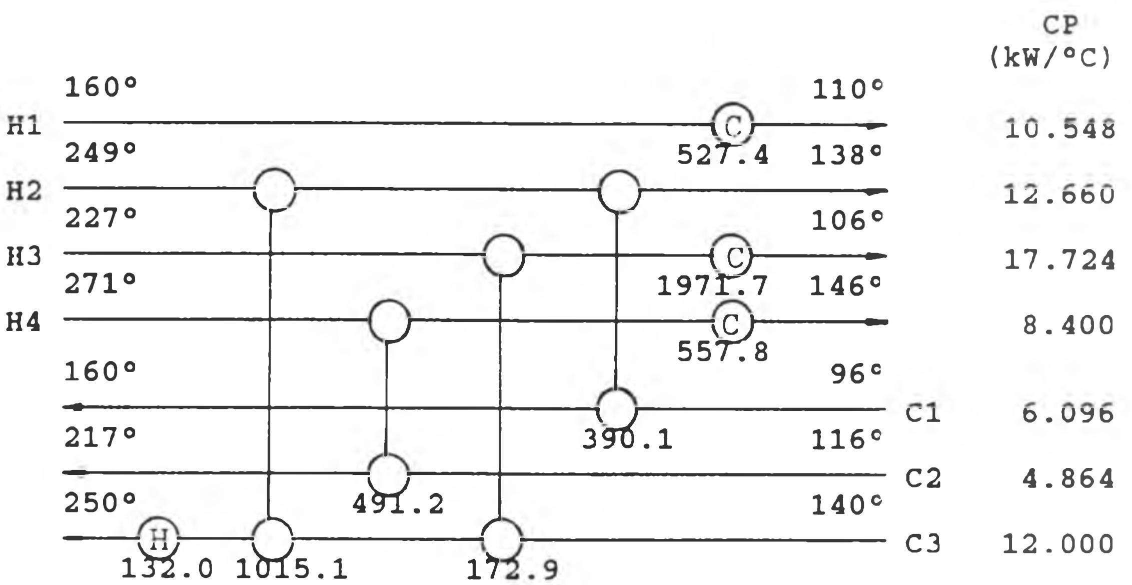
MAXIMUM VIOLATION (°C) ? 2

Result

```
 MERGING TARGET : 7
           LOOP :( 7 , 2 , 4 , 8 )
          MERGE : feasible, no negative heat load
TEMP.DIFFERENCE : violate the given δTmin on match no. 5
                  (δT = 8.82 )
CAN YOU ACCEPT (Y/N)? Y
    MATCH NO. 1       HOT UTILITY  = 132
COLD STREAM NO.  3    Th = 250     Tc = 239     CP = 12
    MATCH NO. 2       HEAT LOAD = 1015.116
HOT STREAM NO.   2    Th = 249     Tc = 168.82  CP = 12.66
COLD STREAM NO.  3    Th = 239     Tc = 154.41  CP = 12
    MATCH NO. 3       HEAT LOAD = 491.264
HOT STREAM NO.   4    Th = 271     Tc = 212.52  CP = 8.4
COLD STREAM NO.  2    Th = 217     Tc = 116     CP = 4.864
    MATCH NO. 4       HEAT LOAD = 172.884
HOT STREAM NO.   3    Th = 227     Tc = 217.25  CP = 17.724
COLD STREAM NO.  3    Th = 154.41  Tc = 140     CP = 12
    MATCH NO. 5       HEAT LOAD = 390.144
HOT STREAM NO.   2    Th = 168.82  Tc = 138     CP = 12.66
COLD STREAM NO.  1    Th = 160     Tc = 96      CP = 6.096
    MATCH NO. 6       COLD UTILITY = 527.4
HOT STREAM NO.   1    Th = 160     Tc = 110     CP = 10.548
```



(a) Initial restricted match network (δTmin = 10 °C)



(b) Final restricted match network (δTmin = 8.82 °C)

Figure 8-18 Networks obtained under restricted match conditions.

MATCH NO. 7 COLD UTILITY = 1971.72

HOT STREAM NO. 3 Th = 217.25 Tc = 106 CP = 17.724

MATCH NO. 8 COLD UTILITY = 558.736

HOT STREAM NO. 4 Th = 212.52 Tc = 146 CP = 8.4

The solution of the restricted match problem provides the network configuration shown in Figure 8-17(a). Note that the utility requirements are equal to the minima predicted but the number of units is one more than the minimum. If δT_{min} is allowed to be violated 1.18 °C, the network is then evolved to the configuration shown in Figure 8-17(b), which attains both MER and the minimum of units.