CHAPTER IV

ENERGY TARGETING SOFTWARE AND EXAMPLES OF APPLICATION

In Chapter II, the pinch design method was introduced to determine the minimum utility requirements along with maximum energy recovery. The pinch approach lets us readily predict the minimum utility requirements prior to actual development of the network. Furthermore an MER network design employing a minimum number of heat exchangers subject to maximum energy recovery can easily be achieved. To aid in the determination of the minimum utility requirements, especially in the presence of multiple streams, an energy targeting computer program has been developed in this chapter.

The following sections describe the features of the program and its limitations, the flowchart, the procedure to run the program, and examples of application selected from numerous text-books and published papers. Additionally, the detailed flowchart and the listing of the source program are presented in Appendix A and B, respectively.

4.1 Features and Limitations of Program

The present program was based on an earlier version published in the Technology Journal [30]. The program was coded in FORTRAN IV to utilize its powerful formatting features highly suitable to complex scientific, mathematical, engineering algorithms and it is executed on a personal computer. The flowchart notation used in Appendix A corresponded to specific program statements in Appendix B. The flowchart illustrated the algorithm used and the rudiments of programming in the 1977 version of the FORTRAN IV language.

The requirements needed to run the program are :

<u>Hardware</u> : A personal computer with two disk drives and 640 K of random-access memory operâting on the Disk Operating System (DOS command). To obtain a hard copy, a printer is recommended.

<u>Software</u> : A 5.25-inch double-sided, double-density, soft section diskette containing the source and working program.

4.1.1 Program Features

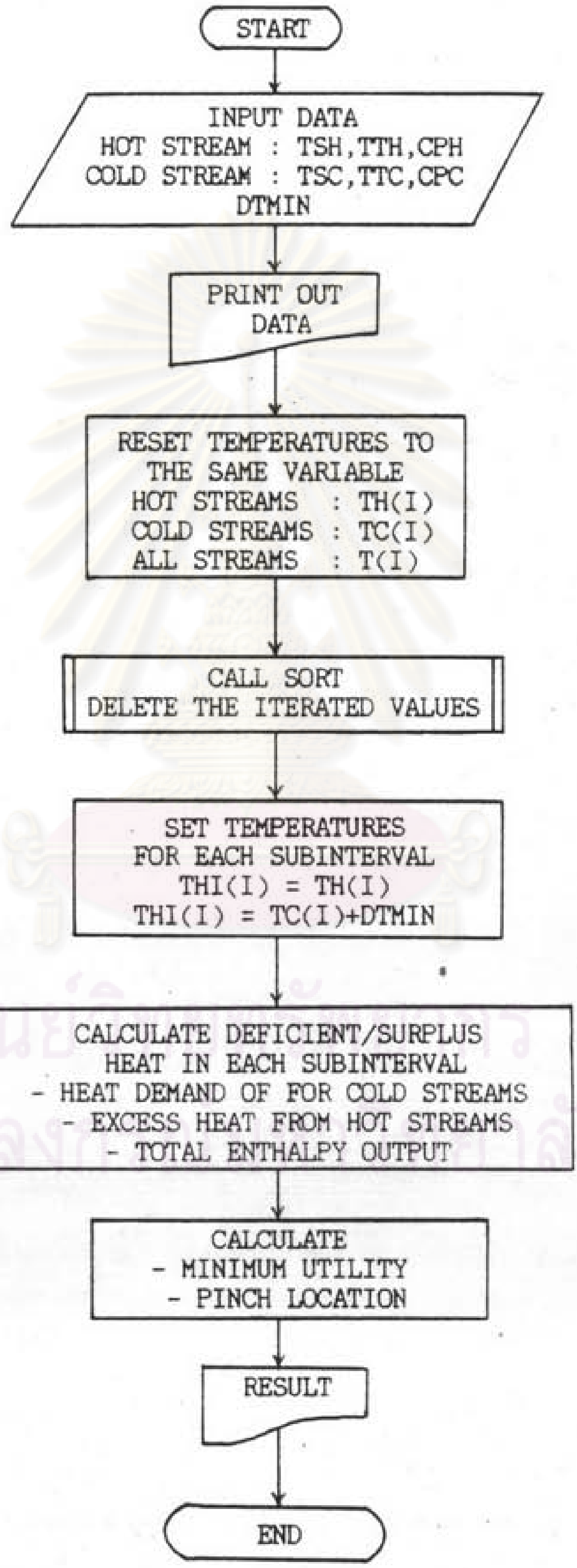
The source program was coded and edited using Turbo Pascal Programming Software as line editor and identified by the filename of THESIS.FOR (see Appendix B). The working program was the compiled and ready-to-execute version obtained with FORTRAN Programming Software (Version 3.3). Its filename and extension was THESIS.EXE. The capability of the present program is as follows :

- Divide the stream temperature intervals into subintervals and then determine the heat surplus (or deficit), and the enthalpy balance within each subinterval.
- Locate the pinch-point temperature.
- Determine the energy targets, i.e., minimum hot and cold utility requirements.

4.1.2 Program Limitations

- Maximum numbers of ten hot streams and ten cold streams are allowed. If more streams are to be handled, it is necessary to proportionally increase all the dimensions of arrays in the source program.
- The heat capacity flowrate of each stream is assumed constant and independent of its inlet and outlet temperatures.
- The present program is not design to deal with the threshold problem.

4.2 Simplified Flowchart of Program



4.3 Input Data and Procedure to Run the Program

4.3.1 Input Data Required

1. Number of hot streams

2. Number of cold streams

3. Supply temperatures, target temperatues, and heat capacity flowrates of all the hot and cold streams.

4. Minimum temperature difference ($\triangle$ Tmin) allowed at pinch point.

Note that the program accepts either of two unit systems, i.e., British Engineering Unit (Btu, hr, ^{o}F), and SI Unit (kW, ^{o}C)

4.3.2 Procedure to Run the Program

Step 1 : Start-up Procedure

Switch on the personal computer and boot the system with DOS commands. Load the working program from file THESIS.EXE.

Step 2 : Input Stream Data

The program will prompt the user to key in all the necessary input data orderly, line by line on the display screen. Caution : the value of any temperature or heat capacity flowrate must be entered with the specified decimal digits.

Step 3 : Output of Results

The following input data and output results will be displayed consecutively : table of hot stream data, table of cold stream data, net surplus or deficit of heat in each subinterval in tabular form, pinch location, and energy targets. In case a hard copy (printout) is desired, use "Control P" prior to the program execution.

4.4 Examples of Application of Energy Targeting Program

The following three examples were selected to test run the present program by comparing the results with those given in the original sources. The first example problem taken from Conceptual Design [2], was the simplest one involving only two hot streams and two cold streams. The second example, a revamp problem of MER design, was taken from User Guide [1], and involved three hot streams and two cold streams. The last and most complicated example was a simplified aromatics plant described in a Chemical Engineering [19].

The instructions that follow illustrate how the program was run and what the outputs were obtained during a run. The three steps described in the previous section have been performed in each example. To distinguish the program statements from the user's responses, user-typed characters are underlined throughout these examples.

Example 1 :

Given : Table 4.1 shows the given data

Table 4.1 : Data for Example 1

Stream No.	Condition	FC_p, Btu/(hr·°F)	T_{in}	T_{out}	Q available, 10^3 Btu/hr
1	Hot	1000	250	120	130
2	Hot	4000	200	100	400
3	Cold	3000	90	150	−180
4	Cold	6000	130	190	−360
					−10

Source : James M. Douglas, Conceptual Design of Chemical Process, pp. 218, McGraw-Hill Book Co.,1st ed., 1988.

Original result :

Pinch Point Temperature : Tc = 130.00 ^{o}F

Minimum Hot Utility Requirement : Qh = 70.00 Btu/hr

Minimum Cold Utility Requirement : Qc = 60.00 Btu/hr

Program Execution :

Step 1 : Start-up procedure

Load the working program by typing the working file name.

A> THESIS

Step 2 : Input data

Input data to the displayed questions. See underlined characters.

```
INPUT THE FOLLOWING DATA

NO. OF HOT STREAMS =
2

NO. OF COLD STREAMS =
2

INPUT TEMPERATURES IN UNIT OF (oF) or (oC)

  IF TEMPERATURE UNIT IS oF : KEY 1

  IF TEMPERATURE UNIT IS oC : KEY 2
1
     HOT-STREAM DATA :

 HOT STREAM No. 1
 SUPPLY TEMPERATURE (oF) =
250.00
 TARGET TEMPERATURE (oF) =
120.00
 HEAT CAPACITY FLOWRATE (BTU/hr-F)
1.00

 HOT STREAM No. 2
 SUPPLY TEMPERATURE (oF) =
200.00
 TARGET TEMPERATURE (oF) =
100.00
 HEAT CAPACITY FLOWRATE (BTU/hr-F)
4.00
```

COLD-STREAM DATA :

COLD STREAM No. 1
SUPPLY TEMPERATURE (oF) =
90.00
TARGET TEMPERATURE (oF) =
150.00
HEAT CAPACITY FLOWRATE (BTU/hr-F) =
3.00

COLD STREAM No. 2
SUPPLY TEMPERATURE (oF) =
130.00
TARGET TEMPERATURE (oF) =
190.00
HEAT CAPACITY FLOWRATE (BTU/hr-F) =
6.00

MINIMUM TEMPERATURE DIFFERENCE (oF) =
10.00

Step 3 : Output of Results

After the minimum temperature difference value 10.00 was keyed in, the following results appeared on the display screen.

HOT-STREAM DATA

HOT STREAM No.	SUPPLY TEMP.	TARGET TEMP.	HEAT CAPACITY FLOWRATE
1	250.00	120.00	1.00
2	200.00	100.00	4.00

COLD-STREAM DATA

COLD STREAM No.	SUPPLY TEMP.	TARGET TEMP.	HEAT CAPACITY FLOWRATE
1	90.00	150.00	3.00
2	130.00	190.00	6.00

MINIMUM TEMPERATURE DIFFERENCE = 10.00

RESULT

INTERVAL No.	HOT - STREAM TEMPERATURE	DEFICIT	CUMULATIVE OUTPUT	HEAT FLOW
	250.00			70.00
1		-50.00	50.00	
	200.00			120.00
2		40.00	10.00	
	160.00			80.00
3		80.00	-70.00	
	140.00			.00
4		-40.00	-30.00	
	120.00			40.00
5		-20.00	-10.00	
	100.00			60.00

```
MINIMUM TEMPERATURE DIFFERENCE          =  10.00   oF
PINCH IS LOCATED AT COLD TEMPERATURE    = 130.00   oF
PINCH IS LOCATED AT HOT TEMPERATURE     = 140.00   oF
```

*********************** ENERGY TARGET ***********************

```
MINIMUM HOT UTILITY REQUIREMENT         =  70.00   BTU/hr
MINIMUM COLD UTILITY REQUIREMENET       =  60.00   BTU/hr
```

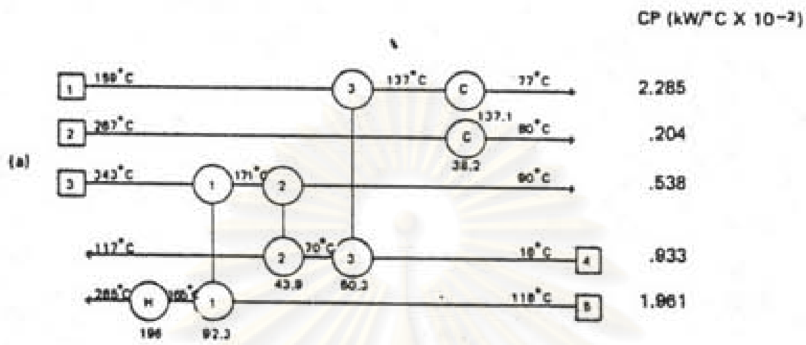
Stop - Program terminated.

The results obtained using the present program agree exactly with the results given in the original source.

Example 2 :

Given : Figure 4.1 shows the given data.

Figure 4.1 : Data for Example 2



Source : Linnhoff, B., et al., A User Guide on Process Integration for the Efficient Use of Energy, pp. 77-80, IChem, Warwick Printing Co.,Ltd., England, 1984.

Original results :

Pinch Point Temperature	:	Tc = 149.00 °C
Minimum Hot Utility Requirement	:	Qh = 106.45 kW
Minimum Cold Utility Requirement	:	Qc = 85.58 kW

Program Exeution :

Step 1 : Start-up procedure

Load the working program by typing the working file name.

A> THESIS

Step 2 : Input data

Input data to the displayed questions. See underlined characters.

INPUT THE FOLLOWING DATA

NO. OF HOT STREAMS =
3

NO. OF COLD STREAMS =
2

INPUT TEMPERATURES IN UNIT OF (oF) or (oC)

IF TEMPERATURE UNIT IS oF : KEY 1

IF TEMPERATURE UNIT IS oC : KEY 2
2

HOT-STREAM DATA :

HOT STREAM No. 1
SUPPLY TEMPERATURE (oC) =
159.00
TARGET TEMPERATURE (oC) =
77.00
HEAT CAPACITY FLOWRATE (kW/oC) =
2.285

HOT STREAM No. 2
SUPPLY TEMPERATURE (oC) =
267.00
TARGET TEMPERATURE (oC) =
80.00
HEAT CAPACITY FLOWRATE (kW/oC) =
0.204

HOT STREAM No. 3
SUPPLY TEMPERATURE (oC) =
343.00
TARGET TEMPERATURE (oC) =
90.00
HEAT CAPACITY FLOWRATE (kW/oC) =
0.538

COLD-STREAM DATA :

COLD STREAM No. 1
SUPPLY TEMPERATURE (oC) =
16.00
TARGET TEMPERATURE (oC) =
117.00
HEAT CAPACITY FLOWRATE (kW/oC) =
0.933

COLD STREAM No. 2
SUPPLY TEMPERATURE (oC) =
118.00
TARGET TEMPERATURE (oC) =
265.00
HEAT CAPACITY FLOWRATE (kW/oC) =
1.961

MINIMUM TEMPERATURE DIFFERENCE (oC) =
10.00

Step 3 : Output of the Results

After the minimum temperature difference of 10.00 was keyed in, the following results appeared on the display screen.

HOT-STREAM DATA

HOT STREAM No.	SUPPLY TEMP.	TARGET TEMP.	HEAT CAPACITY FLOWRATE
1	159.00	77.00	2.29
2	267.00	80.00	.20
3	343.00	90.00	.54

COLD-STREAM DATA

COLD STREAM No.	SUPPLY TEMP.	TARGET TEMP.	HEAT CAPACITY FLOWRATE
1	16.00	117.00	.93
2	118.00	265.00	1.96

MINIMUM TEMPERATURE DIFFERENCE = 10.00

RESULT

INTERVAL No.	HOT - STREAM TEMPERATURE	DEFICIT	CUMULATIVE OUTPUT	HEAT FLOW
	343.00			106.45
1		-36.58	36.58	
	275.00			143.04
2		11.38	25.20	
	267.00			131.65
3		131.65	-106.45	
	159.00			.00
4		-33.05	-73.41	
	128.00			33.05
5		-3.03	-70.38	
	127.00			36.07
6		-77.48	7.10	
	90.00			113.55
7		-15.56	22.66	
	80.00			129.11
8		-4.06	26.72	
	77.00			133.17
9		47.58	-20.87	
	26.00			85.58

```
MINIMUM TEMPERATURE DIFFERENCE              =   10.00    oC
PINCH IS LOCATED AT COLD TEMPERATURE        =  149.00    oC
PINCH IS LOCATED AT HOT TEMPERATURE         =  159.00    oC

*********************** ENERGY TARGET ***********************

MINIMUM HOT UTILITY REQUIREMENT             =  106.45    kW
MINIMUM COLD UTILITY REQUIREMENET           =   85.58    kW

Stop - Program terminated.
```

Again, the results obtained agreed exactly with those reported in the original source.

Example 3 :

Given : Table 4.2 shows the given data

Table 4.2 : Data for Example 3

Stream No.	Stream Type	Temperature °C Supply	Temperature °C Target	MC_p MW/°C	Heat transfer coefficient, h, [W/(°C)(m²)]
1	Hot	327	30	0.100	800
2	Hot	220	160	0.160	500
3	Hot	220	60	0.060	2,000
4	Hot	160	45	0.200	400
5	Cold	100	300	0.100	5,000
6	Cold	35	164	0.070	1,000
7	Cold	80	125	0.175	500
8	Cold	60	170	0.060	200
9	Cold	140	300	0.200	800

Source : Tjaan N. Tjoe and Linnhoff, B., Using Pinch Technology for Process Retrofit, pp. 10, Chemical Engineering, McGraw-Hill, April 28, 1986.

Original results :

Pinch Point Temperature : Tc = 140.00 °C

Minimum Hot Utility Requirement : Qh = 23.50 MW

Minimum Cold Utility Requirement : Qc = 19.90 MW

Program Execution :

Step 1 : Start-up procedure

Load the working program by typing the working file name.

A> THESIS

Step 2 : Input data

Input data to the displayed questions. See underlined characters.

INPUT THE FOLLOWING DATA

NO. OF HOT STREAMS =
4

NO. OF COLD STREAMS =
5

INPUT TEMPERATURES IN UNIT OF (oF) or (oC)

IF TEMPERATURE UNIT IS oF : KEY 1

IF TEMPERATURE UNIT IS oC : KEY 2
2

HOT-STREAM DATA :

HOT STREAM No. 1
SUPPLY TEMPERATURE (oC) =
327.00
TARGET TEMPERATURE (oC) =
30.00
HEAT CAPACITY FLOWRATE (kW/oC) =
0.100

HOT STREAM No. 2
SUPPLY TEMPERATURE (oC) =
220.00
TARGET TEMPERATURE (oC) =
160.00
HEAT CAPACITY FLOWRATE (kW/oC) =
0.160

HOT STREAM No. 3
SUPPLY TEMPERATURE (oC) =
220.00
TARGET TEMPERATURE (oC) =
60.00
HEAT CAPACITY FLOWRATE (kW/oC) =
0.060

HOT STREAM No. 4
SUPPLY TEMPERATURE (oC) =
160.00
TARGET TEMPERATURE (oC) =
45.00
HEAT CAPACITY FLOWRATE (kW/oC) =
0.200

COLD-STREAM DATA :

COLD STREAM No. 1
SUPPLY TEMPERATURE (oC) =
100.00
TARGET TEMPERATURE (oC) =
300.00
HEAT CAPACITY FLOWRATE (kW/oC) =
0.100

COLD STREAM No. 2
SUPPLY TEMPERATURE (oC) =
35.00
TARGET TEMPERATURE (oC) =
164.00
HEAT CAPACITY FLOWRATE (kW/oC) =
0.070

COLD STREAM No. 3
SUPPLY TEMPERATURE (oC) =
80.00
TARGET TEMPERATURE (oC) =
125.00
HEAT CAPACITY FLOWRATE (kW/oC) =
0.175

COLD STREAM No. 4
SUPPLY TEMPERATURE (oC) =
60.00
TARGET TEMPERATURE (oC) =
170.00
HEAT CAPACITY FLOWRATE (kW/oC) =
0.060

COLD STREAM No. 5
SUPPLY TEMPERATURE (oC) =
140.00
TARGET TEMPERATURE (oC) =
300.00
HEAT CAPACITY FLOWRATE (kW/oC) =
0.200

MINIMUM TEMPERATURE DIFFERENCE (oC) =
26.00

Step 3 : Output of results

After the minimum temperature difference of 26.00 was keyed in, the following results appeared on the display screen.

HOT-STREAM DATA

HOT STREAM No.	SUPPLY TEMP.	TARGET TEMP.	HEAT CAPACITY FLOWRATE
1	327.00	30.00	.10
2	220.00	160.00	.16
3	220.00	60.00	.06
4	160.00	45.00	.20

COLD-STREAM DATA

COLD STREAM No.	SUPPLY TEMP.	TARGET TEMP.	HEAT CAPACITY FLOWRATE
1	100.00	300.00	.10
2	35.00	164.00	.07
3	80.00	125.00	.17
4	60.00	170.00	.06
5	140.00	300.00	.20

MINIMUM TEMPERATURE DIFFERENCE = 26.00

RESULT

INTERVAL No.	HOT - STREAM TEMPERATURE	DEFICIT	CUMULATIVE OUTPUT	HEAT FLOW
	327.00			23.50
1		-.10	.10	
	326.00			23.60
2		21.20	-21.10	
	220.00			2.40
3		-.48	-20.62	
	196.00			2.88
4		.24	-20.86	
	190.00			2.64
5		2.64	-23.50	
	166.00			.00
6		-.54	-22.96	
	160.00			.54
7		-1.17	-21.79	
	151.00			1.71
8		1.13	-22.91	
	126.00			.59
9		-1.10	-21.81	
	106.00			1.69
10		-4.60	-17.21	
	86.00			6.29
11		-7.25	-9.96	
	61.00			13.54
12		-.36	-9.60	
	60.00			13.90
13		-4.50	-5.10	
	45.00			18.40
14		-1.50	-3.60	
	30.00			19.90

```
MINIMUM TEMPERATURE DIFFERENCE                =   26.00   oC
PINCH IS LOCATED AT COLD TEMPERATURE          =  140.00   oC
PINCH IS LOCATED AT HOT TEMPERATURE           =  166.00   oC

*********************** ENERGY TARGET ***********************

MINIMUM HOT UTILITY REQUIREMENT               =   23.50   kW
MINIMUM COLD UTILITY REQUIREMENET             =   19.90   kW

Stop - Program terminated.
```

Again the above results agreed exactly with those given in the original source.

4.5 Additional Examples of Application

To check the reliability and robustness of the present program, ten more examples were solved in the same way as the previous three. Table 4.3 summarizes the results of the additional examples that were selected from numerous sources. Once again, the obtained answers agreed exactly with those reported.

Table 4.3 Summary of results of ten additional examples

NO.	PROBLEM	SOURCE	No. OF STREAM		RESULT		
			HOT	COLD	PINCH TEMP.	HOT UTILITY	COLD UTILITY
1	4SP1	AICHE,VOL.24,NO.4 P.648,1978	2	2	Th = 512 Tc = 522	127.68	250.14
2	10SP1	AICHE,VOL.24,NO.4 P.651,1978	5	5	Th = 366.11 Tc = 377.11	83.85	430.49
3	TEST CASE No. 3	CHEM.ENG.SCI.,VOL.38 NO.5,P746,1983	2	2	Th = 90 Tc = 70	107.50	40.00
4	EX3	COMPUT.CHE.ENG. VOL.10,NO.2,1986	4	3	Th = 217 Tc = 227	100.32	0.00
5	DESIGN A	CHEMICAL ENGINEERING APRIL 28,1986	3	3	Th = 100 Tc = 90	3.00	160.00
6	DESIGN B	CHEMICAL ENGINEERING APRIL 28,1986	3	3	Th = 65 Tc = 35	14.50	391.38
7	EX4	COMPUT.CHE.ENG. VOL.11,NO.2,1987	6	1	Th = 100 Tc = 90	3.00	12.50
8	EX1	COMPUT.CHE.ENG.,P 308 VOL.12,NO.4,1988.	2	2	Th = 197 Tc = 188	0.00	14.00
9	EX2	COMPUT.CHE.ENG.,P 309 VOL.12,NO.4,1988.	6	1	Th = 58 Tc = 43	7.71	0.00
10	PMD SOLUTION	COMPUT.CHE.ENG. VOL.12,NO.6,1988	2	2	Th = 90 Tc = 80	20.00	60.00