CHAPTER V

APPLICATION TO AN OIL REFINERY PLANT

In the research, we selected the Bangchak Petroleum Industry Co.,Ltd. as our plant case study. Our interest is centered on the process section of crude oil distillation. The general details of the plant concerning process description and their products, material and energy balance calculations, and energy consumption analysis are presented as follows.

5.1 Plant Location

The Bangchak Petroleum Industry Co.,Ltd is located at 210 Sukumvit 64, Bangchak, Prakanong, Bangkok. The plant area of 192,000 sq.m. is divided into a seaport of 7,200 sq.m., and an industrial process area of 184,800 sq.m. The surrounding areas are

North	:	close to Bangchak channel, and next to the oil tank farm of Petroleum Authority of Thailand.
South	:	close to Bang-oor channel, and next to Thai Plywood Co.,Ltd.
East	:	close to the military camp , and Sukumvit 64.
West	:	close to the Chao-praya river.

The industrial process area is separated into 2 parts, i.e., Crude Oil Distillation area (onsite) and the offsite area, on which are located the tank farm, buildings, and waste water treatment unit.

The onsite area consists of three crude oil refinery plants, i.e., Plant 1 : A daily rated capacity of 5,000 bbl. Presently it is already obsolete and will be scrapped.

Plant 2 : A daily rated capacity of 15,000 bbl. Presently, it is shutdown and is undergoing modification to attain higher distillation efficiency and capacity.

Plant 3 : The only working unit right now with a daily rated capacity of 65,000 bbl. This unit has just been modified and its daily rated capacity upgraded from 50,000 bbl. It started up with the new designed conditions in May, 89.

5.2 General Process Description

The crude oil refining process may be categorized into six units as follows :

- Unit 100 : Topping Unit
- Unit 200 : Pretreating Unit
- Unit 300 : Magnaforming Unit
- Unit 400 : Gas Recovery Unit
- Unit 500 : Light Naphtha Merox Unit
- Unit 1700 : Kerosene Treating Unit

Crude oil is first sent to the topping unit (100) to fractionate into product fractions.. The crude gas from the overhead of the topping column is compressed and then contacted with light naphtha in the gas recovery unit (400). The overhead liquid (unstabilized light naphtha) from the fractionator is also sent to the gas recovery unit. The top sidestream (heavy naphtha) is sent to the pretreating unit (200). The second sidestream (kerosene) is sent to the kerosene treating unit (1700). The third sidestream (diesel oil), fourth sidestream (gas oil) and the reduced crude are sent directly to blending. A portion of the reduced crude is sent for use in the plant fuel system. (See simplified Process Flow Diagram in Figure 5.1.)

5.3 Evaluation Conditions

1. Plant No.3, the only one in operation, is selected for consideration.

2. The evaluation will be carried out only on the topping unit (unit 100) area.

3. All of the evaluated process conditions belong to the old plant, i.e., prior to upgrade and modification finished by May 89. However, certain results will also be compared with those of the new plant at the end of this chapter.

4. Design data of the old plant are used for evaluation. Note that logsheets of the actual operating data are not available.

5. The approaches of Pinch Technology and of Exergy formerly mentioned in Chapter II and III are used in our evaluation.

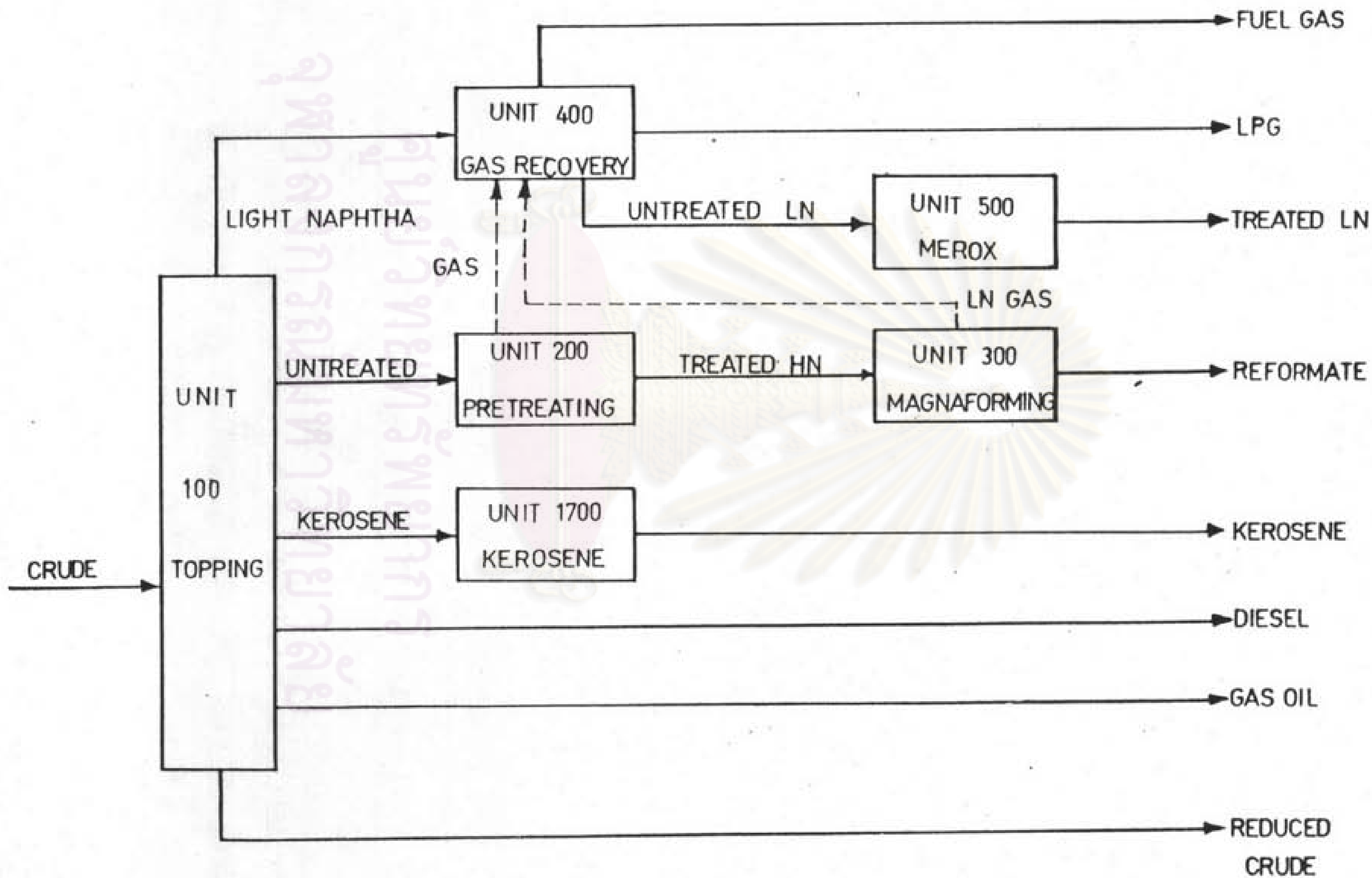


Figure 5.1 Simplified process flow diagram

5.4 Description of Based Case (Old Plant)

The topping unit is designed to process 50,000 bpsd (barrel per stream day) of Arabian crude oil. It fractionates the crude oil into unstabilized light naphtha, heavy naphtha, kerosene, diesel oil, gas oil and reduced crude by flash vaporization and fractionation in the fractionator C-101.

5.4.1 Description of flow : (see Figure 5.2)

1. Crude Preheat Circuit : Crude oil from storage is pumped by pump P-111 A/B at the design rate of 50,000 bpsd and is preheated by heat exchange with light distillate circulating through E-101, kerosene product through E-102, diesel product through E-103, diesel oil circulating through E-104, gas oil through E-115 and reduced crude through E-105 to about 231.4 ^{o}C (448 ^{o}F) before entering the crude furnace F-101. Table 5-1 summarizes the temperatures of the crude oil entering and leaving each heat exchanger.

Table 5.1 : Crude oil temperature at the inlet and outlet of each heat exchanger

Exchanger Number	Crude Preheated by	Crude In		Crude Out	
		^{o}F	^{o}C	^{o}F	^{o}C
E-101A/B	Circulating Light Distillation (Tube Side)	95	35	188	87
E-102	Kerosene Product (Tube Side)	188	87	212	100
E-103	Diesel Product (Tube Side)	212	100	262	128
E-104	Circulating Diesel (Tube Side)	262	128	297	147
E-115	Gas Oil Product (Tube Side)	297	147	432	222
E-105A/C	Reduced Crude (Shell Side)	297	147	448	231

2. Crude Furnace F-101 : The crude heater is a vertical, bottom fired furnace having a heat convection section, a four-pass radiant section and a steam superheating coil in the

convection section. Fifty-psig steam is super heated to 316 ^{o}C (600 ^{o}F) for use in the fractionator C-101, heater transfer line, and side-stream strippers C-102, C-103, C-104, and C-105.

3. Topping Column C-101 : The crude is heated in furnace F-101 to the temperature required in the flash zone of the fractionator C-101. The designed temperature for the flash zone is 379.8 ^{o}C (715 ^{o}F) when the flash zone pressure is 17 psig.

Superheated steam may be added to the crude oil along the transfer line between the crude heater F-101 and the fractionator C-101 to improve the fractionation of the crude oil in the fractionator without having to increase the flash zone temperature. The flashed liquid and vapor are separated in the flash zone. The liquid is steam stripped on trays 34 through 37 and the reduced crude is then pumped by pump P-108 through the crude oil preheat exchanger E-105, water cooler E-112 A-D / E-118 A/B and then to the battery limit.

4. Gas Oil Product : The crude oil vapor rises upward through the trays of the fractionator. The heaviest fraction (gas oil) condenses on tray 30 at about 334 ^{o}C (633 ^{o}F) where it flows under level control to gas oil stripper C-105. The gas oil is stripped of entrained light vapor by superheated steam. The light vapor returns to the fractionator above tray 29, while the gas oil product is pumped by pump P-107 to the gas oil storage through crude oil preheat exchanger E-115 and water cooler E-111.

5. Diesel Oil Product : Diesel oil is condensed on tray 25 at about 282 ^{o}C (540 ^{o}F) and flows by level control to diesel

stripper C-104, where it is stripped of entrained light vapor by superheated steam. The vapor returns to the fractionator above tray 21 and the liquid is pumped by pump P-105 through crude oil preheat exchanger E-103, water cooler E-110 A-C / E-114 / E-117, coalescer D-104 (to remove insoluble water emulsion), and then to storage.

6. Circulating Diesel Reflux : A stream of unstripped diesel, called circulating reflux, is drawn from tray 24 by pump P-106 and sent to debutanizer reboiler E-403 to provide reboil heat for the debutanizer and also to provide crude preheat in E-104 before being returned to the fractionator at tray 21.

7. Kerosene Product : Kerosene vapor continues upward through the fractionator and condenses on tray 16 at about 213.3 ^{o}C (416 ^{o}F) where it flows under level control to kerosene stripper C-103. Here it is steam stripped and the vapor is returned to the fractionator above tray 15. The liquid is pumped by pump P-103 through crude oil preheat exchanger E-102, water cooler E-108 A/B, E-116 and coalescer D-103 (to remove insoluble water emulsion), then to kerosene storage.

8. Circulating Light Distillate : A stream of unstripped light distillate, called circulating reflux, is drawn from tray 11 by pump P-104 to provide crude preheat in E-101 before being returned to the fractionator at tray 8.

9. Heavy Naphtha : Heavy naphtha condenses on tray 7 at 149 ^{o}C (300 ^{o}F) and flows under level control to heavy naphtha stripper C-102 where it is stripped of light vapor by steam. The vapor returns to the fractionator above tray 6 and the heavy naphtha

product is pumped by pump P-102 to either the catalytic reformer, or through water cooler E-108 to heavy naphtha storage.

The properties of the sidestream products (kerosene, diesel, etc.) are controlled by their respective rates of removal, and the distribution of reflux between the circulating reflux and the tower top reflux. Provision is made to inject ammonia, or neutralizing amine, into the fractionator to control corrosion in the upper portion of the tower, and in the overhead system.

10. C-101 Overhead Circuit : The overhead vapor leaves the fractionator at about 122.2 ^{o}C (252 ^{o}F) and consists of gas, light naphtha reflux, and light straight-run product. The overhead vapor is condensed in a two-stage system. Light naphtha for top reflux is condensed in the first-stage reflux condenser E-106 and accumulated in the reflux drum D-101. Vapor from D-101 passes through overhead condenser E-107 to condense out light naphtha product in overhead receiver D-102. Drum D-101 provides hold-up for the fractionator reflux, and is controlled at about 86.1 ^{o}C (187 ^{o}F) by a temperature control valve on the process line that by-pass exchanger E-106.

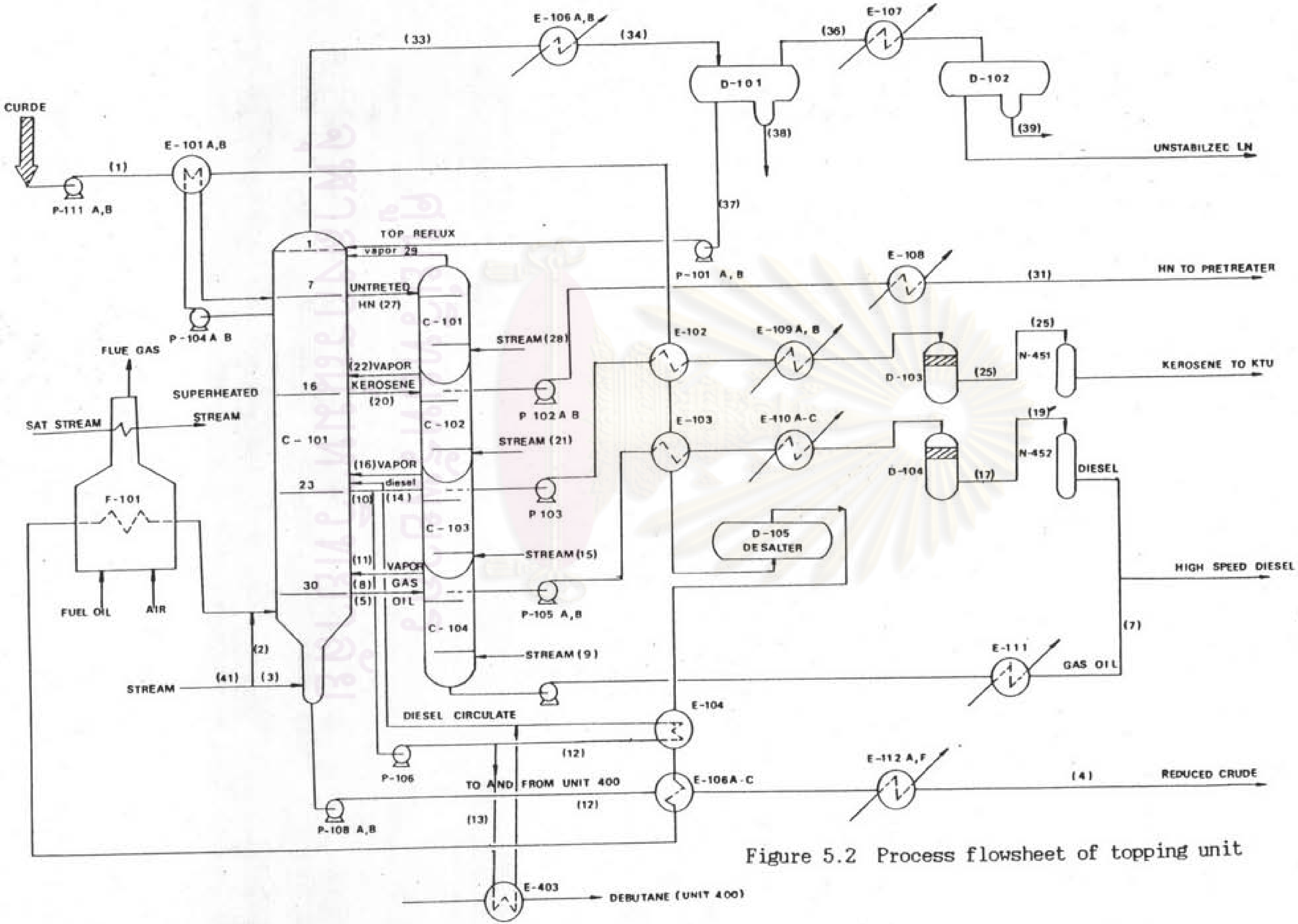


Figure 5.2 Process flowsheet of topping unit

5.4.2 Material and Energy Balance

Table 5.2 shows the data (refered from Table C.4, Appendix C) for material and energy balance analysis. The boundary of interest is shown in process flowsheet Figure 5.3.

To determine the heat capacity (Cp) of petroleum fractions, we can use either Figure E.3 and E.4 in Appendix E or equations below

$$Cp = ((1.01679 \times SpGr + 4.2059) \times (T_{av} \times 10^{-4})) - (0.52 \times SpGr) + 0.846$$

and

$$^{o}API = \frac{141.5}{SpGr\ 60/60} - 131.5$$

where

Cp	=	heat capacity	(Btu/lb-F)
$SpGr$	=	specific gravity at 60 ^{o}F	(-)
T_{av}	=	average temperature	(^{o}F)
^{o}API	=	gravity of petroleum products in degree API gravity scale	(-)

Remark : ^{o}API gravities are readily converted to specific gravities 60/60 ^{o}F by Figure E.1 in Appendix E.

Table 5.2 Data for material - energy balances

No.	Material	Conditions					
		Feed rate (lb/hr)	Temperature (°F)	°API	Average MW	K	Cp (Btu/lb-F)
1	Crude charge	619,150	80	35	211.6	11.7	0.44
2	Gas/light Naphtha	76,179	100	78	58.7	12.7	0.54
3	Heavy Naphtha	59,565	120	53.6	128.9	11.9	0.50
4	Kerosene	94,092	120	43.9	174.4	11.9	0.48
5	Diesel Oil	98,029	120	34.3	241.5	11.8	0.45
6	Gas Oil	50,245	120	27.3	316.0	11.7	0.43
7	Reduced Crude	241,040	180	15.3	512.9	11.7	0.41
8	Saturated steam	33,780	T = 298 °F, P = 50 Psig Enthalpy = 1179.1 Btu/hr				
9	Air feed	182,732.88	T = 80 °F, 25 % excess (See Appendix D-1)				
10	Fuel Oil feed	10,632.6	T = 200 °F, °API = 15, Cp = 0.43 LHV = 17,500 Btu/hr				
11	Steam output - From D-101	25,490	T = 187 °F, P = 1 atm., Enthalpy = 155.0 Btu/hr				
	- From D-102	8,290	T = 100 °F, P = 1 atm., Enthalpy = 67.97 Btu/hr				
12	Flue gas	193,356.18	T = 656 °F, Cp = 0.26 Btu/hr (See Appendix D-1)				
13	Electricity	: Supply for pump No. P-101 to P-110 = 396.1 kW.					
14	Humidity in plant air	: 0.0143 lb water/lb dry air					
15	Temperature reference = 80 °F						

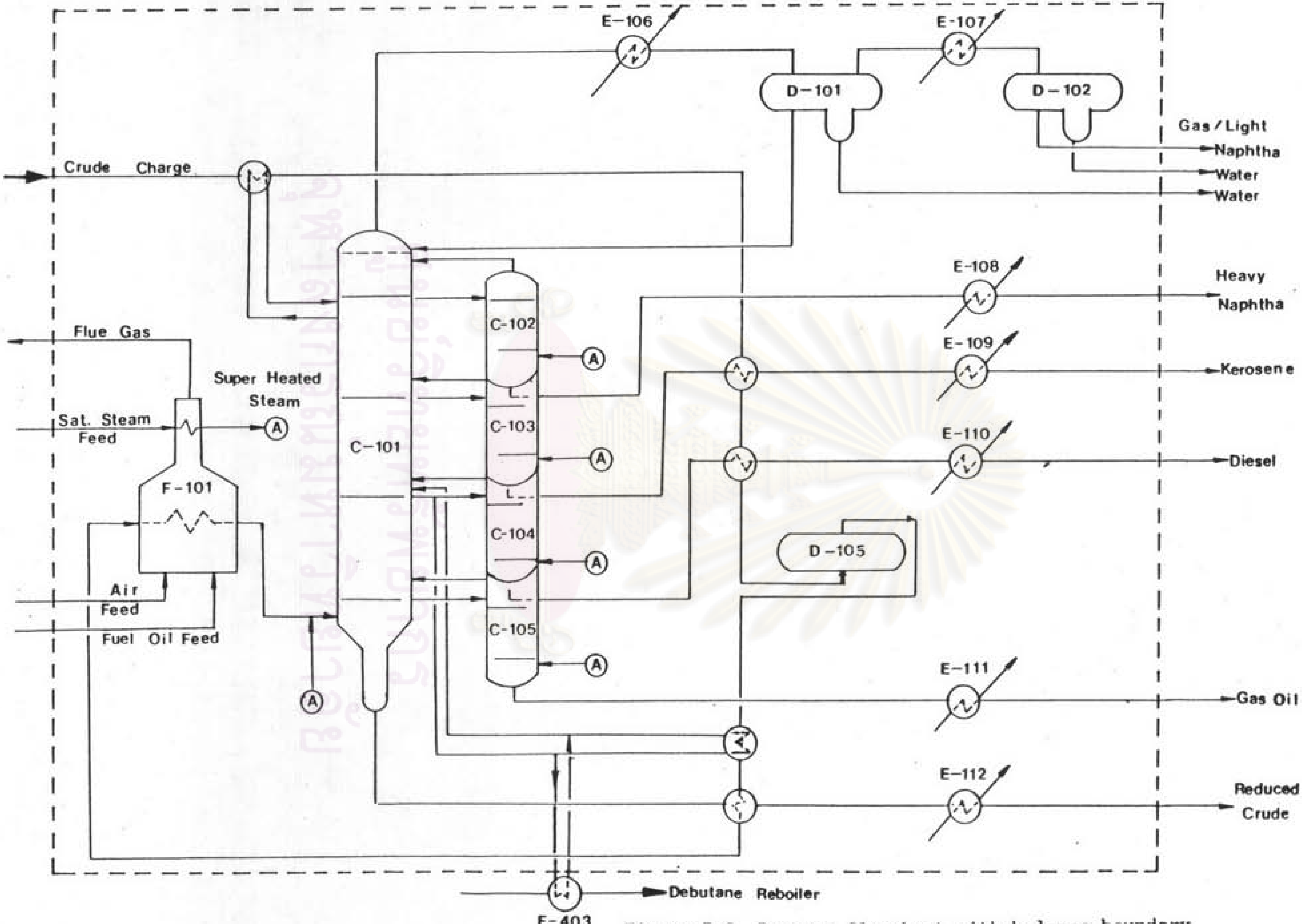


Figure 5.3 Process flowsheet with balance boundary

A) Material Balance

Basis : 1 hour operation

	Input	lb
1.	crude charge	619,150.0
2.	steam feed	33,780.0
3.	fuel oil feed	10,623.6
4.	air feed	182,732.6
	Total material input	846,286.2

	Output	lb
1.	gas/light naphtha	76,179.0
2.	heavy naphtha	59,565.0
3.	kerosene	94,092.0
4.	diesel	98,029.0
5.	gas oil	50,245.0
6.	reduced crude	241,104.0
7.	steam from D-101, D-102	33,780.0
8.	flue gas	193,356.2
	Total material output	846,286.2

Remark : Weight of water vapor entering as air humidity is substracted from the weight of water vapor in the flue gas.

B) Energy Balance : Reference temperature = 80 ^{o}F

Input		MBtu
1. Sensible heat of crude charge (T = 80 ^{o}F)	=	0.00
2. Enthalpy of fuel oil		
a. Sensible heat = 10623.6(0.43)(200-80)	=	0.54
b. Heat of combustion = 10623.6 x 17500	=	185.91
3. Enthalpy of steam = 33780 x 1179.1	=	39.83
4. Enthalpy of air (T = 80 ^{o}F)	=	0.00
Total energy input	=	226.28

Output		MBtu
1. Enthalpy of gas/light naphtha		
= 76179(0.54)(100-80)	=	0.82
2. Enthalpy of heavy naphtha		
= 59565(0.50)(120-80)	=	1.19
3. Enthalpy of kerosene		
= 94092(0.48)(120-80)	=	1.79
4. Enthalpy of diesel		
= 98029(0.45)(120-80)	=	1.78
5. Enthalpy of gas oil		
= 50245(0.43)(120-80)	=	0.87
6. Enthalpy of reduced crude		
= 214040(0.41)(180-80)	=	9.94
7. Heat to steam (Saturated liquid)		
a. from D-101 = 25490(155.0)	=	3.95
b. from D-102 = 8290(67.97)	=	0.56

Output (Continued)		MBtu
8. Net heat to cooling water (E-106 to E-112)		
(89.10+22.88+4.87+5.27+7.47+14.05+21.55)		
(see Table D.1, Appendix D-2)	=	165.19
9. Heat to debutane reboiler (E-403)		
(see Table D.1, Appendix D-2)	=	11.29
10. Sensible heat to dry flue gas		
(see Appendix D-1)	=	29.74
11. Loss and radiation (see Appendix D-1)	=	2.89
Total energy output	=	230.01

$$\% \text{ error} = \frac{(230.01 - 226.28) \times 100}{226.28}$$

$$= 1.65 \%$$

Remark : The net energy output is slightly higher than the net energy input. The unexpected higher value of 3.73 MBtu might come from the mean specific heat of each stream. However, a 1.65 % error seems insignificant. Thus we can say that, the obtained data are considerably reliable for our further analysis.

5.4.3 Grid Diagram Representation

The heat exchanger network in the flowsheet form in Figure 5.4 (a) is reproduced in the grid form in Figure 5.4 (b), with stream temperature and match heat load marked on. The grid shows all the flowsheet heat exchangers, heater, and coolers with their heat loads and corresponding stream temperature (in ^{o}F). The stream data are listed in Table 5.3.

The existing hot utility is 149.40 MBtu/hr, and the net cold utility is 167.31 MBtu/hr.

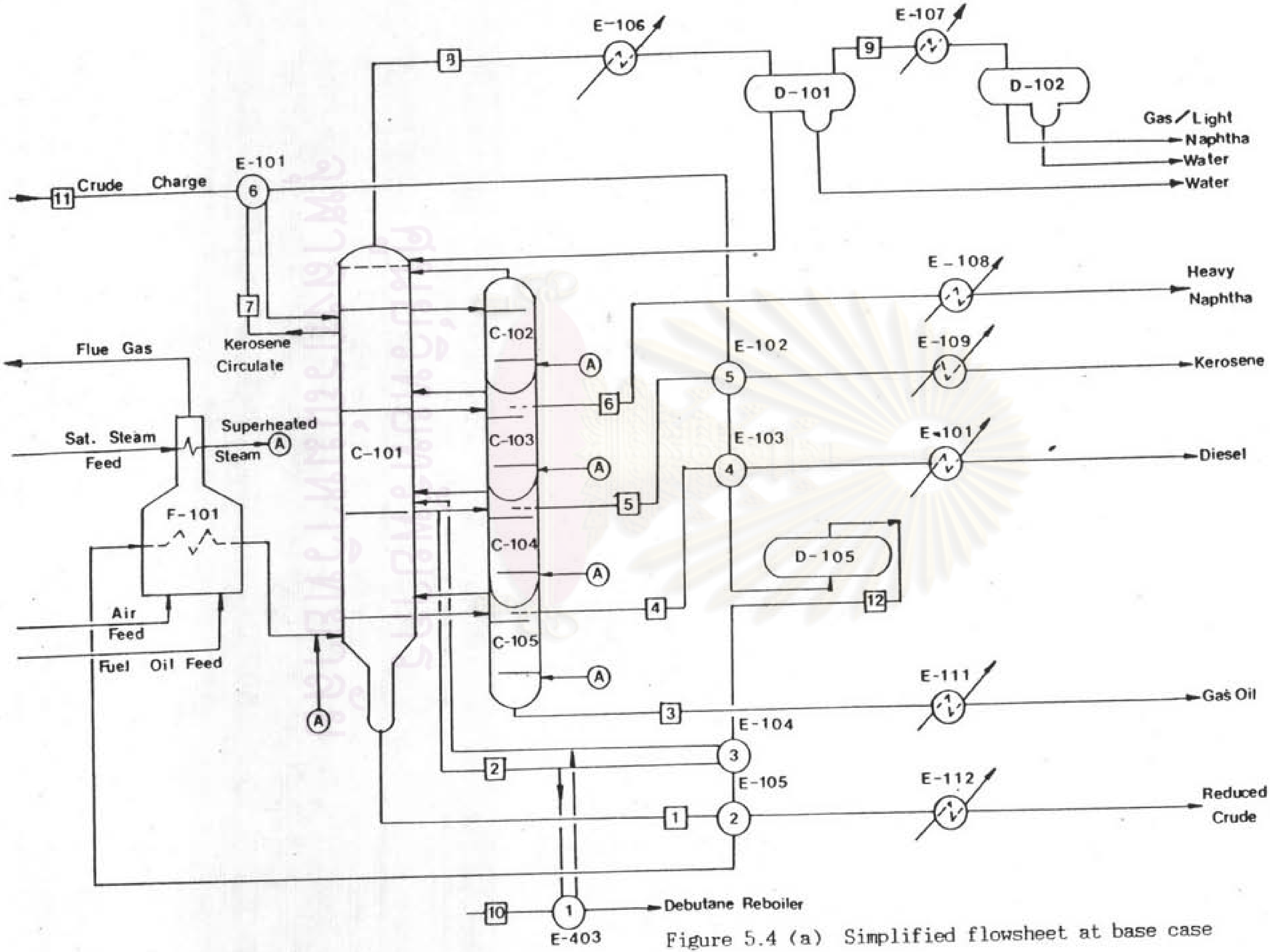


Figure 5.4 (a) Simplified flowsheet at base case

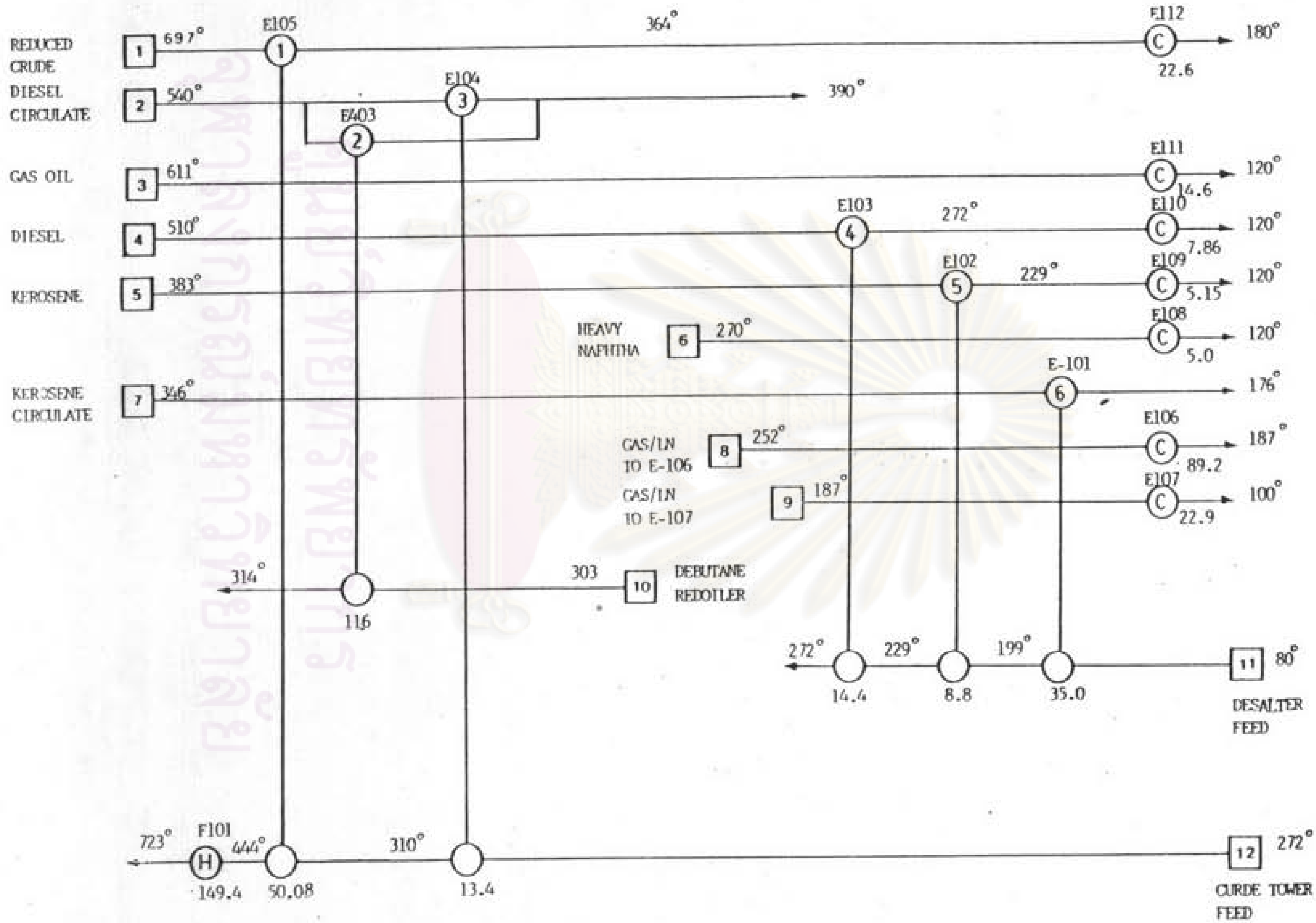


Figure 5.4 (b) Grid representation diagram

Table 5.3 Stream data

No.	Stream	Temp. (°F)	Ht Exgr No.	Heat load (MBtu/hr)	CUM H (MBtu/hr)	FCpm (dH/dT)	FCpm (Total)
1	Reduced crude	697	E-105	50.08	72.68		
		364	E-112	22.60	22.60	0.1504	
		180		0.00	0.00	0.1228	0.1406
2	Diesel circulate	540	E-104	25.00			
		390	+E-103	0.00		0.1667	
3	Gas oil	611	E-111	14.60			
		120		0.00		0.0297	
4	Diesel oil	510	E-103	14.40	22.26		
		272	E-110	7.86	7.86	0.0605	
		120		0.00	0.00	0.0517	0.0571
5	Kerosene	383	E-102	8.80	13.95		
		229	E-109	5.15	5.15	0.0571	
		120		0.00	0.00	0.0472	0.0530
6	Heavy naphtha	270	E-108	5.00			
		120		0.00		0.0333	
7	Kerosene Cir.	346	E-101	35.00			
		176		0.00		0.2059	
8	Gas/LN to E-106	252	E-106	89.20			
		187		0.00		1.3723	
9	Gas/LN to E-107	187	E-107	22.90			
		100		0.00		0.2632	
10	Debutane reboil.	303		0.00		1.0545	
		314	E-403	11.60			
11	Desalter feed	80		0.00	0.00	0.2941	0.3031
		199	E-101	35.00	35.00	0.2933	
		229	E-102	8.80	43.80	0.3349	
		272	E-103	14.40	58.20		
12	Crude tower feed	272		0.00	0.00	0.3526	0.4720
		310	E-104	13.40	13.40	0.3737	
		444	E-105	50.08	63.48	0.5355	
		723	F-101	149.40	212.88		

5.5 Pinch Design

5.5.1 Data Extraction and Energy Targeting

1. First-Law Analysis

According to our evaluation on the previous subsection, we have twelve distinct streams in our system, i.e., nine hot streams and three cold streams. The properties of each stream are presented in Table 5.4.

If we simply calculate the heat available in the hot streams and heat required for 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 the Table 5-4, and the first two entries are determined as follows:

$$Q1 = F1Cp1\triangle T1 = (0.1406 \text{ MBtu/(hr-F)})(697-180 \text{ oF})$$
$$= 72.68 \text{ MBtu/hr}$$
$$Q2 = F2Cp2\triangle T2 = (0.1667 \text{ Mbtu/(hr-F)})(540-390 \text{ oF})$$
$$= 25.06 \text{ MBtu/hr}$$

Thus, 17.91 MBtu/hr must be rejected to cold utilities if there be no restriction on temperature-driving forces.

2. Temperature-Intervals

The smallest values of $\triangle$ Tmin in the base case (Figure 5.4,b) is 30 ^{O}F at the cold end of match 5. As a first step, we choose a mimimum driving force of 36 ^{O}F between any pair of hot and cold streams. Next we establish two temperature scales on a graph, one for the hot streams and the other for the cold streams, the latter being shifted by 36 ^{O}F from the former. Then we plot the stream data on this graph with a series of temperature intervals that correspond to the heads and tails of the stream arrows on the graph, i.e., the inlet and outlet temperatures of all the hot and cold streams given in Table 5.4 (see Figure 5.5) are plotted on this respective scales. Note that eighteen intervals are obtained.

Table 5.4 First law calculation

Stream No.	Tin (°F)	Tout (°F)	Feed (lb)	°API	FCpm (MBtu/hr°F)	HEAT LOAD (MBtu/hr)
Hot stream						
1	697	180	241040	15.3	0.1406	72.68
2	540	390	250000	35.3	0.1667	25.00
3	611	120	50245	27.3	0.0297	14.60
4	510	120	98029	34.3	0.0571	22.26
5	383	120	94092	43.9	0.0530	13.95
6	270	120	59565	53.6	0.0333	5.00
7	346	176	350000	50.9	0.2059	35.00
8	252	187	476540	64.6	1.3723	89.20
9	187	100	84469	78.0	0.2632	22.90
Cold stream						
10	303	314	311600	76.6	1.0545	-11.60
11	80	272	619150	35.0	0.3031	-58.20
12	272	723	619150	35.0	0.4720	-212.88
					Total	17.91

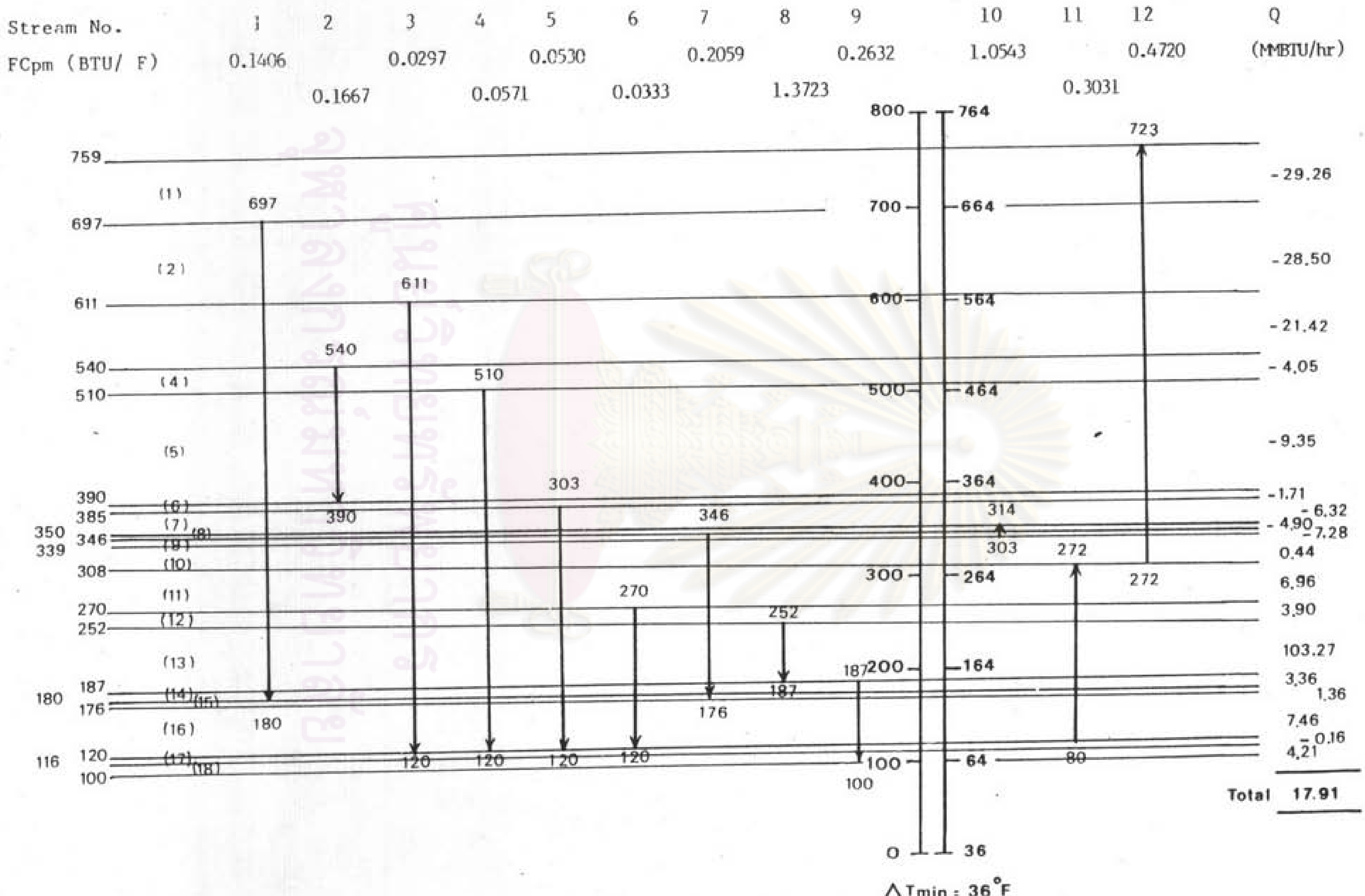


Figure 5.5 Temperature intervals

Setting up the intervals in this way guarantees that full heat interchange within any interval is possible. Hence, each interval will have either a net surplus or net deficit of heat as dictated by enthalpy balance. Knowing the stream population in each interval (from Figure 5.5) we can easily calculate the enthalpy balances for each interval according to :-

$$Qi = [\sum(FCp)hot,i - \sum(FCp)cold,i)] \triangle Ti$$

Thus, for the first three intervals we obtain

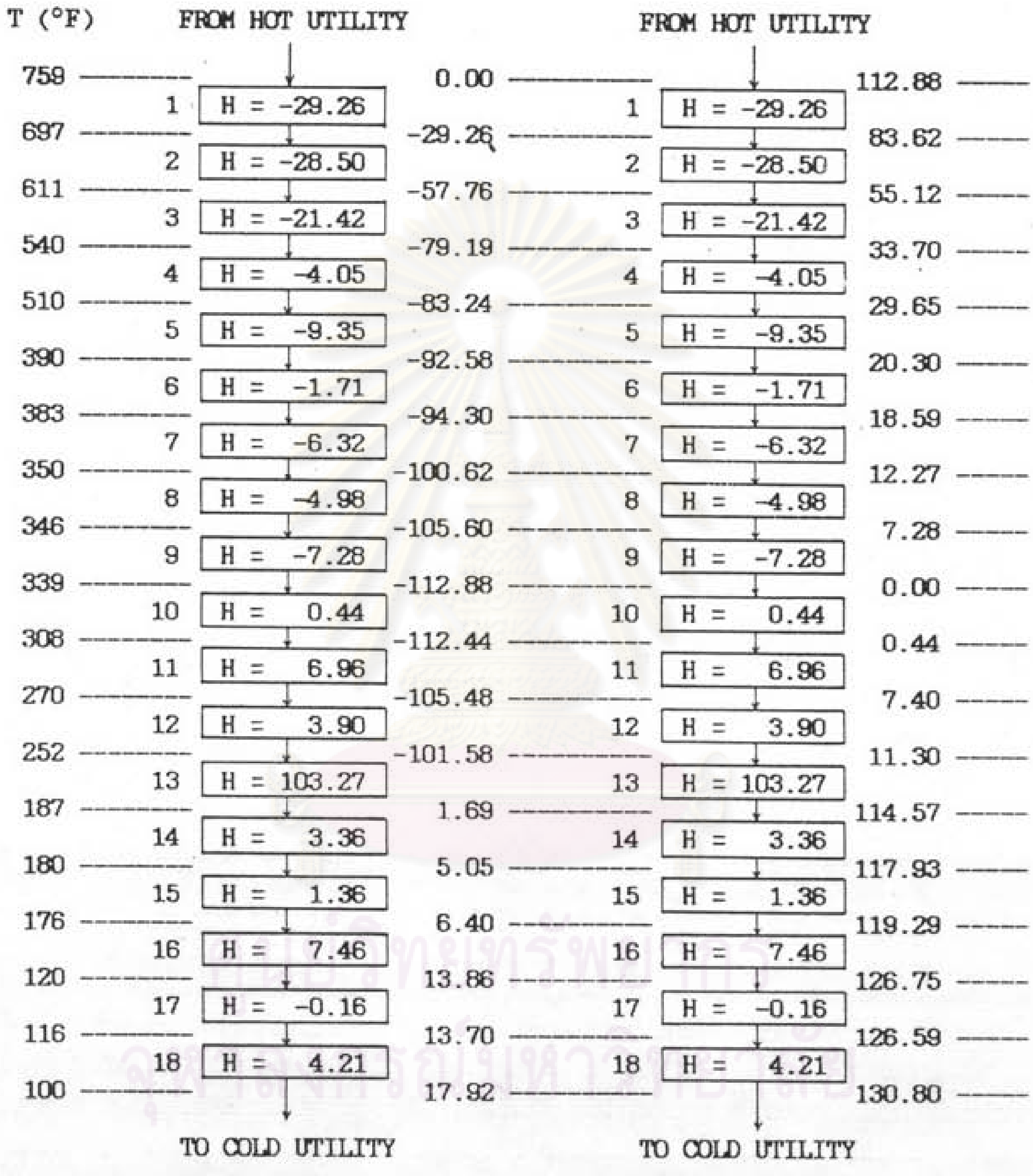
$$Q1 = (0-0.472)(759-697) = -29.2640$$

$$Q2 = (0.1406-0.472)(697-611) = -28.5004$$

$$Q3 = (0.1406+0.0297-0.4720)(611-540) = -21.4207$$

The results for the other intervals are shown in Figure 5.5. We also note that the summation of the heat available in all the intervals is 17.19 MBtu/hr, which is identical to the result obtained for the first law calculation.

We now exploit a key feature of the temperature intervals. Namely, any heat available in interval i is hot enough to supply any duty in interval i+1. This is shown in Figure 5.6 (a). In our problem, the heat flow across interval one to interval twelve clearly shows some negative magnitudes, which is thermodynamically infeasible. To make it just feasible, 112.88 MBtu/hr of heat must be added from the hot utility (above interval one) as shown in Figure 5.6 (b), and cascaded down through the system. By enthalpy balance this means that all heat flows are increased by 112.88 MBtu/hr. The net result of this operation is that the minimum utility requirements have been predicted, i.e., 112.88 MBtu/hr hot, and 130.80 MBtu/hr cold. Further, the position of the pinch has been located. This is at 339 ^{o}F on the boundary of the hot temperature scale, at which heat flow is zero.



INFEASIBLE
(a)

PINCH,Qh-min,Qc-min
(b)

Figure 5.6 Cascade diagram

3. Temperature-Enthalpy Diagram

To construct a temperature-enthalpy diagram, we shall define the enthalpy corresponding to the coldest temperature of any hot stream as our base condition, i.e., at t = 110 ^{o}F (see Figure 5.5), H = 0. Next we calculate the cumulative heat available in the aggregate of all applicable hot streams as we consecutively move to higher temperature intervals. Thus, from Figure 5.5 we obtain the following :

$T1 = 100\ ^{o}F \quad Ho = 0 \qquad\qquad \text{Cum H} = 0$

$T2 = 120\ ^{o}F \quad H1 = 0.2632(120-100) = 5.264 \qquad \text{Cum H} = 5.264$

$T3 = 176\ ^{o}F \quad H2 = (0.0297+0.0571+0.0530+0.0333+0.2632)(176-120)$

$= 24.4328 \qquad \text{Cum H} = 29.6968$

The results of the other intervals are shown in Table 5.5 (a).

Table 5.5 (a) Temperature - Enthalpy diagram (hot streams)

No.	T (^{o}F)	$\triangle$ T	Q	CUM Q
1	100		0.00	0.00
2	120	20.0	5.26	5.26
3	176	56.0	24.43	29.70
4	180	4.0	2.57	32.27
5	187	7.0	5.48	37.75
6	252	65.0	122.97	160.72
7	270	18.0	9.35	170.07
8	346	76.0	36.96	207.03
9	383	37.0	10.37	217.41
10	390	7.0	1.59	219.00
12	540	30.0	10.11	276.40
13	611	71.0	12.09	288.49
14	697	86.0	12.09	300.58

Next at the lowest temperature of all cold streams (T = 80 ^{O}F), we define the enthalpy as the minimum cooling requirement Qc,min (130.7990 MBtu/hr). Then we calculate the cumulative enthalpy in each temperature interval :

T1 = 180 ^{O}F Ho = 130.7990 Cum H = 130.7990

T2 = 272 ^{O}F H1 = 0.3031(272-80) = 58.1952 Cum H = 188.9942

T3 = 303 ^{O}F H2 = (0.4720)(303-272)

= 14.6328 Cum H = 203.6262

The remainning results are shown in Table 5.5 (b).

Table 5.5 (b) Temperature - Enthalpy diagram (cold streams)

No.	T (^{O}F)	$\triangle$ T	Q	CUM Q
1	80		130.80	130.80
2	272	192.0	58.20	188.99
3	303	31.0	14.63	203.63
4	314	11.0	16.79	220.42
5	723	409.0	193.05	413.47

The data on Table 5.5 are plotted on Figure 5.7. We note that the enthalpy of the hot streams that must be rejected to a cold utility is Qc = 130.80 MBtu/hr, and the amount of heat that must be supplied from a hot utility is Qh = 112.88 MBtu/hr. Moreover, at Th = 339 ^{O}F and Tc = 303 ^{O}F, we see that the minimum approach temperature occurs, i.e., the heating and cooling curves are closest together. Thus this temperature-enthalpy diagram gives us exactly the same information we have obtained previously.

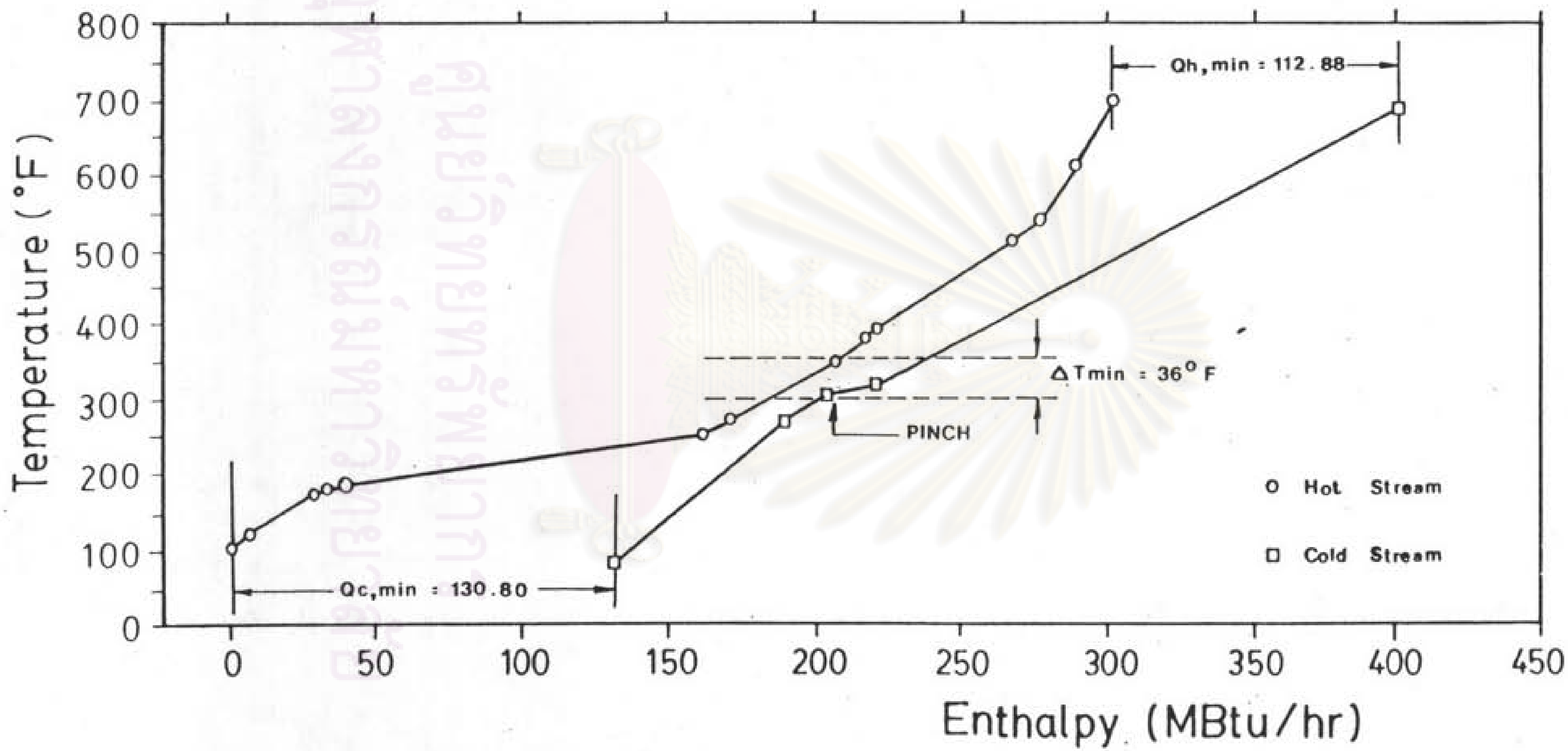


Figure 5.7 Composite curves

4. Application of Energy Targeting Software

When we apply the Energy Targeting Software introduced in the previous Chapter to the present problem, the following results are obtained. Of course, the results agree exactly with the above hand-calculation.

A> THESIS

```
INPUT THE FOLLOWING DATA

NO. OF HOT STREAMS =
9

NO. OF COLD STREAMS =
3

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) =
697.00
 TARGET TEMPERATURE (oF) =
180.00
 HEAT CAPACITY FLOWRATE (BTU/hr-F)
0.1406

 HOT STREAM No. 2
 SUPPLY TEMPERATURE (oF) =
540.00
 TARGET TEMPERATURE (oF) =
390.00
 HEAT CAPACITY FLOWRATE (BTU/hr-F)
0.1667

 HOT STREAM No. 3
 SUPPLY TEMPERATURE (oF) =
611.00
 TARGET TEMPERATURE (oF) =
120.00
 HEAT CAPACITY FLOWRATE (BTU/hr-F)
0.0297
```

HOT STREAM No. 4
SUPPLY TEMPERATURE (oF) =
510.00
TARGET TEMPERATURE (oF) =
120.00
HEAT CAPACITY FLOWRATE (BTU/hr-F)
0.0571

HOT STREAM No. 5
SUPPLY TEMPERATURE (oF) =
383.00
TARGET TEMPERATURE (oF) =
120.00
HEAT CAPACITY FLOWRATE (BTU/hr-F)
0.0530

HOT STREAM No. 6
SUPPLY TEMPERATURE (oF) =
270.00
TARGET TEMPERATURE (oF) =
120.00
HEAT CAPACITY FLOWRATE (BTU/hr-F)
0.0333

HOT STREAM No. 7
SUPPLY TEMPERATURE (oF) =
346.00
TARGET TEMPERATURE (oF) =
176.00
HEAT CAPACITY FLOWRATE (BTU/hr-F)
0.2059

HOT STREAM No. 8
SUPPLY TEMPERATURE (oF) =
252.00
TARGET TEMPERATURE (oF) =
187.00
HEAT CAPACITY FLOWRATE (BTU/hr-F)
1.3723

HOT STREAM No. 9
SUPPLY TEMPERATURE (oF) =
187.00
TARGET TEMPERATURE (oF) =
100.00
HEAT CAPACITY FLOWRATE (BTU/hr-F)
0.2632

COLD-STREAM DATA :

COLD STREAM No. 1
SUPPLY TEMPERATURE (oF) =
303.00
TARGET TEMPERATURE (oF) =
314.00
HEAT CAPACITY FLOWRATE (BTU/hr-F) =
1.0545

COLD STREAM No. 2
SUPPLY TEMPERATURE (oF) =
80.00
TARGET TEMPERATURE (oF) =
272.00
HEAT CAPACITY FLOWRATE (BTU/hr-F) =
0.3031

COLD STREAM No. 3
SUPPLY TEMPERATURE (oF) =
272.00
TARGET TEMPERATURE (oF) =
723.00
HEAT CAPACITY FLOWRATE (BTU/hr-F) =
0.4720

MINIMUM TEMPERATURE DIFFERENCE (oF) =
36.00

HOT-STREAM DATA

HOT STREAM No.	SUPPLY TEMP.	TARGET TEMP.	HEAT CAPACITY FLOWRATE
1	697.00	180.00	.14
2	540.00	390.00	.17
3	611.00	120.00	.03
4	510.00	120.00	.06
5	383.00	120.00	.05
6	270.00	120.00	.03
7	346.00	176.00	.21
8	252.00	187.00	1.37
9	187.00	100.00	.26

COLD-STREAM DATA

COLD STREAM No.	SUPPLY TEMP.	TARGET TEMP.	HEAT CAPACITY FLOWRATE
1	303.00	314.00	1.05
2	80.00	272.00	.30
3	272.00	723.00	.47

MINIMUM TEMPERATURE DIFFERENCE = 36.00

RESULT

INTERVAL No.	HOT – STREAM TEMPERATURE	DEFICIT	CUMULATIVE OUTPUT	HEAT FLOW
	759.00			112.88
1		29.26	-29.26	
	697.00			83.62
2		28.50	-57.76	
	611.00			55.12
3		21.42	-79.19	
	540.00			33.70
4		4.05	-83.24	
	510.00			29.65
5		9.35	-92.58	
	390.00			20.30
6		1.71	-94.30	
	383.00			18.59
7		6.32	-100.62	
	350.00			12.27
8		4.98	-105.60	
	346.00			7.28
9		7.28	-112.88	
	339.00			.00
10		-.44	-112.44	
	308.00			.44
11		-6.96	-105.48	
	270.00			7.40
12		-3.90	-101.58	
	252.00			11.30
13		-103.27	1.69	
	187.00			114.57
14		-3.36	5.05	
	180.00			117.93
15		-1.36	6.40	
	176.00			119.29
16		-7.46	13.86	
	120.00			126.75
17		.16	13.70	
	116.00			126.59
18		-4.21	17.92	
	100.00			130.80

```
MINIMUM TEMPERATURE DIFFERENCE            =   36.00   oF
PINCH IS LOCATED AT COLD TEMPERATURE      =  303.00   oF
PINCH IS LOCATED AT HOT TEMPERATURE       =  339.00   oF

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

MINIMUM HOT UTILITY REQUIREMENT           =  112.88   BTU/hr
MINIMUM COLD UTILITY REQUIREMENET         =  130.80   BTU/hr

Stop - Program terminated.
```

5.5.2 Design of Maximum-Energy-Recovery Heat-Exchanger Networks

Now that we have obtained estimates of the minimum heating and cooling requirements, we proceed to design a heat-exchanger network that fulfils such requirements. We conceptually divide the design problem in two parts : first we design a subnetwork for those streams lying above the pinch and then another for those below the pinch. Remember that our design goal is also to maximise compatibility with the existing plant.

1. Design Above the Pinch

As the first step in the design procedure, we calculate the heat load between either the inlet temperature of a hot stream or the outlet temperature of a cold stream and the pinch temperature by the expression $Q = FCp\triangle T$. Using the set of stream data in Table 5.3, the heat load above the pinch for each stream has been determined as :

Stream No.	$Q = FCpm\triangle T$		Q (MBtu/hr)
Hot stream			
1	$Q = 50.08 + 0.1228(364-339)$	=	53.2
2	$Q = 0.1667(540-390)$	=	25.0
3	$Q = 0.0297(611-339)$	=	8.1
4	$Q = 0.0605(510-339)$	=	10.3
5	$Q = 0.0571(383-339)$	=	2.5
7	$Q = 0.2059(346-339)$	=	1.4
Cold stream			
10	$Q = 1.0545(314-303)$	=	11.6
12	$Q = 0.3526(310-303) + 50.8 + 149.4$	=	202.0

Figure 5.8 (a) shows the set of streams above the pinch. The first point to relise is that, because there are six hot streams and only two cold streams immediately above the pinch, some of the cold streams must be split according to the pinch design rule ($Nh \leq Nc$). We must remember that above the pinch, if the best performance is to be obtained, no utility cooling should be used. This means that all hot streams must be brought down to pinch temperature by interchange against the available cold streams. We must therefore start the design at the pinch and find matches that fulfil this condition.

The first design decision is shown in Figure 5.8 (b). Matches 1, 2, and 5 are previously present in the existing plant, the others being newly installed. Using the design heuristic for feasible matches above the pinch that requires $FhCph \leq FcCpc$, we now assign loads to these matches. The loads on matches 7 and 8 are maximised to "tick-off" streams 5 and 7, respectively. Then match 2 is maximised to "tick-off" stream 10. The combined cold end temperature of the split cold stream 12 should not be cooled below 474 ^{o}F (because the supply temperature of stream 4 is 510 ^{o}F). This dictates the maximum load on match 1, which becomes a design decision. Therefore, heat load of 20.45 MBtu/hr is assigned to match 1. This in turn fixes the load on match 3, 4, 5 and 6 by enthalpy balance.

The stream matching conditions corresponding to Figure 5.8 (b) are listed as below.

Match No. 1		Heat Load 20.45 MBtu/hr		
Hot Stream No. 1	:	Th = 697.0 ^{o}F	Tc = 561.02 ^{o}F	FCp = 0.1228
Cold Stream No. 12	:	Tc = 474.0 ^{o}F	Th = 512.2 ^{o}F	FCp = 0.3526
Match No. 2		Heat Load 7.70 MBtu/hr		
Hot Stream No. 2b	:	Th = 540.0 ^{o}F	Tc = 390.0 ^{o}F	FCp = 0.0513
Cold Stream No. 10	:	Tc = 306.7 ^{o}F	Th = 314.0 ^{o}F	FCp = 1.0545
Match No. 3		Heat Load 10.3 MBtu/hr		
Hot Stream No. 4	:	Th = 510.0 ^{o}F	Tc = 339.0 ^{o}F	FCp = 0.0605
Cold Stream No. 12d	:	Tc = 303.0 ^{o}F	Th = 473.0 ^{o}F	FCp = 0.0606
Match No. 4		Heat Load 8.1 MBtu/hr		
Hot Stream No. 3	:	Th = 611.0 ^{o}F	Tc = 339.0 ^{o}F	FCp = 0.0297
Cold Stream No. 12c	:	Tc = 303.0 ^{o}F	Th = 474.0 ^{o}F	FCp = 0.0474
Match No. 5		Heat Load 17.3 MBtu/hr		
Hot Stream No. 2a	:	Th = 540.0 ^{o}F	Tc = 390.0 ^{o}F	FCp = 0.1153
Cold Stream No. 12b	:	Tc = 303.0 ^{o}F	Th = 447.0 ^{o}F	FCp = 0.1200
Match No. 6		Heat Load 32.75 MBtu/hr		
Hot Stream No. 1	:	Th = 561.02 ^{o}F	Tc = 339.0 ^{o}F	FCp = 0.1228
Cold Stream No. 12a	:	Tc = 303.0 ^{o}F	Th = 491.7 ^{o}F	FCp = 0.1735
Match No. 7		Heat Load 2.5 MBtu/hr		
Hot Stream No. 5	:	Th = 383.0 ^{o}F	Tc = 339.0 ^{o}F	FCp = 0.0571
Cold Stream No. 10	:	Tc = 304.33 ^{o}F	Th = 306.7 ^{o}F	FCp = 1.0545

Match No. 8 : Heat Load 1.4 MBtu/hr

Hot Stream No. 7 : Th = 346.0 ^{o}F Tc = 339.0 ^{o}F FCp = 0.2059

Cold Stream No. 10 : Tc = 303.0 ^{o}F Th = 304.33 ^{o}F FCp = 1.0545

Hot Utility : Heat Load 112.88 MBtu/hr

Cold Stream No. 12 : Tc = 512.2 ^{o}F Th = 723.0 ^{o}F FCp = 0.3526

The complete above-the-pinch design is shown in Figure 5.8 (b). In all eight exchangers are require, and one hot utility included. It is obvious that we have satisfied the minimum heating requirement of 112.88 MBtu/hr as predicted. The stream temperatures are also shown on Figure 5.8 (b), and the temperature driving force at both ends of every heat exchanger is either 36 ^{o}F or greater.

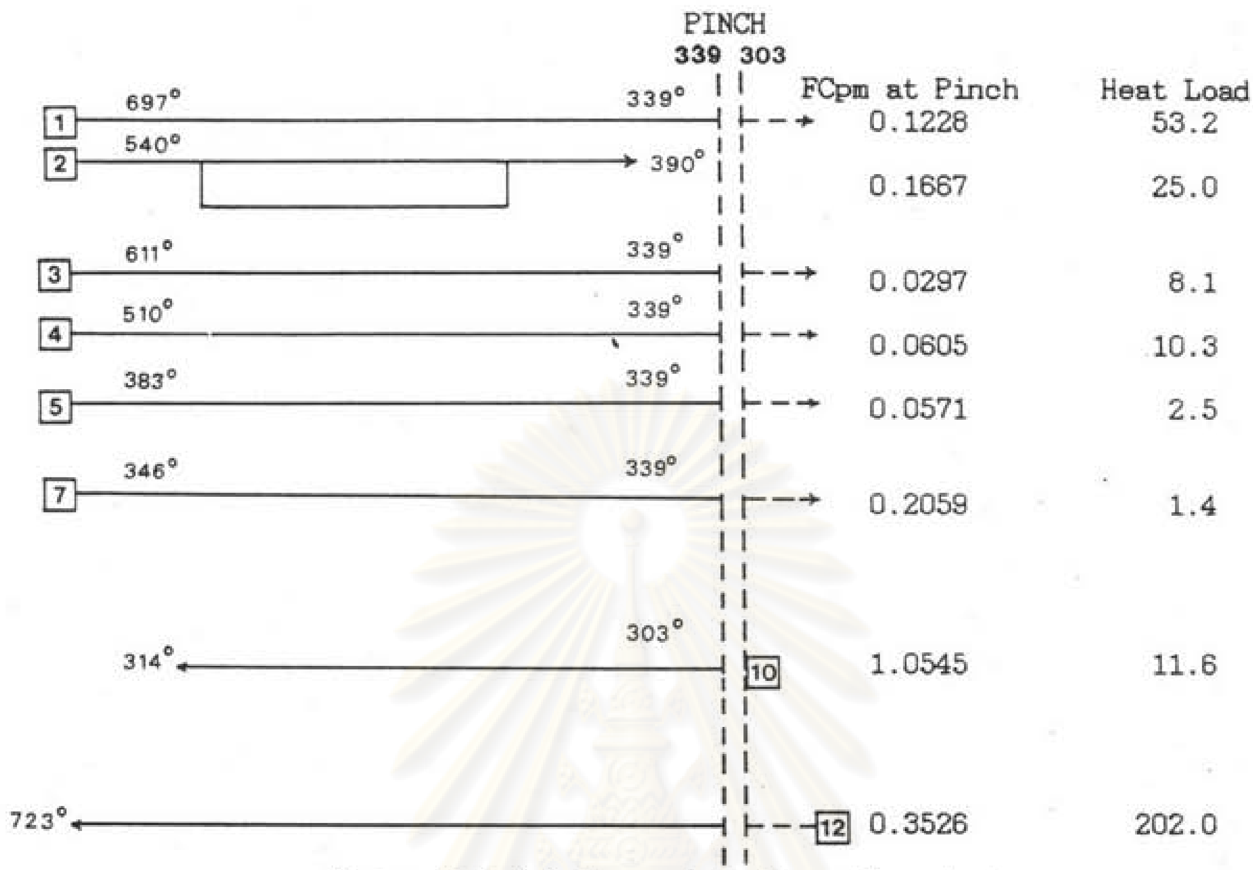


Figure 5.8 (a) Stream set above the pinch

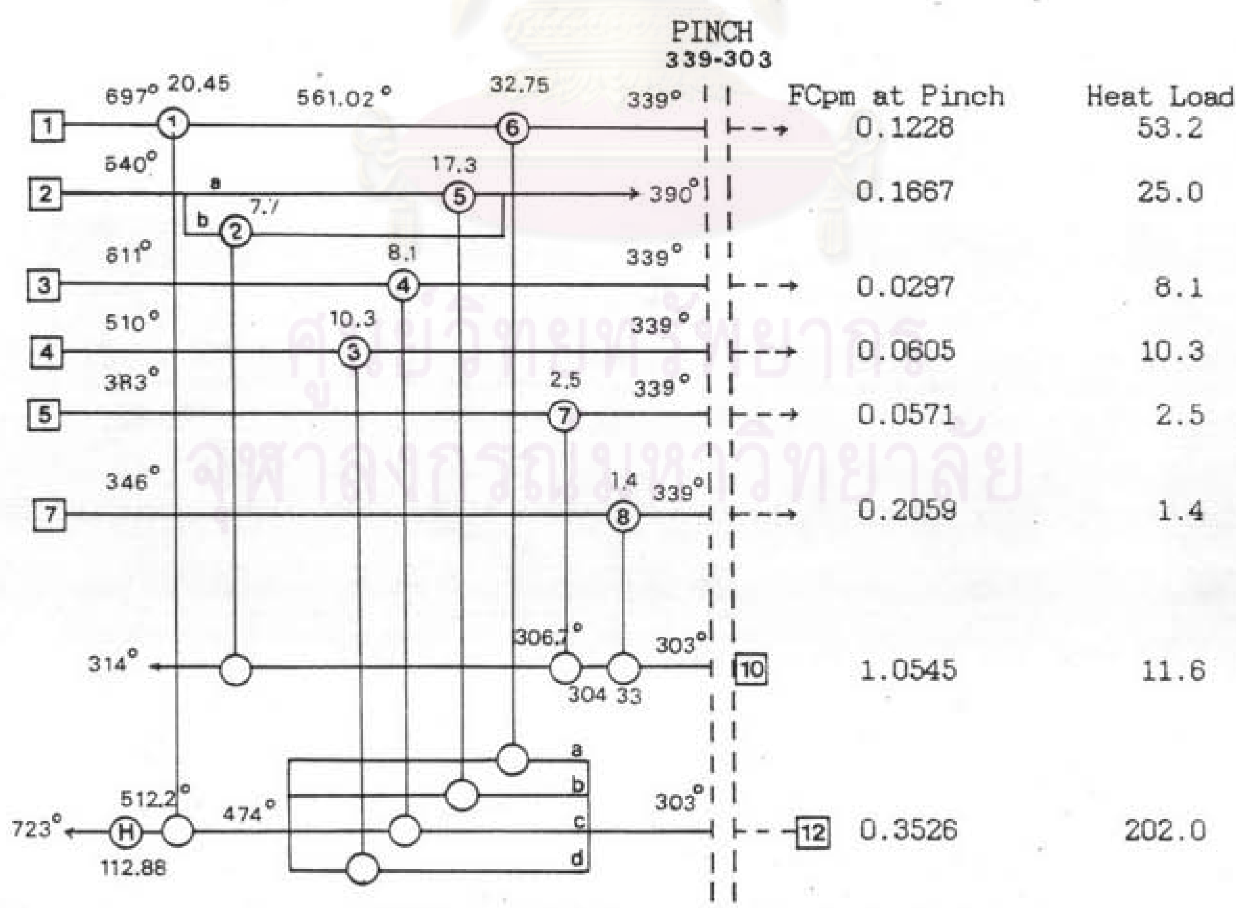


Figure 5.8 (b) Above-the-pinch design

2. Design Below the Pinch

Likewise we calculate the heat loads between either the inlet or the outlet temperature and the pinch temperature for each stream. The calculating procedure is similar to that for the-above-pinch design.

Stream No.	$Q = FCpm\Delta T$	Q (MBtu/hr)
Hot stream		
1	Q = 0.1228(339-180)	= 19.5
3	Q = 0.0297(339-120)	= 6.5
4	Q = 0.0605(339-272) + 7.86	= 12.0
5	Q = 0.0571(339-229) + 5.15	= 11.4
6	Q = 0.033(270-120)	= 5.0
7	Q = 0.2059(339-176)	= 33.6
8	Q = 1.3723(252-187)	= 89.2
9	Q = 0.2632(187-100)	= 22.9
Cold stream		
11	Q = 0.3031(272-80)	= 58.2
12	Q = 0.3526(303-272)	= 10.9

Below the pinch, the design steps follow the same concept, but with the design criteria mirroring those of "above-the-pinch" design. Figure 5.9 (a) shows the set of streams below the pinch. For a feasible match we require that $FhCph \geq FcCpc$. The stream matching conditions corresponding to Figure 5.9 (b) are listed as below.

Match No. 9		Heat Load 3.8 MBtu/hr		
Hot Stream No.	1 :	Th = 339.0 ^{o}F	Tc = 308.0 ^{o}F	FCp = 0.1228
Cold Stream No.	12a :	Tc = 272.0 ^{o}F	Th = 303.0 ^{o}F	FCp = 0.1229

Match No. 10 Heat Load 0.9 MBtu/hr

Hot Stream No. 3 : Th = 339.0 ^{o}F Tc = 308.0 ^{o}F FCp = 0.0297

Cold Stream No. 12b : Tc = 272.0 ^{o}F Th = 303.0 ^{o}F FCp = 0.0291

Match No. 11 Heat Load 1.9 MBtu/hr

Hot Stream No. 4 : Th = 339.0 ^{o}F Tc = 308.0 ^{o}F FCp = 0.0605

Cold Stream No. 12c : Tc = 272.0 ^{o}F Th = 303.0 ^{o}F FCp = 0.0615

Match No. 12 Heat Load 1.8 MBtu/hr

Hot Stream No. 5 : Th = 339.0 ^{o}F Tc = 308.0 ^{o}F FCp = 0.0571

Cold Stream No. 12d : Tc = 272.0 ^{o}F Th = 303.0 ^{o}F FCp = 0.0582

Match No. 13 Heat Load 2.5 MBtu/hr

Hot Stream No. 1 : Th = 339.0 ^{o}F Tc = 326.8 ^{o}F FCp = 0.2059

Cold Stream No. 12e : Tc = 272.0 ^{o}F Th = 303.0 ^{o}F FCp = 0.0809

Match No. 14 Heat Load 8.19 MBtu/hr

Hot Stream No. 1 : Th = 308.0 ^{o}F Tc = 241.3 ^{o}F FCp = 0.1228

Cold Stream No. 11 : Tc = 154.8 ^{o}F Th = 272.0 ^{o}F FCp = 0.0699

Match No. 15 Heat Load 28.01 MBtu/hr

Hot Stream No. 7 : Th = 326.8 ^{o}F Tc = 190.8 ^{o}F FCp = 0.2059

Cold Stream No. 11a : Tc = 154.8 ^{o}F Th = 272.0 ^{o}F FCp = 0.2390

Match No. 16 Heat Load 11.9 MBtu/hr

Hot Stream No. 8 : Th = 252.0 ^{o}F Tc = 243.3 ^{o}F FCp = 1.3723

Cold Stream No. 11 : Tc = 114.34 ^{o}F Th = 134.8 ^{o}F FCp = 0.0699

Match No. 17 Heat Load 10.1 MBtu/hr

Hot Stream No. 4 : Th = 308.0 ^{o}F Tc = 120.0 ^{o}F FCp = 0.0605

Cold Stream No. 11 : Tc = 80.0 ^{o}F Th = 114.34 ^{o}F FCp = 0.0699

Cold Utility No. C-18 : Heat Load 7.51 MBtu/hr

Hot Stream No. 1 : Th = 241.3 ^{o}F Tc = 120.0 ^{o}F FCp = 0.1228

Cold Utility No. C-19 : Heat Load 5.6 MBtu/hr

Hot Stream No. 3 : Th = 308.0 ^{o}F Tc = 120.0 ^{o}F FCp = 0.0297

Cold Utility No. C-20 : Heat Load 9.6 MBtu/hr

Hot Stream No. 5 : Th = 308.0 ^{o}F Tc = 120.0 ^{o}F FCp = 0.0571

Cold Utility No. C-21 : Heat Load 5.0 MBtu/hr

Hot Stream No. 6 : Th = 270.0 ^{o}F Tc = 120.0 ^{o}F FCp = 0.0333

Cold Utility No. C-22 : Heat Load 3.08 MBtu/hr

Hot Stream No. 7 : Th = 190.8 ^{o}F Tc = 176.0 ^{o}F FCp = 0.2059

Cold Utility No. C-23 : Heat Load 77.3 MBtu/hr

Hot Stream No. 8 : Th = 243.3 ^{o}F Tc = 187.0 ^{o}F FCp = 1.3723

Cold Utility No. C-24 : Heat Load 22.9 MBtu/hr

Hot Stream No. 9 : Th = 187.0 ^{o}F Tc = 100.0 ^{o}F FCp = 0.2632

The complete design for the below pinch is shown in Figure 5.9 (b). We see that the total amount of heat rejected to cold utility is Qc = 130.9 MBtu/hr, which is identical to the predicted minimum cooling requirement. The required number of heat exchangers and cold utilities are 9 and 7, respectively. Also, the temperature driving force at both ends of every exchanger is either 36 ^{o}F or greater, so the design is always feasible.

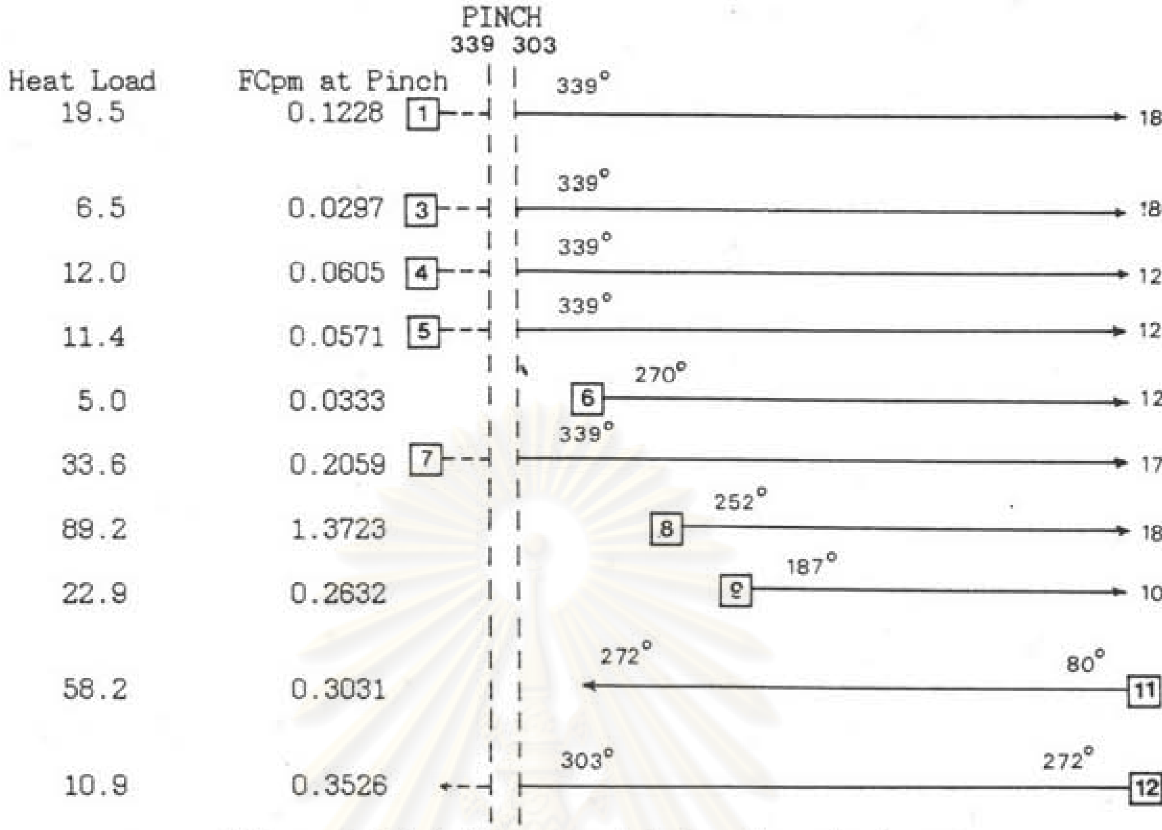


Figure 5.9 (a) Stream set below the pinch

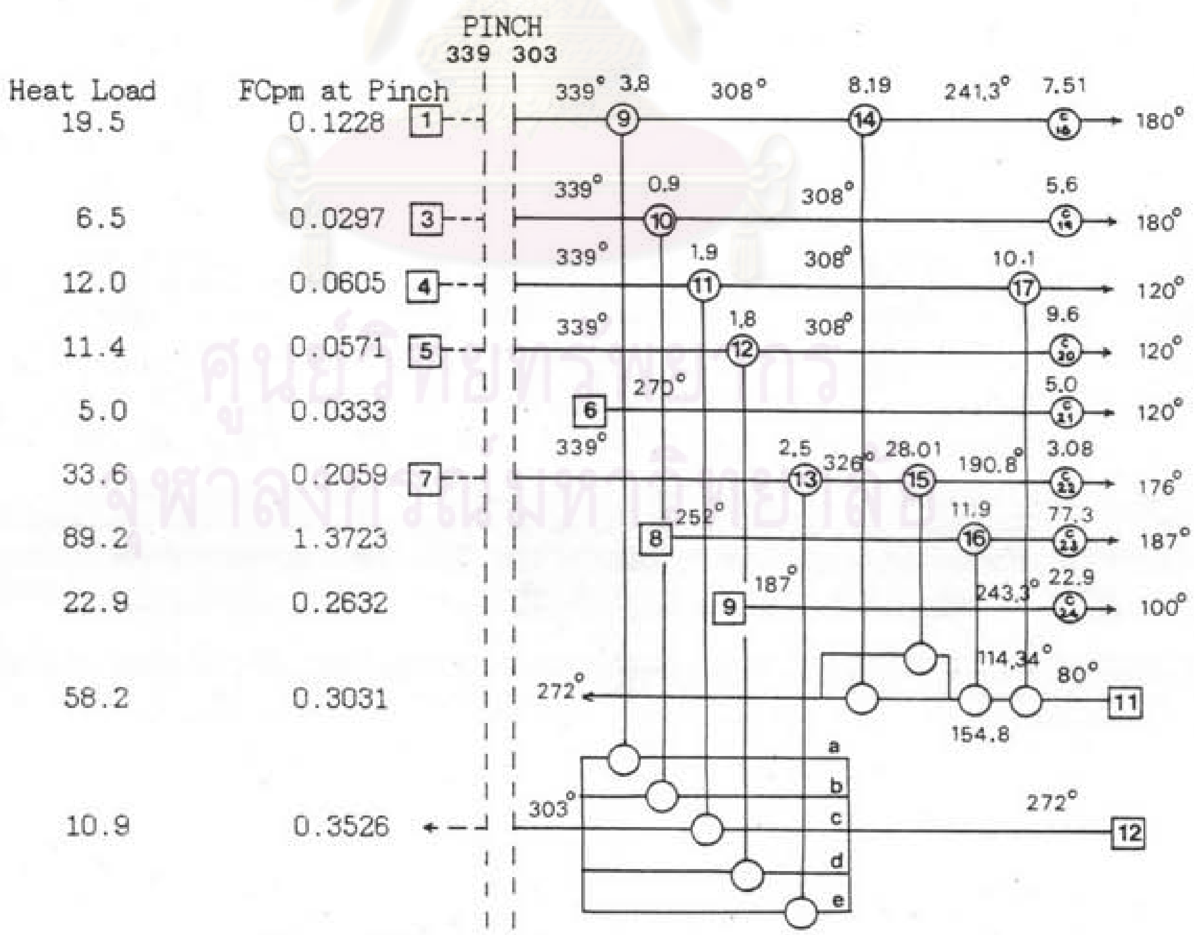


Figure 5.9 (b) Below-the-pinch design

3. Complete MER Design

The complete MER design is obtained by merging the two subnetwork "above" and "below" the pinch, with the result shown in Figure 5.10. The total heating load is 112.88 MBtu/hr, while the total cooling load is 130.9 MBtu/hr. The whole network consists of seventeen exchangers, one heater and seven coolers. In other words, twenty-five units of heat transfer equipment in all.

To compare the energy consumption, the original design required 149.40 MBtu/hr of hot utility, whereas 167.31 MBtu/hr of total cold utilities. Therefore, by our MER design, 72.9 MBtu/hr (or 23 %) of fuel saving is acheived, i.e., 36.5 MBtu/hr saved from hot utility, as well as, 36.4 MBtu/hr of cooling water saving is acheived.

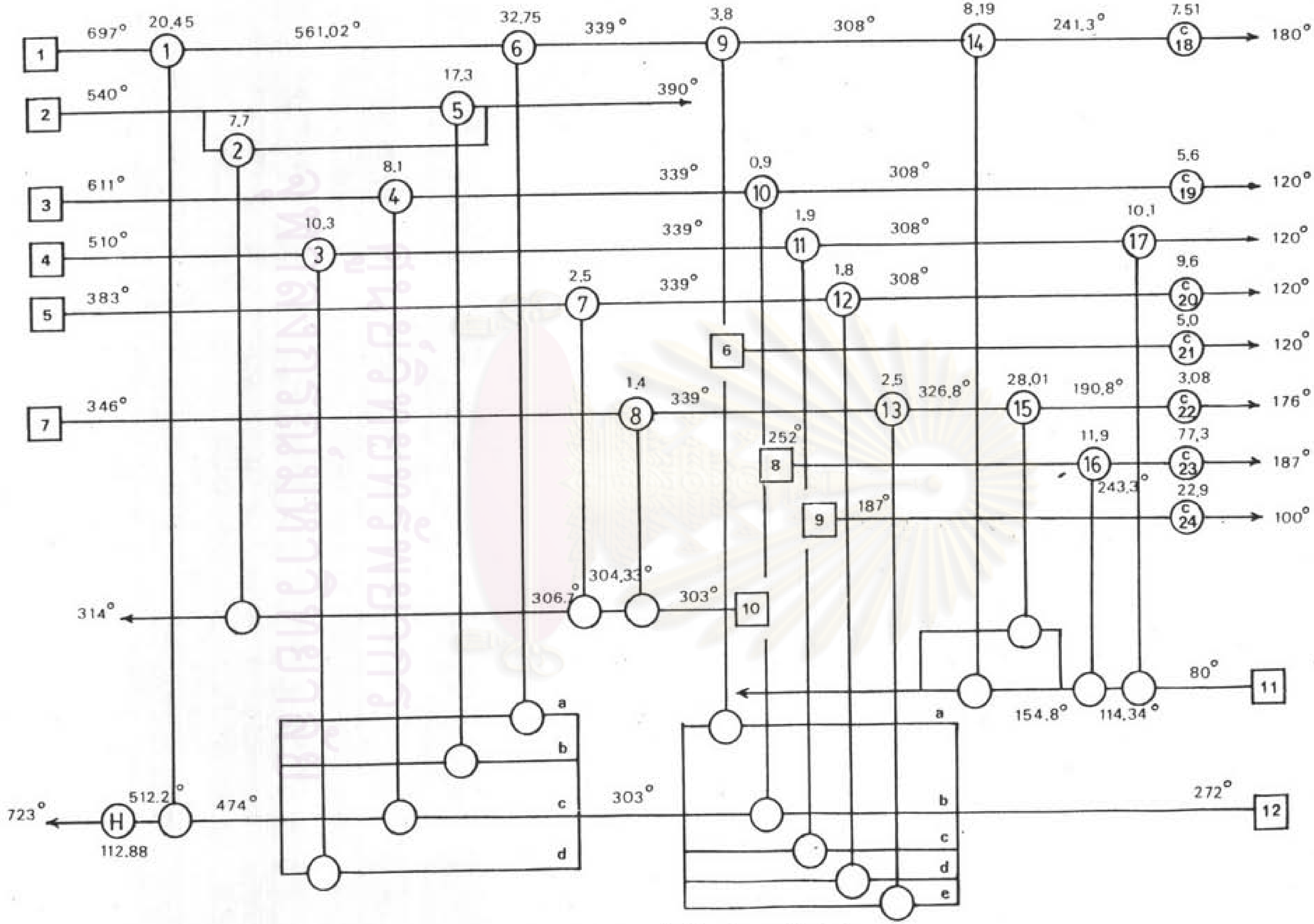


Figure 5.10 MER design and first evaluation

5.5.3 Design Evolution - Relaxation

It can be seen that, though highly energy-efficient, the MER design pays a heavy in terms of additional heat transfer area and number of units needed for modification. An obvious strategy to adopt in evolving the MER design is to increase somewhat the heat load of the fired heater, perhaps up to the maximum capacity of the existing equipment. The objective is to reduce the number of exchangers in our design by "relaxing" the utility requirement.

Hence, we have a procedure for reducing the number of heat exchangers (which we intuitively expect will substantially reduce the capital costs) at the expense of consuming slightly more energy (which will increase the operating costs). By adopting this strategy, the resulting alternative design is as shown in Figure 5.11. The interchanged loads and the stream temperatures are chosen so as to ensure maximum compatibility with the existing plant. The total heating load is 126.18 MBtu/hr, cooling load is 144.0 MBtu/hr (more in - more out compared to the MER design). Here twelve exchangers, one heater, and eight coolers are required. With this design evolution we can save 46.53 MBtu/hr (or 15 %) of energy saving is acheived, i.e., 23.2 MBtu/hr saved from hot utility and 23.3 MBtu/hr saved from cold utilities.

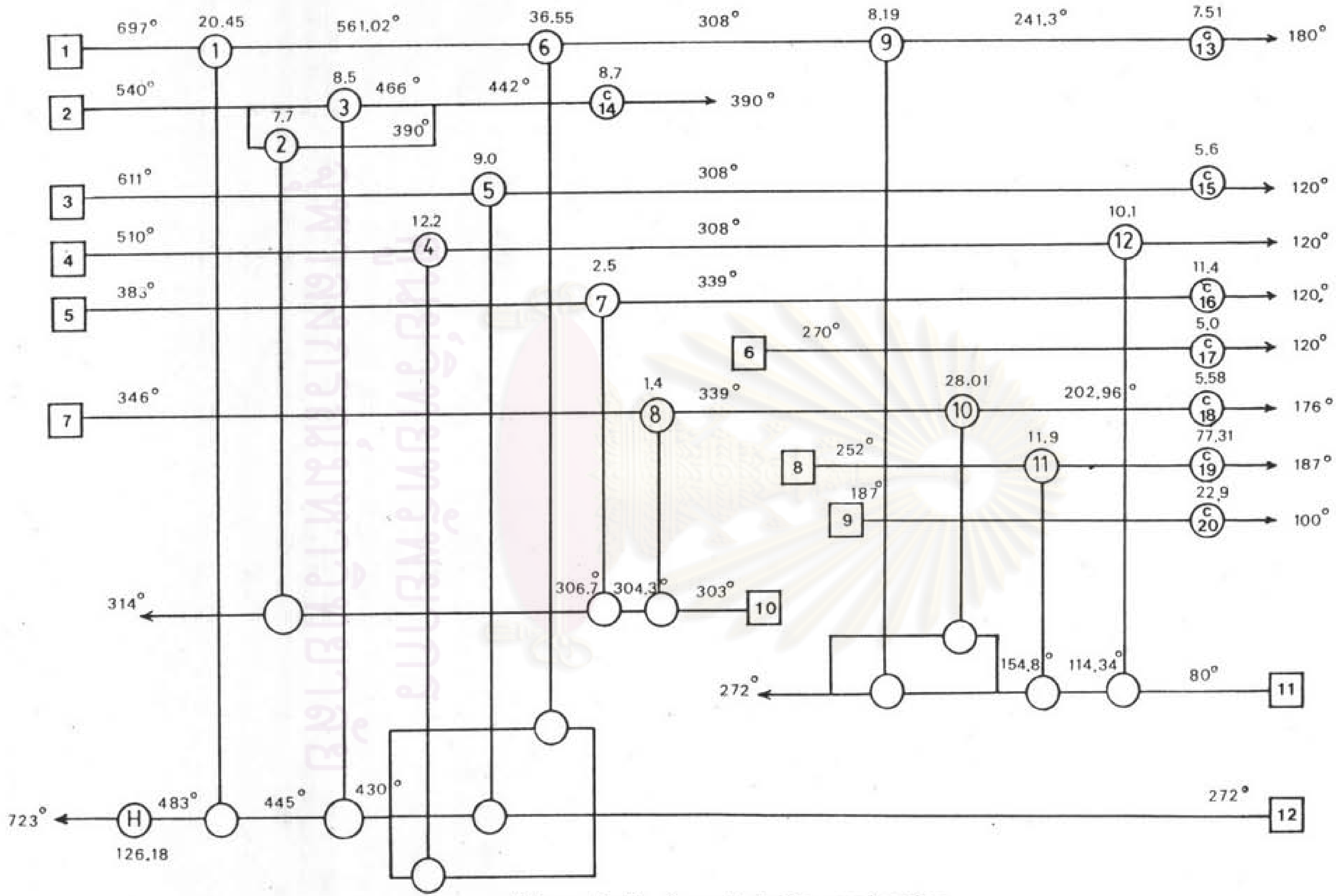


Figure 5.11 Second design evaluation

5.5.4 Summary of Energy Consumptions

By using the pinch design method, we have established a strategy for the effective improvement of process heat recovery. The total energy consumptions for the MER design and the relaxed design are compared with the base case in Table 5.6.

Table 5.6 Summary of energy consumptions

Scheme	Energy Consumption (MBtu/hr)			% Saving	
	Hot Utilties	Cold Utilties	Total	Fuel	Cooling Water
1. Base case	149.4	167.31	316.71	0	0
2. Relaxed design	126.18	144.0	270.18	15.54	13.39
3. MER design	112.88	130.99	243.87	24.44	21.71

5.6 Energy Utilization Diagram and Exergy Loss in Process Integration

In the previous section, the evaluation has been based essentially on the Pinch Design Method. The design "relaxation" offers a method to reduce the capital costs over a slight increase in operating costs. In this section, the exergy analysis method introduced in Chapter III will be applied to Plant #3 of the Bangchak Petroleum Industries (B.P.I.).

The exergy approach should give useful insight into the effectiveness of energy utilization by a process system, which is one of the keys to effective energy integration in system design and operation. The fundamental reasons for the higher thermal efficiency of the new designs will also be clarified with the aid of the Energy-Utilization-Diagram (EUD), and some practical suggestions made to further improve their thermal efficiency.

5.6.1 Comparative Analysis on the Energy Utilization Diagram

We have investigated the three alternative design of the heat exchanger network for B.P.I. (i.e., base case, MER design, and relaxed design) using the Pinch Design Method. Here their EUD's will be set up ,respectively, to make a comparative study of the exergy losses and also the accompanying degradation in energy quality.

1. Base Case

Figure 5.12 (a) shows the Temperature-Enthalpy (T-H) Diagram of the refinery base case. To construct a EUD for the same case, we use the same abscissa axis (H) as the T-H curve, but change the coordinate axis from the temperature (^{O}F) to the availability factor (A) defined as

$$A = 1 - (To/T)$$

where A = availability factor

To = reference (dead-state) temperature (^{o}R) ; ($537\ ^{o}R$ or $77\ ^{o}F$)

T = temperature (^{o}R)

The conversion of T to A are tabulated in Tables 5.7 (a) and 5.7 (b), respectively, for the hot and cold composite curves. To find the shaded area ,i.e., the exergy loss, we apply the Simpson´s rule of numerical integration. The average values of A and delta H for each integration interval are listed in columns 6 and 7 of Table 5.7. Then the integral areas below the hot and cold composite curves are readily calculated as shown in the last column of the table.

To obtain the shaded area of interest, we have to substract the total area below the cold composite curve from that below the hot composite curve. The shaded area is thus determined in Table 5.7.

Table 5.7 (a) Energy level and exergy analysis of the hot streams in the Base Case

NO.	TEMP (°F)	TEMP (°R)	A = 1-To/T	CUM H (MBtu/hr)	DEL H (MBtu/hr)	AVERAGE A	AREA (MBtu/hr)
1	100	560	0.0411	0.0000			
2	120	580	0.0741	5.2640	5.2640	0.0576	0.3032
3	176	636	0.1557	'29.6968	24.4328	0.1149	2.8073
4	180	640	0.1609	32.2656	2.5688	0.1583	0.4066
5	187	647	0.1700	37.7452	5.4796	0.1655	0.9067
6	252	712	0.2458	160.7187	122.9735	0.2079	25.5663
7	270	730	0.2644	170.0715	9.3528	0.2551	2.3858
8	346	806	0.3337	207.0303	36.9588	0.2991	11.0531
9	383	843	0.3630	217.4051	10.3748	0.3484	3.6142
10	390	850	0.3682	218.9969	1.5918	0.3656	0.5820
11	510	970	0.4464	266.2889	47.2920	0.4073	19.2627
12	540	1000	0.4630	276.3989	10.1100	0.4547	4.5970
13	611	1071	0.4986	288.4902	12.0913	0.4808	5.8135
14	697	1157	0.5359	300.5818	12.0916	0.5172	6.2542

Total area under the hot composite curve	=	83.5526
Overlapping area = 0.5461 x 149.40	=	81.5928
Total area under the hot composite curve		165.1454

Table 5.7 (b) Energy level and exergy analysis of the cold streams in the Base Case

NO.	TEMP (°F)	TEMP (°R)	A = 1-To/T	CUM H (MBtu/hr)	DEL H (MBtu/hr)	AVERAGE A	AREA (MBtu/hr)
1	80	540	0.0056	167.309			
2	272	732	0.2664	225.5042	58.1952	0.1360	7.9131
3	303	763	0.2962	240.1362	14.6320	0.2813	4.1159
4	314	774	0.3062	256.9277	16.7915	0.3012	5.0576
5	723	1183	0.5461	449.9757	193.0480	0.4261	82.2646

Total area under the cold composite curve = 99.3512

Shaded Area = Exergy loss = 165.1454 - 99.3512 = 65.7942
****

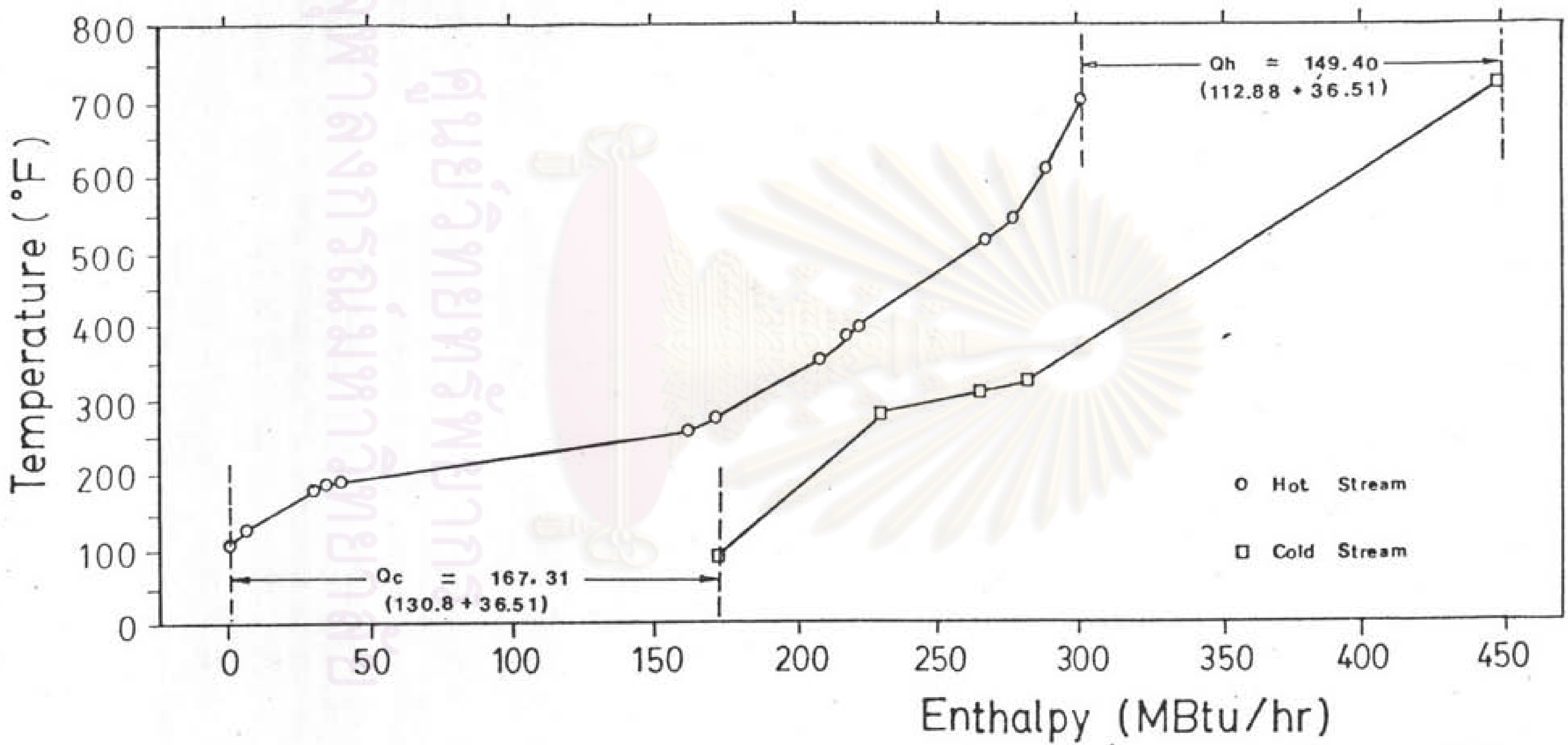


Figure 5.12 (a) Temperature - Enthalpy diagram (base case)

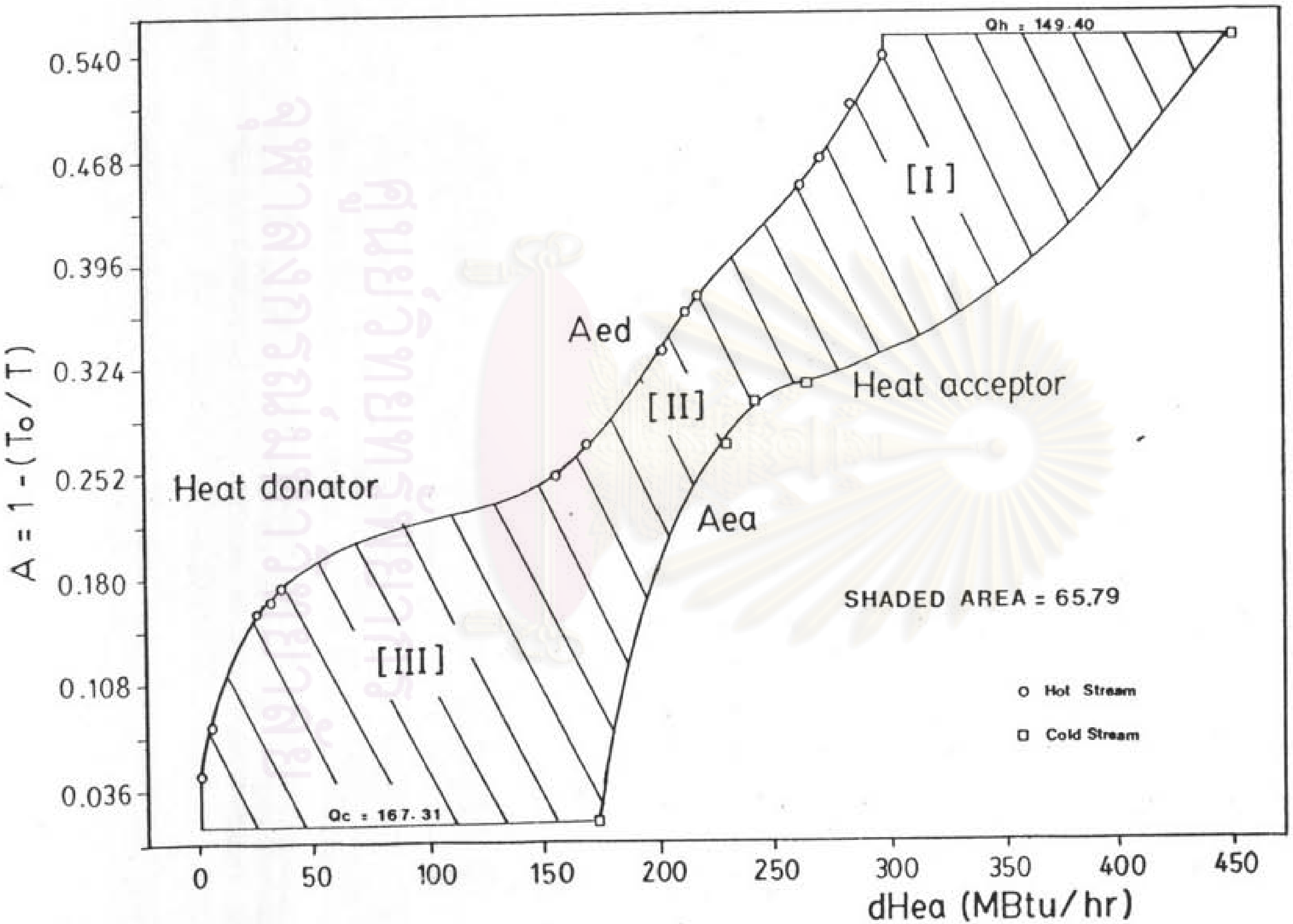


Figure 5.12 (b) EUD for base case

Figure 5.12 (b) shows the EUD of the refinery base case. The curve on the upper left hand side represents the energy level Aed for the heat donating composite curve versus the amount of released heat, dHed. Similarly, the curve on the lower right hand side represents the energy level Aea for the heat-accepting composite curves versus the absorbed amount of heat dHea. The shaded area between the curve Aed and Aea represents the amount of exergy loss in the whole heat-exchange operation. Three major regimes contribute to exergy loss. The first exergy loss regium (I) is located at a high energy level (A = 0.540). The second regime (II) is seen at the pinch point (A = 0.324). The last (III) is found at the low energy level (A = 0.216). The total exergy loss is 65.7942 MBtu/hr, as shown in Table 5.7. The total utility consumption on the abscissa is 316.71 MBtu/hr, i.e., 167.31 MBtu/hr of cold utility and 149.4 MBtu/hr of hot utility.

Fortunately, the heat network in the present refinery process covers a wide range of temperatures and gives various possibilities to improve the effectiveness of energy utilization. In order to reduce the exergy loss, it is important to systematically reorganize the network to minimize the temperature difference. The MER design obtained in the previous section will next be analyzed to elucidate the effectiveness of that design.

2. MER Design

Figures 5.13 (a) and 5.13 (b) show side by side the T-H diagram and the EUD of the above MER design, respectively. The method of EUD construction involves exactly the same procedure as in the base case design. Anyway, the basic data and calculation results of the hot and cold composite curves are provided in Tables 5.8 (a) and (b).

By comparing the EUD of the MER design (Figure 5.13,b) with that of the base case (Figure 5.12,b), we see that the total utility consumption readed from the abscissa is reduced from 316.71 MBtu/hr to 243.78 MBtu/hr, equivalent to 23 % reduction (as has been determined by the Pinch method). This improvement in energy efficiency is a result of the decrease in the exergy loss. As seen in Figure 5.13 (b), there is a significant decrease in irreversibility, mainly because of the more effective stream matching. In addition, since hot of condensete is recovered, the medium-and low-grade thermal energy is also recovered.

In summary, the shaded areas of regimes (I), (II), and (III) have extreamly been reduced, especially in the case of regime (II) (around the pinch point). More specifically, the exergy loss accompanied by the whole heat exchange operation could be lowered from 65.79 MBtu/hrto 45.3561 MBtu/hr, or 35.62 %. This reduction is quite remarkable.

Table 5.8 (a) Energy level and exergy analysis of the hot streams in the MER design

NO.	TEMP (°F)	TEMP (°R)	A = 1-To/T	CUM H (MBtu/hr)	DEL H (MBtu/hr)	AVERAGE A	AREA (MBtu/hr)
1	100	560	0.0411	0.0000			
2	120	580	0.0741	5.2640	5.2640	0.0576	0.3032
3	176	636	0.1557	29.6968	24.4328	0.1149	2.8073
4	180	640	0.1609	32.2656	2.5688	0.1583	0.4066
5	187	647	0.1700	37.7452	5.4796	0.1655	0.9067
6	252	712	0.2458	160.7187	122.9735	0.2079	25.5663
7	270	730	0.2644	170.0715	9.3528	0.2551	2.3858
8	346	806	0.3337	207.0303	36.9588	0.2991	11.0531
9	383	843	0.3630	217.4051	10.3748	0.3484	3.6142
10	390	850	0.3682	218.9969	1.5918	0.3656	0.5820
11	510	970	0.4464	266.2889	47.2920	0.4073	19.2627
12	540	1000	0.4630	276.3989	10.1100	0.4547	4.5970
13	611	1071	0.4986	288.4902	12.0913	0.4808	5.8135
14	697	1157	0.5359	300.5818	12.0916	0.5172	6.2542

Total area under the hot composite curve = 83.5526

Overlapping area = 0.5461 x 112.90 = 61.6547

Total area under the hot composite curve 145.2073

Table 5.8 (b) Energy level and exergy analysis of the cold streams in the MER design

NO.	TEMP (°F)	TEMP (°R)	A = 1-To/T	CUM H (MBtu/hr)	DEL H (MBtu/hr)	AVERAGE A	AREA (MBtu/hr)
1	80	540	0.0056	130.799			
2	272	732	0.2664	188.9942	58.1952	0.1360	7.9131
3	303	763	0.2962	203.6262	14.6320	0.2813	4.1159
4	314	774	0.3062	220.4177	16.7915	0.3012	5.0576
5	723	1183	0.5461	413.4657	193.0480	0.4261	82.2646

Total area under the cold composite curve = 99.3512

Shaded Area = Exergy loss = 145.2073 - 99.3512 = 45.8561

****

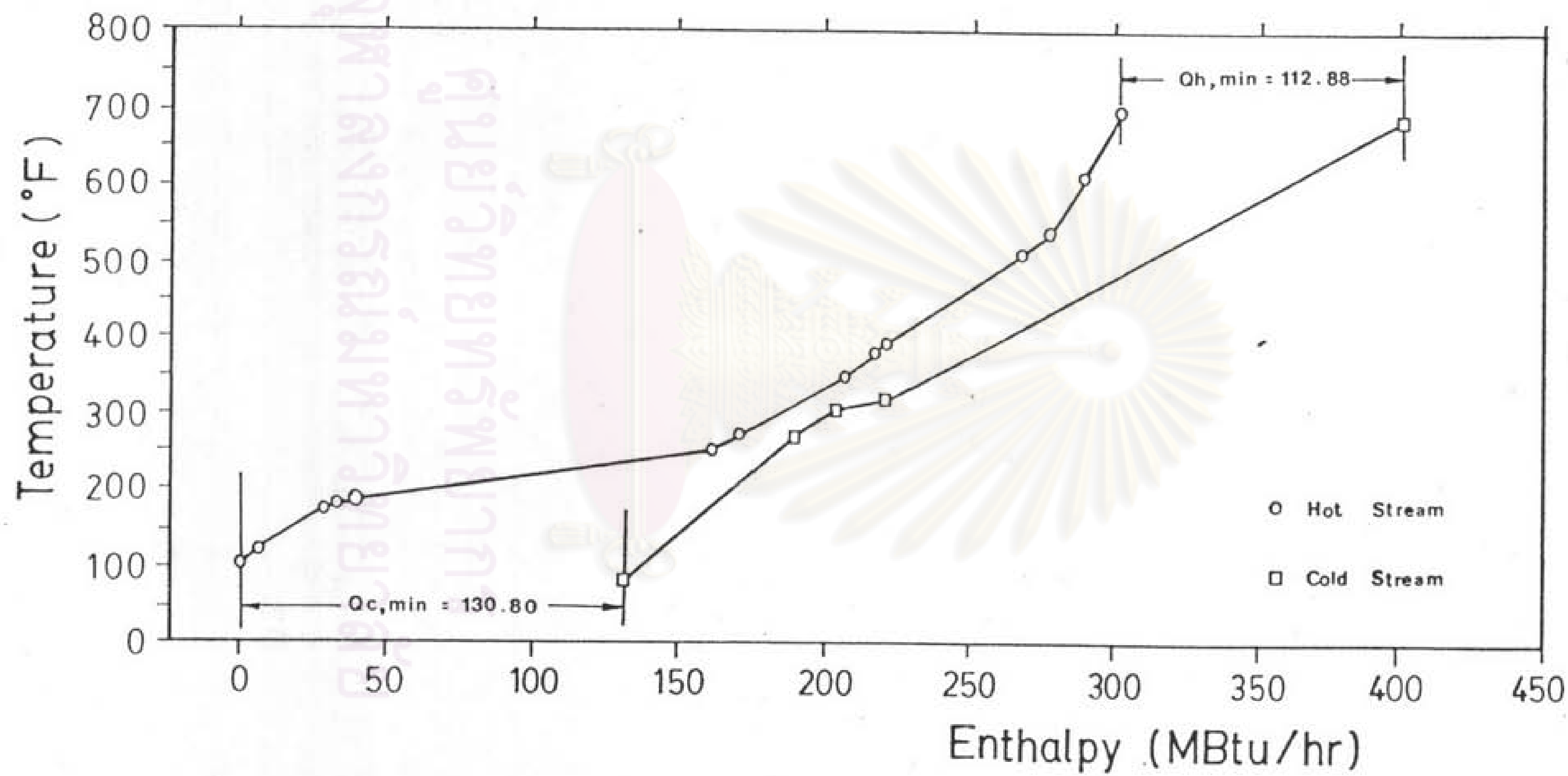


Figure 5.13 (a) Temperature - Enthalpy diagram (MER design)

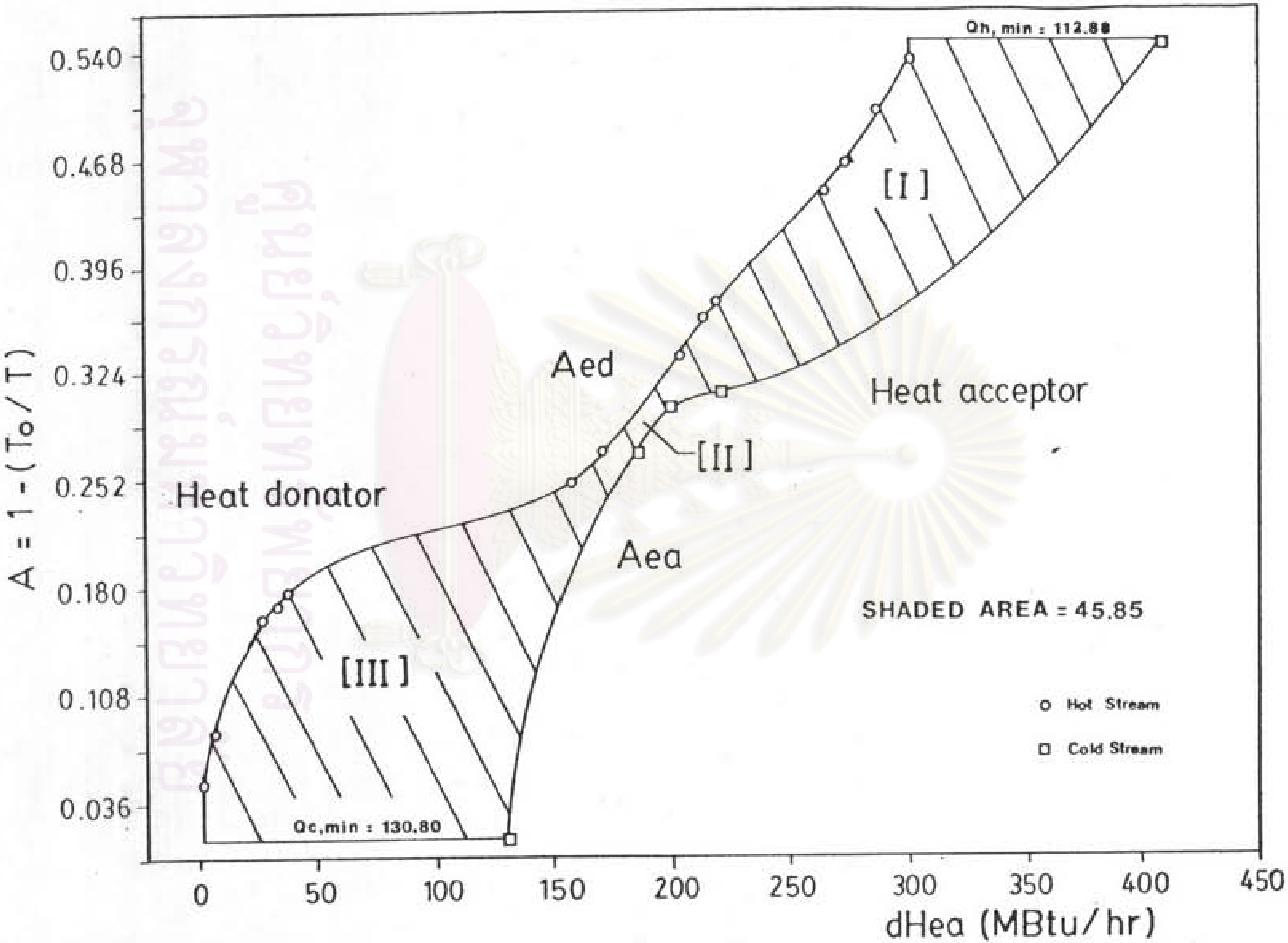


Figure 5.13 (b) EUD for MER design

3. "Relaxed" Design

Similar to case of the MER design, Figures 5.14 (a) and (b) represent the T-H diagram and the EUD of the relaxed design case. The basic data and calculation results of both hot and cold composite curves are provided ,respectively, in Tables 5.9 (a) and (b).

By comparing the EUD of the relaxed design case (Figure 5.14,b) with the MER design case (Figure 5.12,b), the total utility requirement read from the abscissa is reduced from 316.71 MByu/hr to 270.18 MBtu/hr, equivalent to about 15 % compared to the base case.

According to the shaded area in the diagram, the exergy loss in the relaxed design system is 53.1193 MBtu/hr. This means a 19.23 % reduction from the base case design. However, this corresponds to a slightly higher exergy loss as well as higher utility consumption compared to the MER design. As already discussed in the previous section, the MER design pays a penalty in terms of a higher number of extra heat exchangers required. Obviously, further evaluation based on economic analysis is necessary to find out the best alternative design. The matter will be considerd in the next Chapter.

Table 5.9 (a) Energy level and exergy analysis of the hot streams in the relaxed design

NO.	TEMP (°F)	TEMP (°R)	A = 1-To/T	CUM H (MBtu/hr)	DEL H (MBtu/hr)	AVERAGE A	AREA (MBtu/hr)
1	100	560	0.0411	0.0000			
2	120	580	0.0741	5.2640	5.2640	0.0576	0.3032
3	176	636	0.1557	29.6968	24.4328	0.1149	2.8073
4	180	640	0.1609	32.2656	2.5688	0.1583	0.4066
5	187	647	0.1700	37.7452	5.4796	0.1655	0.9067
6	252	712	0.2458	160.7187	122.9735	0.2079	25.5663
7	270	730	0.2644	170.0715	9.3528	0.2551	2.3858
8	346	806	0.3337	207.0303	36.9588	0.2991	11.0531
9	383	843	0.3630	217.4051	10.3748	0.3484	3.6142
10	390	850	0.3682	218.9969	1.5918	0.3656	0.5820
11	510	970	0.4464	266.2889	47.2920	0.4073	19.2627
12	540	1000	0.4630	276.3989	10.1100	0.4547	4.5970
13	611	1071	0.4986	288.4902	12.0913	0.4808	5.8135
14	697	1157	0.5359	300.5818	12.0916	0.5172	6.2542

Total area under the hot composite curve = 83.5526

Overlapping area = 0.5461 x 126.20 = 68.9178

Total area under the hot composite curve 152.4704

Table 5.9 (b) Energy level and exergy analysis of the cold streams in the relaxed design

NO.	TEMP (°F)	TEMP (°R)	A = 1-To/T	CUM H (MBtu/hr)	DEL H (MBtu/hr)	AVERAGE A	AREA (MBtu/hr)
1	80	540	0.0056	144			
2	272	732	0.2664	202.1952	58.1952	0.1360	7.9131
3	303	763	0.2962	216.8272	14.6320	0.2813	4.1159
4	314	774	0.3062	233.6187	16.7915	0.3012	5.0576
5	723	1183	0.5461	426.6670	193.0483	0.4261	82.2647

Total area under the cold composite curve = 99.3513

Shaded Area = Exergy loss = 152.4704 - 99.3513 = 53.1191

****

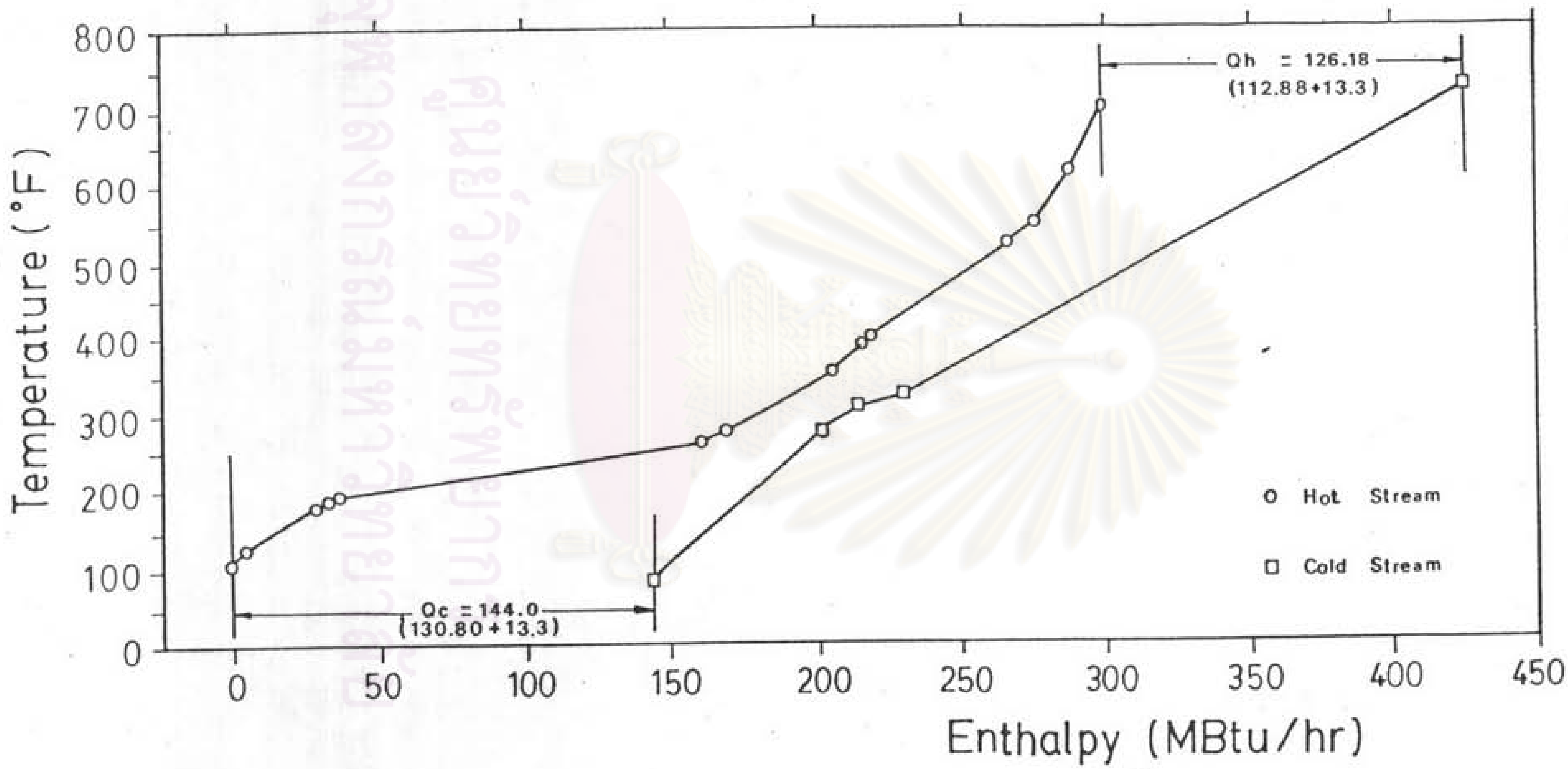


Figure 5.14 (a) Temperature - Enthalpy diagram (relaxed design)

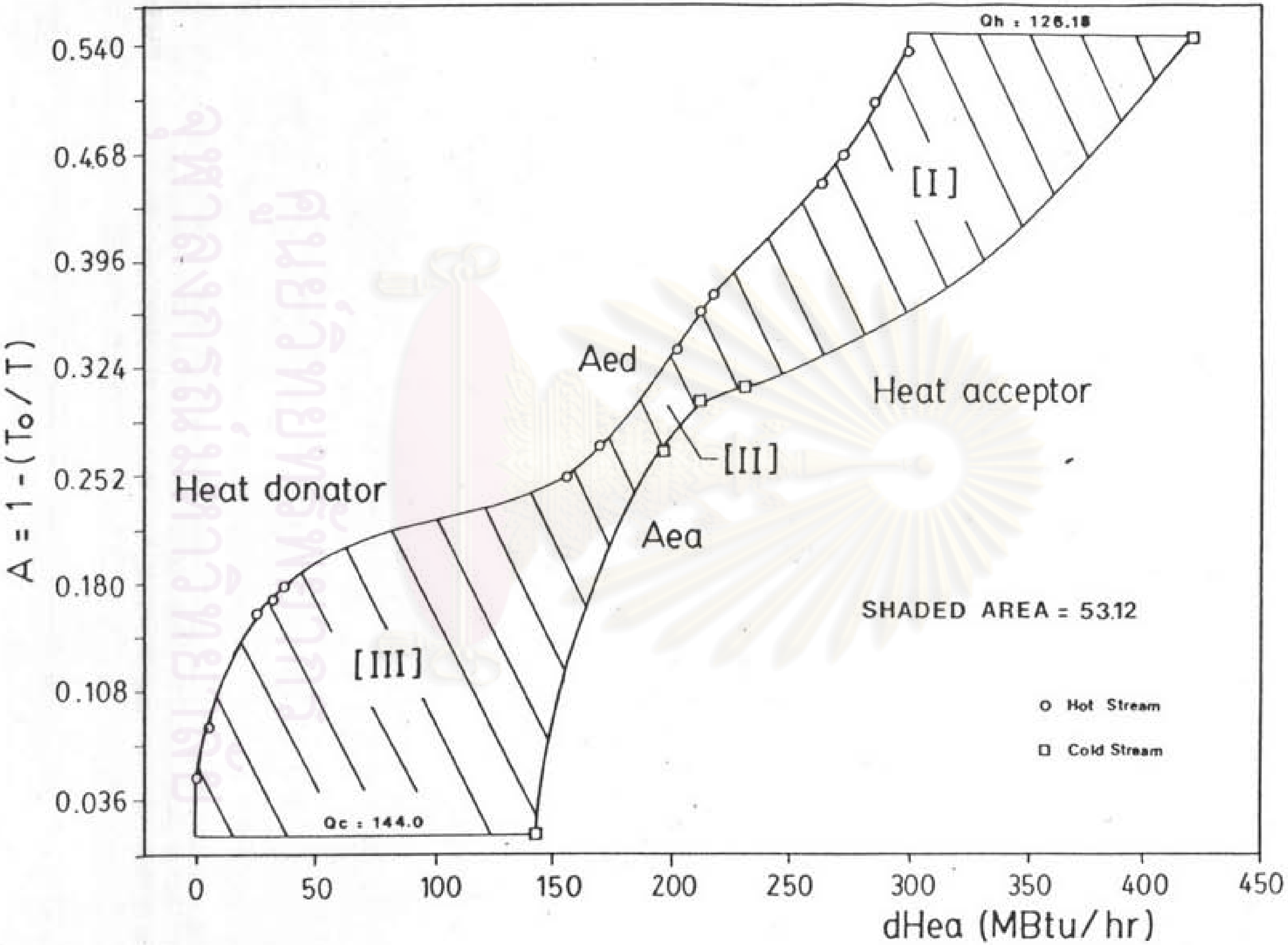


Figure 5.14 (b) EUD for relaxed design

5.6.2 Summary of Exergy Losses

The EUD's of all the three design alternatives have been constructed. Next a comparative analysis of the exergy loss expected in each design is illustratred in Table 5.10.

Table 5.10 Summary of exergy losses

Scheme	Exergy Loss (MBtu/hr)	% Above Minimum
1. Base Case	63.79	39.12
2. Relaxed Design	53.12	15.85
3. MER Design	45.85	0.0

The exergy loss encountered in the base case is significantly higher than the other two design alternatives. It is clearly reflected in higher utility requirements and lower energy efficiency of the base case. Thus it reconfirms the validity and effectiveness of the Pinch Design Method.

5.7 Energy and Exergy Analysis of the Modified Plant

As mentioned earlier in Section 5.1, Plant No.3 of Bangchak Petroleum Industries was the one being operated and it was modified in 1988 to upgrade its daily rated capacity. The work was carried out by the consortium of Toyo Engineering Corporation, Italian-Thai Development Coporation, and Toyo-Thai Coporation.

Before modification of the plant, our analysis has shown that it has rather low energy efficiency and a large amount of exergy loss in the heat exchanger network has been identified. In this section, an evaluation on the utility consumption of the modified plant will be carried out in the same manner as has been done with the original plant.

5.7.1 Base Case Design of Modified Plant

The modified plant has been designed to process 65,000 barrels of crude oil per day. At the topping unit, the feed crude is heated upto the boiling points and fractionated to produce the desired products such as naphtha, kerosene, diesel oil, gas oil and fuel oil.

In the original plant configuration energy to heat up the feed crude is given by a fired (pipestill) heater and a series of heat exchangers to recover heat from hot fluids leaving the topping column. Energy conservation in the restructuring project has naturally been focused on the minimization of fuel consumption in the fired heater. For this purpose, additional heat exchangers have been installed in the feed train to recover even more heat from the hot effluents from the topper to the extent economically justified.

5.7.2 Stream Data and Utility Requirements of the Modified Plant

A simplified process flow diagram of the modified plant is shown in Figures 5.15 (a),(b),(c). Figure 5.15 (d) is the grid diagram of the new heat exchanger network showing the stream temperatures, heat load, and pairings of the process streams. The stream data is listed in Table 5.11.

The available design data gives the following utility consumption of the modified plant : hot utility requirement 125.99 MBtu/hr, and cold utility requirement 97.54 MBtu/hr.

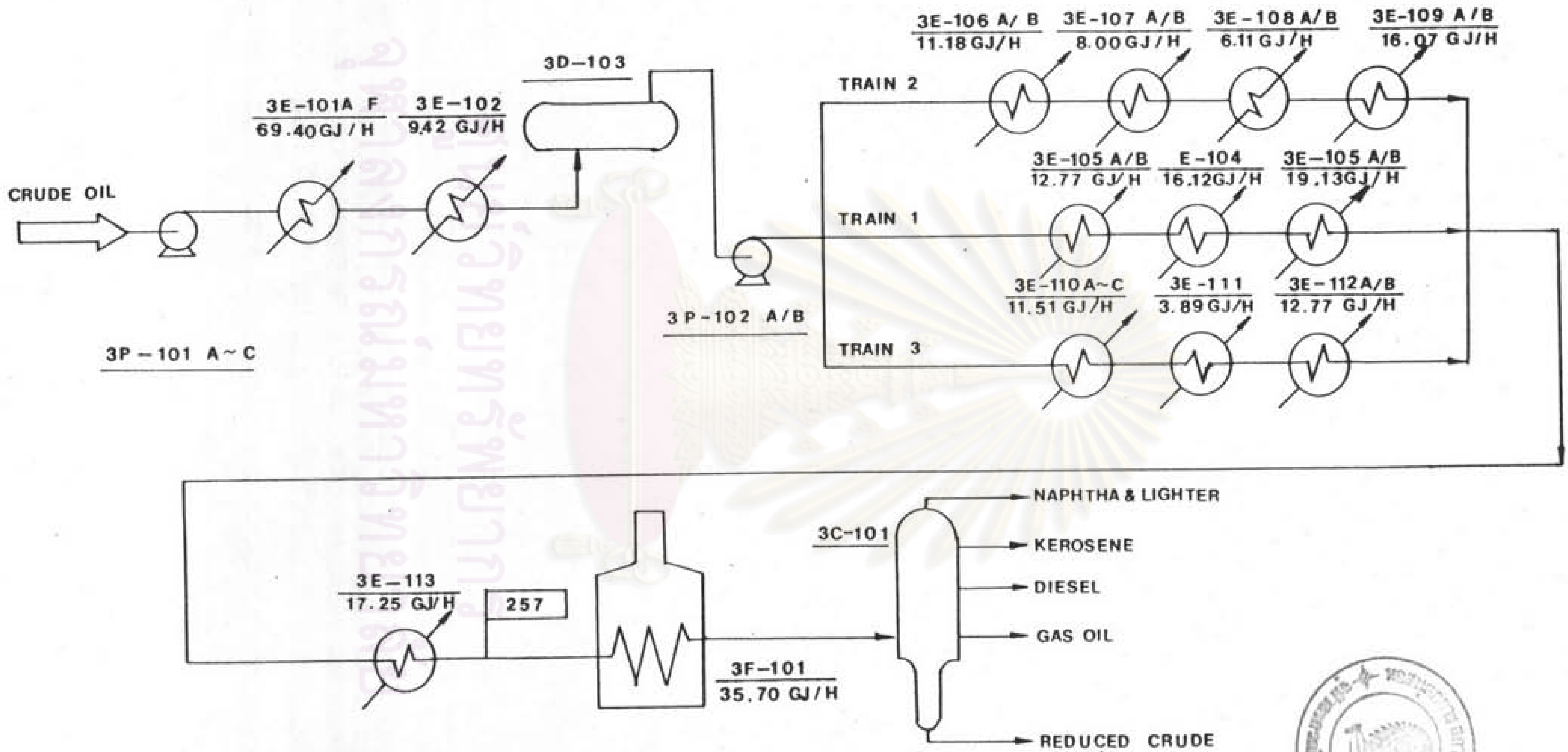


Figure 5.15 (a) Simplified process flow diagram (subsystem 1)

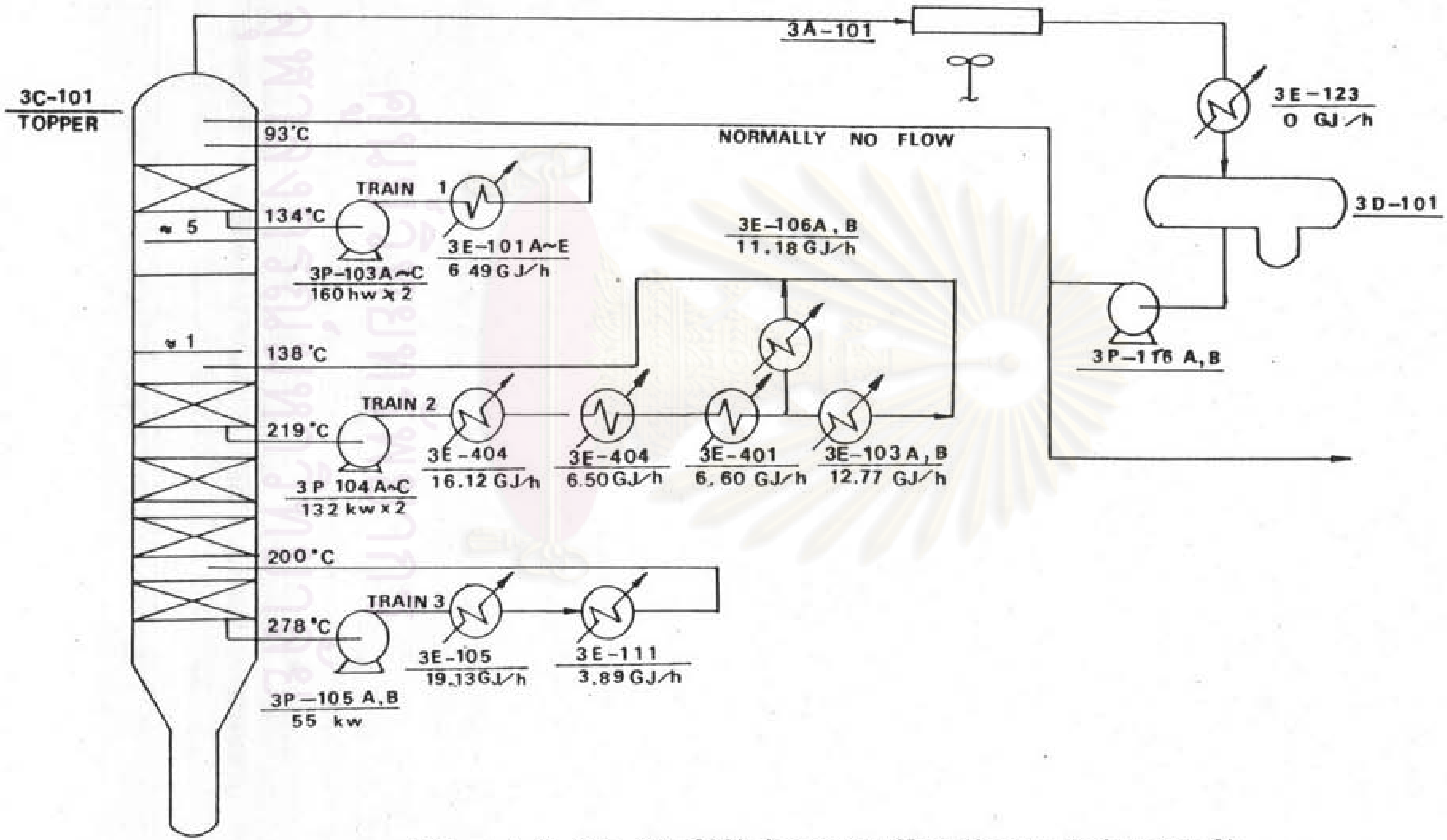


Figure 5.15 (b) Simplified process flow diagram (subsystem 2)

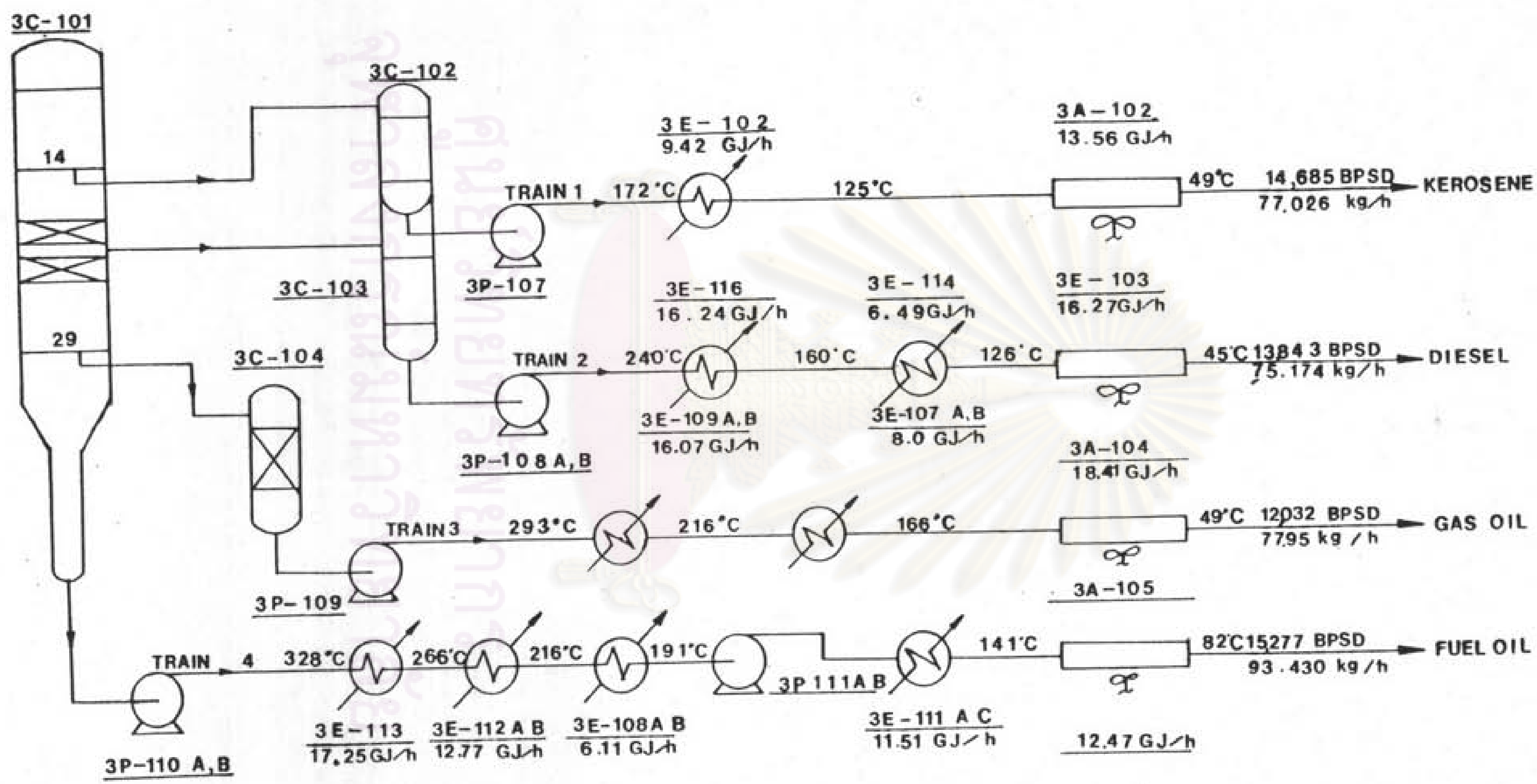


Figure 5.15 (c) Simplified process flow diagram (subsystem 3)

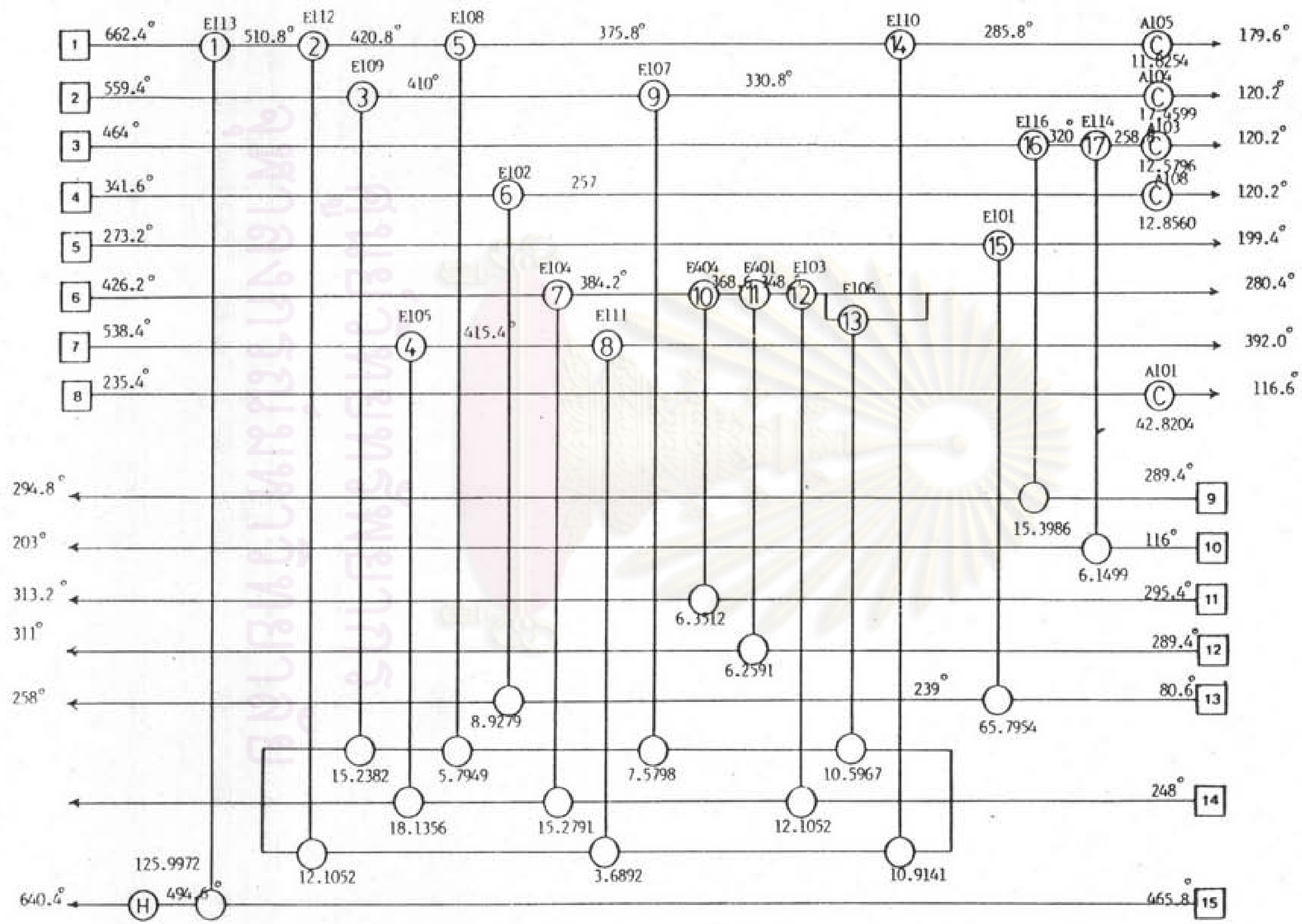


Figure 5.15 (d) Grid diagram (subsystem 1, 2, 3)

Table 5.11 Stream data of the modified plant

A) Hot Stream

No.	Stream	Temp. (°F)	Ht Exgr NO.	Heat load (MBtu/hr)	CUM H (MBtu/hr)	FCpm (dH/dT)	FCpm (Total)
1	Reduced crude	662.4	E-113	16.3507	56.9903		
		510.8	E-112	12.1052	40.6396	0.1079	
		420.8	E-108	5.7949	28.5344	0.1345	0.1180
		375.8	E-110	10.9141	22.7395	0.1288	
		285.8	A-105	11.8254	11.8254	0.1213	
		179.6			0.0000	0.1113	
2	Gas oil	559.4	E-109	15.2382	40.2779		
		410.0	E-107	7.5798	25.0397	0.1020	0.0917
		330.8	A-104	17.4599	17.4599	0.0957	
		120.2			0.0000	0.0829	
3	Diesel oil	464.0	E-116	15.3986	34.1280		
		320.0	E-114	6.1499	18.7294	0.1069	0.0993
		258.8	A-103	12.5796	12.5796	0.1005	
		120.2			0.0000	0.0908	
4	Kerosene	341.6	E-102	8.9279	21.7839		
		257.0	A-102	12.8560	12.8560	0.1055	
		120.2			0.0000	0.0940	0.0984
5	Kerosene Circ.	273.2	E-101	65.7954	65.7954		
		199.4			0.0000	0.8915	
6	Diesel oil Circ.	426.2	E-104	15.2791	50.5913		
		384.8	E-404	6.3512	35.3122	0.3691	
		368.6	E-401	6.2591	28.9610	0.3921	0.3470
		348.8	E-103	22.7019	22.7019	0.3161	
		280.4	+E-106		0.0000	0.3319	
7	Gas oil Circ.	532.4	E-105	18.1356	21.8249		
		415.4	E-111	3.6892	3.6892	0.1550	0.1554
		392.0			0.0000	0.1577	
8	Gas/LN to A-101	235.4	A-101	42.8204	42.8204		
		116.6			0.0000	0.3604	

Table 5.11 Stream data (continued)

B) <u>Cold Stream</u>

No.	Stream	Temp. (°F)	Ht Exgr NO.	Heat load (MBtu/hr)	CUM H (MBtu/hr)	FCpm (dH/dT)	FCpm (Total)
9	C-105 feed	289.4			0.0000		
		294.8	E-116	15.3986	15.3986	2.8516	
10	C-105 reboiler	116.6			0.0000		
		203.0	E-114	6.1499	6.1499	0.0712	
11	Debutane reboil.	298.4			0.0000		
		313.2	E-404	6.3512	6.3512	0.4291	
12	Deetane reboil.	289.4			0.0000		
		311.0	E-401	6.2591	6.2591	0.2898	
13	Desalter feed	80.6			0.0000		
		239.0	E-101	65.7954	65.7954	0.4154	0.4193
		258.8	E-102	8.9279	74.7233	0.4509	
14	E-113 feed	248.0			0.0000		
		465.8	***	111.4382	111.4382	0.5117	
15	Crude tower feed	465.8			0.0000		
		494.6	E-113	16.3507	16.3507	0.5677	0.8153
		640.4	F-101	125.9972	142.3479	0.8642	

5.7.3 Energy Targets by the Pinch Design Method

The minimum energy targets of hot and cold utility requirements are readily determined with the aid of the present Energy Targetting Software. Note that the smallest value of $\triangle$ Tmin in the modified plant (Figure 5.15,d) is 18 ^{O}F at the cold end of match 6. Therefore, the global $\triangle$ Tmin of 27 ^{O}F is selected as energy targeting calculation.

A> THESIS

```
INPUT THE FOLLOWING DATA

NO. OF HOT STREAMS =
8

NO. OF COLD STREAMS =
7

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) =
662.4
 TARGET TEMPERATURE (oF) =
179.6
 HEAT CAPACITY FLOWRATE (BTU/hr-F)
0.1180

 HOT STREAM No. 2
 SUPPLY TEMPERATURE (oF) =
559.4
 TARGET TEMPERATURE (oF) =
120.2
 HEAT CAPACITY FLOWRATE (BTU/hr-F)
0.0917

 HOT STREAM No. 3
 SUPPLY TEMPERATURE (oF) =
464.0
 TARGET TEMPERATURE (oF) =
120.2
 HEAT CAPACITY FLOWRATE (BTU/hr-F)
0.0993
```

HOT STREAM No. 4
SUPPLY TEMPERATURE (oF) =
341.6
TARGET TEMPERATURE (oF) =
120.2
HEAT CAPACITY FLOWRATE (BTU/hr-F)
0.0984

HOT STREAM No. 5
SUPPLY TEMPERATURE (oF) =
273.2
TARGET TEMPERATURE (oF) =
199.4
HEAT CAPACITY FLOWRATE (BTU/hr-F)
0.8915

HOT STREAM No. 6
SUPPLY TEMPERATURE (oF) =
426.2
TARGET TEMPERATURE (oF) =
280.4
HEAT CAPACITY FLOWRATE (BTU/hr-F)
0.3470

HOT STREAM No. 7
SUPPLY TEMPERATURE (oF) =
532.4
TARGET TEMPERATURE (oF) =
392.0
HEAT CAPACITY FLOWRATE (BTU/hr-F)
0.1554

HOT STREAM No. 8
SUPPLY TEMPERATURE (oF) =
234.4
TARGET TEMPERATURE (oF) =
116.6
HEAT CAPACITY FLOWRATE (BTU/hr-F)
0.3604

COLD-STREAM DATA :

COLD STREAM No. 1
SUPPLY TEMPERATURE (oF) =
289.4
TARGET TEMPERATURE (oF) =
294.8
HEAT CAPACITY FLOWRATE (BTU/hr-F) =
2.8516

COLD STREAM No. 2
SUPPLY TEMPERATURE (oF) =
116.6
TARGET TEMPERATURE (oF) =
203.0
HEAT CAPACITY FLOWRATE (BTU/hr-F) =
0.0712

COLD STREAM No. 3
SUPPLY TEMPERATURE (oF) =
298.4
TARGET TEMPERATURE (oF) =
313.2
HEAT CAPACITY FLOWRATE (BTU/hr-F) =
0.4291

COLD STREAM No. 4
SUPPLY TEMPERATURE (oF) =
289.4
TARGET TEMPERATURE (oF) =
311.0
HEAT CAPACITY FLOWRATE (BTU/hr-F) =
0.2898

COLD STREAM No. 5
SUPPLY TEMPERATURE (oF) =
80.6
TARGET TEMPERATURE (oF) =
258.8
HEAT CAPACITY FLOWRATE (BTU/hr-F) =
0.4193

COLD STREAM No. 6
SUPPLY TEMPERATURE (oF) =
248.0
TARGET TEMPERATURE (oF) =
465.8
HEAT CAPACITY FLOWRATE (BTU/hr-F) =
0.5117

COLD STREAM No. 7
SUPPLY TEMPERATURE (oF) =
465.8
TARGET TEMPERATURE (oF) =
640.4
HEAT CAPACITY FLOWRATE (BTU/hr-F) =
0.8153

MINIMUM TEMPERATURE DIFFERENCE (oF) =
27.0

HOT-STREAM DATA

HOT STREAM No.	SUPPLY TEMP.	TARGET TEMP.	HEAT CAPACITY FLOWRATE
1	662.40	179.60	.12
2	559.40	120.20	.09
3	464.00	120.20	.10
4	341.60	120.20	.10
5	273.20	199.40	.89
6	426.20	280.40	.35
7	532.40	392.00	.16
8	234.40	116.60	.36

COLD-STREAM DATA

COLD STREAM No.	SUPPLY TEMP.	TARGET TEMP.	HEAT CAPACITY FLOWRATE
1	289.40	294.80	2.85
2	116.60	203.00	.07
3	298.40	313.20	.43
4	289.40	311.00	.29
5	80.60	258.80	.42
6	248.00	465.80	.51
7	465.80	640.40	.82

MINIMUM TEMPERATURE DIFFERENCE = 27.00

RESULT

INTERVAL No.	HOT – STREAM TEMPERATURE	DEFICIT	CUMULATIVE OUTPUT	HEAT FLOW
	667.40			120.46
1		4.08	-4.08	
	662.40			116.38
2		71.82	-75.90	
	559.40			44.56
3		16.35	-92.25	
	532.40			28.21
4		17.83	-110.08	
	492.80			10.38
5		4.22	-114.30	
	464.00			6.16
6		1.79	-116.09	
	426.20			4.37
7		-10.25	-105.84	
	392.00			14.62
8		-7.27	-98.57	
	341.60			21.89
9		-.34	-98.23	
	340.20			22.23
10		.41	-98.64	
	338.00			21.82
11		6.00	-104.64	
	325.40			15.82
12		.17	-104.81	
	321.80			15.65
13		15.65	-120.46	
	316.40			.00
14		-7.43	-113.03	
	285.80			7.43
15		.95	-113.99	
	280.40			6.47
16		2.83	-116.81	
	275.00			3.65
17		.02	-116.83	
	273.20			3.62
18		-34.13	-82.71	
	234.40			37.75
19		-5.46	-77.25	
	230.00			43.21
20		-35.77	-41.48	
	199.40			78.97
21		-5.49	-35.99	
	179.60			84.46
22		-5.73	-30.26	
	143.60			90.20
23		-5.39	-24.87	
	120.20			95.59
24		.21	-25.08	
	116.60			95.38
25		3.77	-28.85	
	107.60			91.61

```
MINIMUM TEMPERATURE DIFFERENCE              =   27.00    oF
PINCH IS LOCATED AT COLD TEMPERATURE        =  289.40    oF
PINCH IS LOCATED AT HOT TEMPERATURE         =  316.40    oF

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

MINIMUM HOT UTILITY REQUIREMENT             =  120.46    BTU/hr
MINIMUM COLD UTILITY REQUIREMENET           =   91.61    BTU/hr

Stop - Program terminated.
```

5.7.4 Temperature-Enthalpy Diagram

To construct the T-H diagram of the modified plant, we determine the composite curves for the hot and cold streams as performed in section 5.5.1. The T-H diagram of the heat exchanger network for the modified plant is shown in Figure 5.16. Tables 5.12 (a) and (b) show the aggregate of all applicable hot and cold streams for constructing composite curves.

Table 5.12 (a) Temperature-Enthalpy diagram (after modified plant : hot streams)

No.	T (°F)	△ T	Q	CUM Q
1	116.6		0.00	0.00
2	120.2	3.6	1.30	1.30
3	179.6	59.4	38.60	39.90
4	199.4	19.8	15.20	55.10
5	235.4	36.0	59.73	114.83
6	273.2	37.8	49.10	163.93
7	280.4	7.2	2.93	166.86
8	341.6	61.2	46.17	213.03
9	392.0	50.4	33.06	246.10
10	426.2	34.2	27.75	273.85
11	464.0	37.8	17.55	291.40
12	532.4	68.4	24.97	316.37
13	559.4	27.0	5.66	322.04
14	662.4	103.0	12.15	334.19

Table 5.12 (b) Temperature-Enthalpy diagram
(after modified plant : cold streams)

No.	T (°F)	△ T	Q	CUM Q
1	80.6		91.61	91.61
2	116.6	36.0	15.09	106.70
3	203.0	86.4	42.38	149.08
4	248.0	45.0	18.87	167.95
5	258.8	10.8	10.05	178.01
6	289.4	30.6	15.66	193.67
7	294.8	5.4	19.73	213.39
8	298.4	3.6	2.89	216.28
9	311.0	12.6	15.51	231.78
10	313.2	2.2	2.07	233.85
11	465.8	152.6	78.09	311.94
12	640.4	174.6	142.35	454.29

Of course, both methods of utility estimation ,i.e., on the software program and via the constructions of the composite curves, gave the same results as follows.

1. The pinch point is located at a cold temperature of 289.40 °F.
2. Minimum hot utility requirement is 120.46 MBtu/hr.
3. Minimum cold utility requirement is 91.61 MBtu/hr.

Note that the minimum temperature driving force is set to be 27 °F.

Comparing these results to the prevailing utility consumptions, i.e., 125.9972 MBtu/hr of hot utility (4.39 % above minimum), and 97.5413 MBtu/hr of cold utility (6.08 % above minimum) we may conclude with confidential that the process system design of the modified plant satisfies the minimum utility targets of the maximum heat recovery.

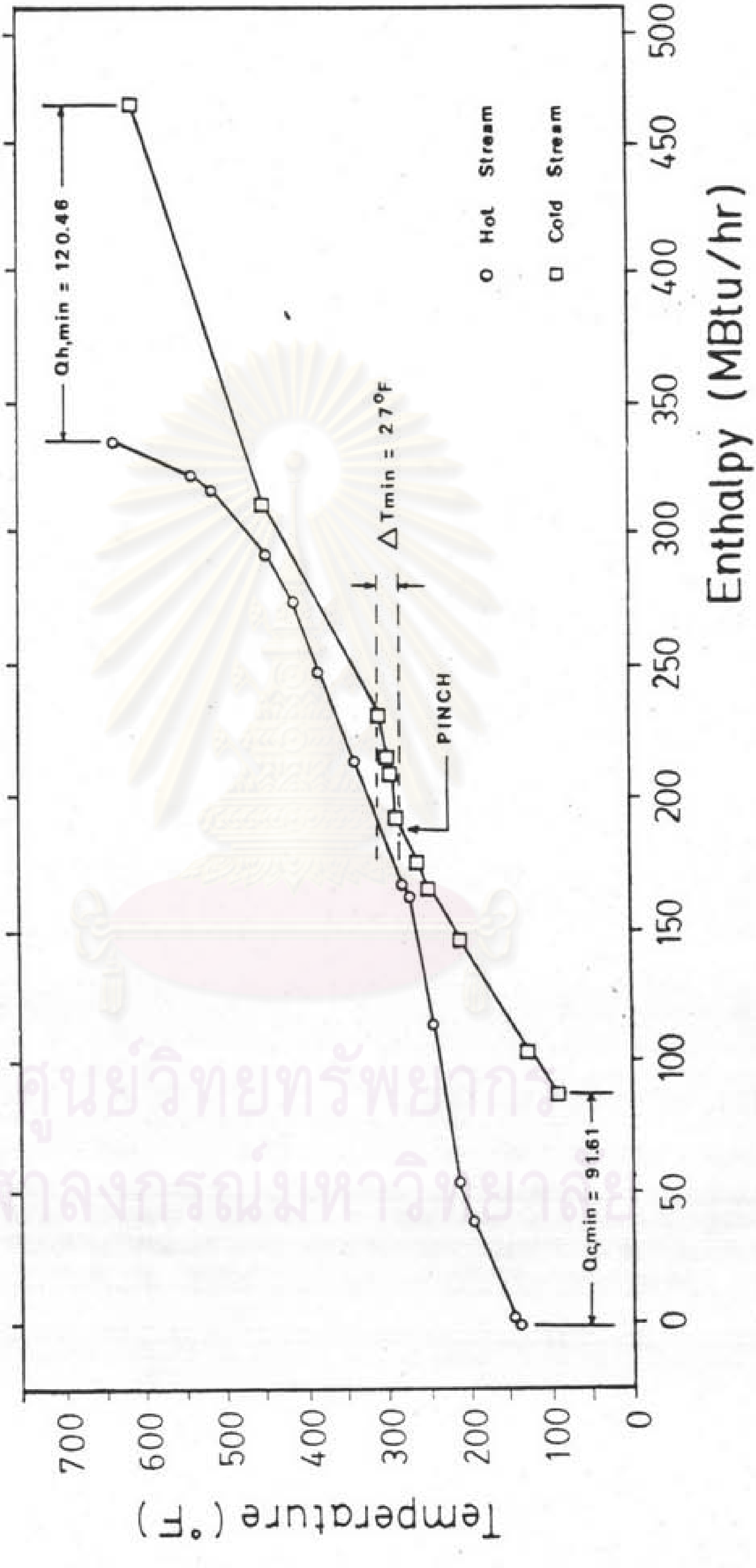


Figure 5.16 Composite curve (new design)

5.7.5 Energy Utilization Diagram and Exergy Loss

Follow the same procedure of EUD construction as determined in section 5.6 (before modified plant), the comparative analysis on the EUD of the after modified plant between base case and MER is determined as below.

1. Base Case

Figures 5.17 (a) and (b) show the corresponding T-H diagram and EUD of the modified plant (base case). The basic data and the calculation results of the hot and cold composite curves are provided, respectively, in Tables 5.13 (a) and (b).

Base on the shaded area in the EUD, the exergy loss in the heat exchanger network of the modified plant is obtained as 37.9968 MBtu/hr.

Table 5.13 (a) Energy level and exergy analysis of the hot streams in the base case (modified plant)

NO.	TEMP (°F)	TEMP (°R)	A = 1-To/T	CUM H (MBtu/hr)	DEL H (MBtu/hr)	AVERAGE A	AREA (MBtu/hr)
1	116.6	576.6	0.0687	0.0000			
2	120.2	580.2	0.0745	1.2974	1.2974	0.0716	0.0929
3	179.6	639.6	0.1604	39.8956	38.5982	0.1174	4.5328
4	199.4	659.4	0.1856	55.0980	15.2024	0.1730	2.6303
5	235.4	695.4	0.2278	114.8328	59.7348	0.2067	12.3474
6	273.2	733.2	0.2676	163.9312	49.0984	0.2477	12.1611
7	280.4	740.4	0.2747	166.8645	2.9333	0.2712	0.7954
8	341.6	801.6	0.3301	213.0338	46.1693	0.3024	13.9617
9	392.0	852.0	0.3697	246.0962	33.0624	0.3499	11.5687
10	426.2	886.2	0.3940	273.8461	27.7499	0.3819	10.5971
11	464.0	924.0	0.4188	291.4004	17.5543	0.4064	7.1347
12	532.4	992.4	0.4589	316.3732	24.9728	0.4389	10.9595
13	559.4	1019.4	0.4732	322.0351	5.6619	0.4661	2.6387
14	662.4	1122.4	0.5216	334.1891	12.1540	0.4974	6.0453

Total area under the hot composite curve = 95.4656
Overlapping area = 0.5216 x 125.9972 = 65.7201

Total area under the hot composite curve 161.1857

Table 5.13 (b) Energy level and energy analysis of the cold streams in the base case (modified plant)

NO.	TEMP (°F)	TEMP (°R)	A = 1-To/T	CUM H (MBtu/hr)	DEL H (MBtu/hr)	AVERAGE A	AREA (MBtu/hr)
1	80.6	540.6	0.0067	97.5413			
2	116.6	576.6	0.0687	112.6361	15.0948	0.0377	0.5686
3	203.0	663.0	0.1900	155.0153	42.3792	0.1294	5.4823
4	248.0	708.0	0.2415	173.8838	18.8685	0.2158	4.0715
5	258.8	718.8	0.2529	183.9386	10.0548	0.2472	2.4858
6	289.4	749.4	0.2834	199.5966	15.6580	0.2682	4.1991
7	294.8	754.8	0.2886	219.3234	19.7268	0.2860	5.6417
8	298.4	758.4	0.2919	222.2088	2.8854	0.2902	0.8375
9	311.0	771.0	0.3035	237.7143	15.5055	0.2977	4.6162
10	313.2	773.2	0.3055	239.7841	2.0698	0.3045	0.6302
11	465.8	925.8	0.4200	317.8695	78.0854	0.3627	28.3233
12	640.4	1100.4	0.5120	460.2209	142.3514	0.4660	66.3327

Total area under the cold composite curve = 123.1889

Shaded Area = Exergy loss = 161.1857 - 123.1889 = 37.9969
****

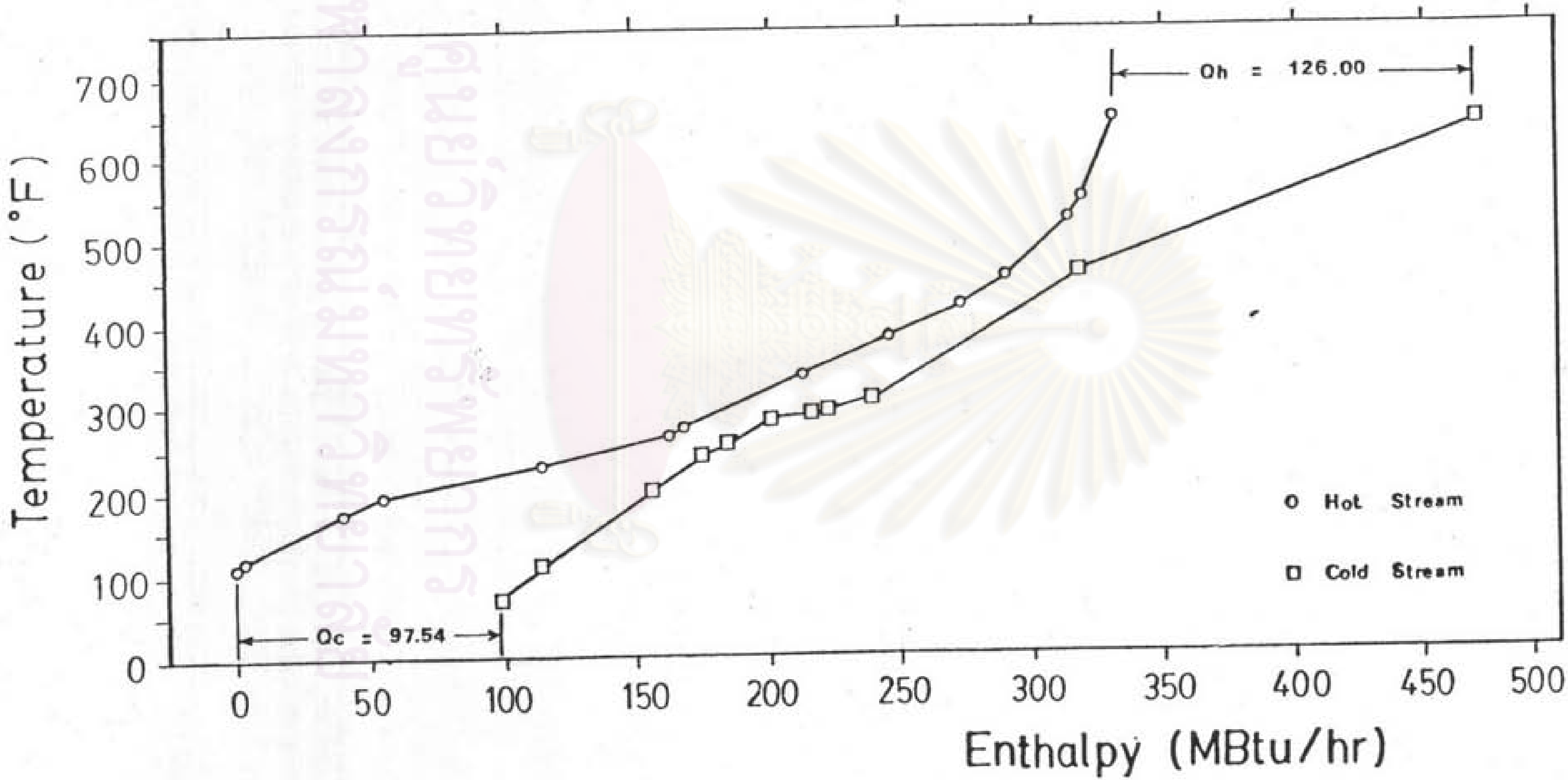


Figure 5.17 (a) Temperature - Enthalpy diagram of the modified plant (new design)

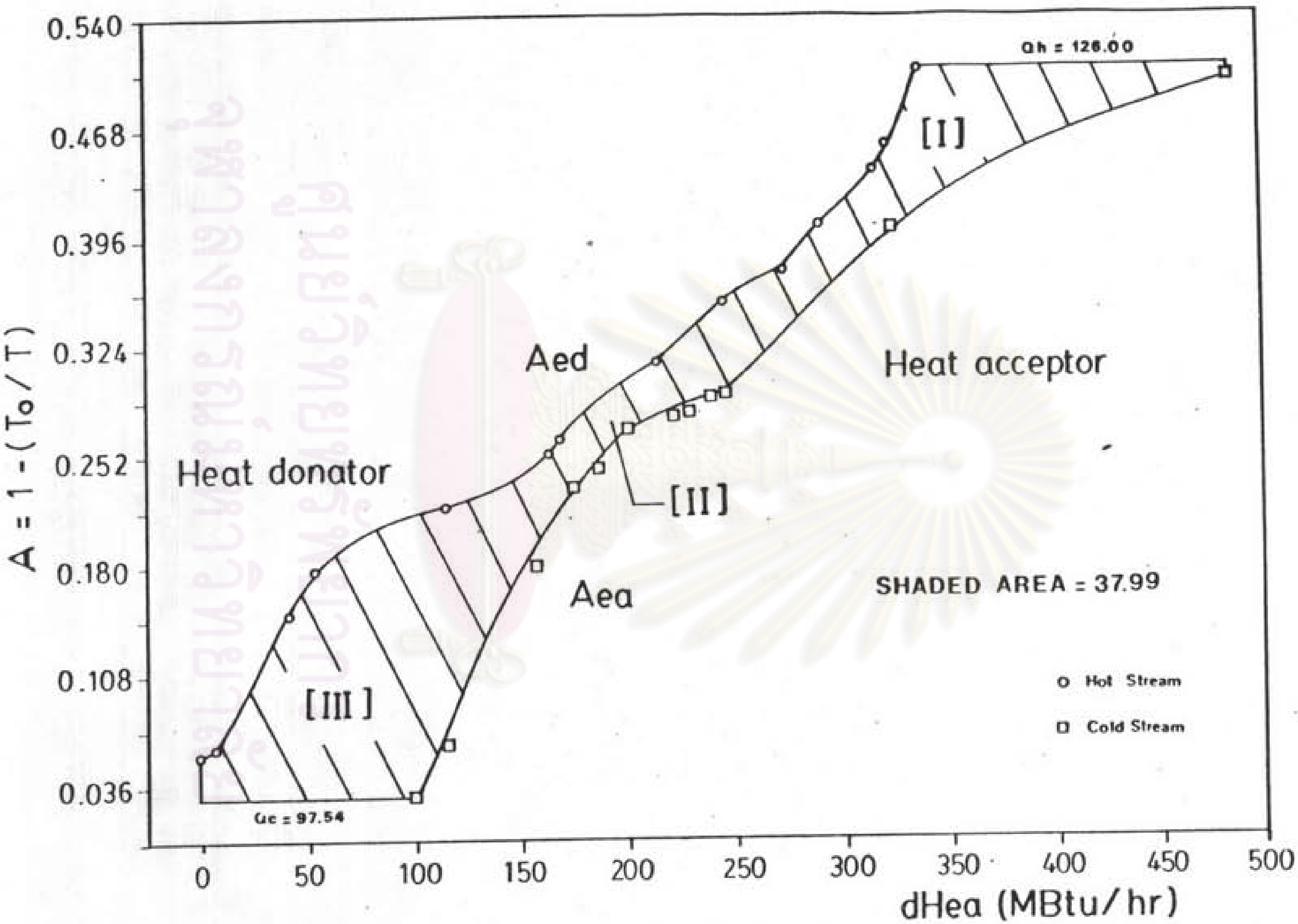


Figure 5.17 (b) EUD of the modified plant (new design)

2. MER design

Similar to case of the base case, Figures 5.18 (a) and (b) show the corresponding T-H diagram and EUD of the MER design. The basic data and the calculation results of the hot and cold composite curves are provided, respectively, in Tables 5.14 (a) and (b).

Base on the shaded area in the EUD, the exergy loss in the heat exchanger network of the MER design is 35.1076 MBtu/hr.

Table 5.14 (a) Energy level and exergy analysis of the hot streams in the MER design (modified plant)

NO.	TEMP (°F)	TEMP (°R)	A = 1-To/T	CUM H (MBtu/hr)	DEL H (MBtu/hr)	AVERAGE A	AREA (MBtu/hr)
1	116.6	576.6	0.0687	0.0000			
2	120.2	580.2	0.0745	1.2974	1.2974	0.0716	0.0929
3	179.6	639.6	0.1604	39.8956	38.5982	0.1174	4.5328
4	199.4	659.4	0.1856	55.0980	15.2024	0.1730	2.6303
5	235.4	695.4	0.2278	114.8328	59.7348	0.2067	12.3474
6	273.2	733.2	0.2676	163.9312	49.0984	0.2477	12.1611
7	280.4	740.4	0.2747	166.8645	2.9333	0.2712	0.7954
8	341.6	801.6	0.3301	213.0338	46.1693	0.3024	13.9617
9	392.0	852.0	0.3697	246.0962	33.0624	0.3499	11.5687
10	426.2	886.2	0.3940	273.8461	27.7499	0.3819	10.5971
11	464.0	924.0	0.4188	291.4004	17.5543	0.4064	7.1347
12	532.4	992.4	0.4589	316.3732	24.9728	0.4389	10.9595
13	559.4	1019.4	0.4732	322.0351	5.6619	0.4661	2.6387
14	662.4	1122.4	0.5216	334.1891	12.1540	0.4974	6.0453

Total area under the hot composite curve = 95.4656

Overlapping area = 0.5216 x 120.4580 = 62.8309

Total area under the hot composite curve 158.2965

Table 5.14 (b) Energy level and exergy analysis of the cold streams in the MER design (modified plant)

NO.	TEMP (°F)	TEMP (°R)	A = 1-To/T	CUM H (MBtu/hr)	DEL H (MBtu/hr)	AVERAGE A	AREA (MBtu/hr)
1	80.6	540.6	0.0067	91.6072			
2	116.6	576.6	0.0687	106.7020	15.0948	0.0377	0.5686
3	203.0	663.0	0.1900	149.0812	42.3792	0.1294	5.4823
4	248.0	708.0	0.2415	167.9497	18.8685	0.2158	4.0715
5	258.8	718.8	0.2529	178.0045	10.0548	0.2472	2.4856
6	289.4	749.4	0.2834	193.6625	15.6580	0.2682	4.1991
7	294.8	754.8	0.2886	213.3893	19.7268	0.2860	5.6417
8	298.4	758.4	0.2919	216.2747	2.8854	0.2902	0.8375
9	311.0	771.0	0.3035	231.7802	15.5055	0.2977	4.6162
10	313.2	773.2	0.3055	233.85	2.0698	0.3045	0.6302
11	465.8	925.8	0.4200	311.9354	78.0854	0.3627	28.3233
12	640.4	1100.4	0.5120	454.2868	142.3514	0.4660	66.3327

Total area under the cold composite curve = 123.1889

Shaded Area = Exergy loss = 158.2965 - 123.1889 = 35.1076

****

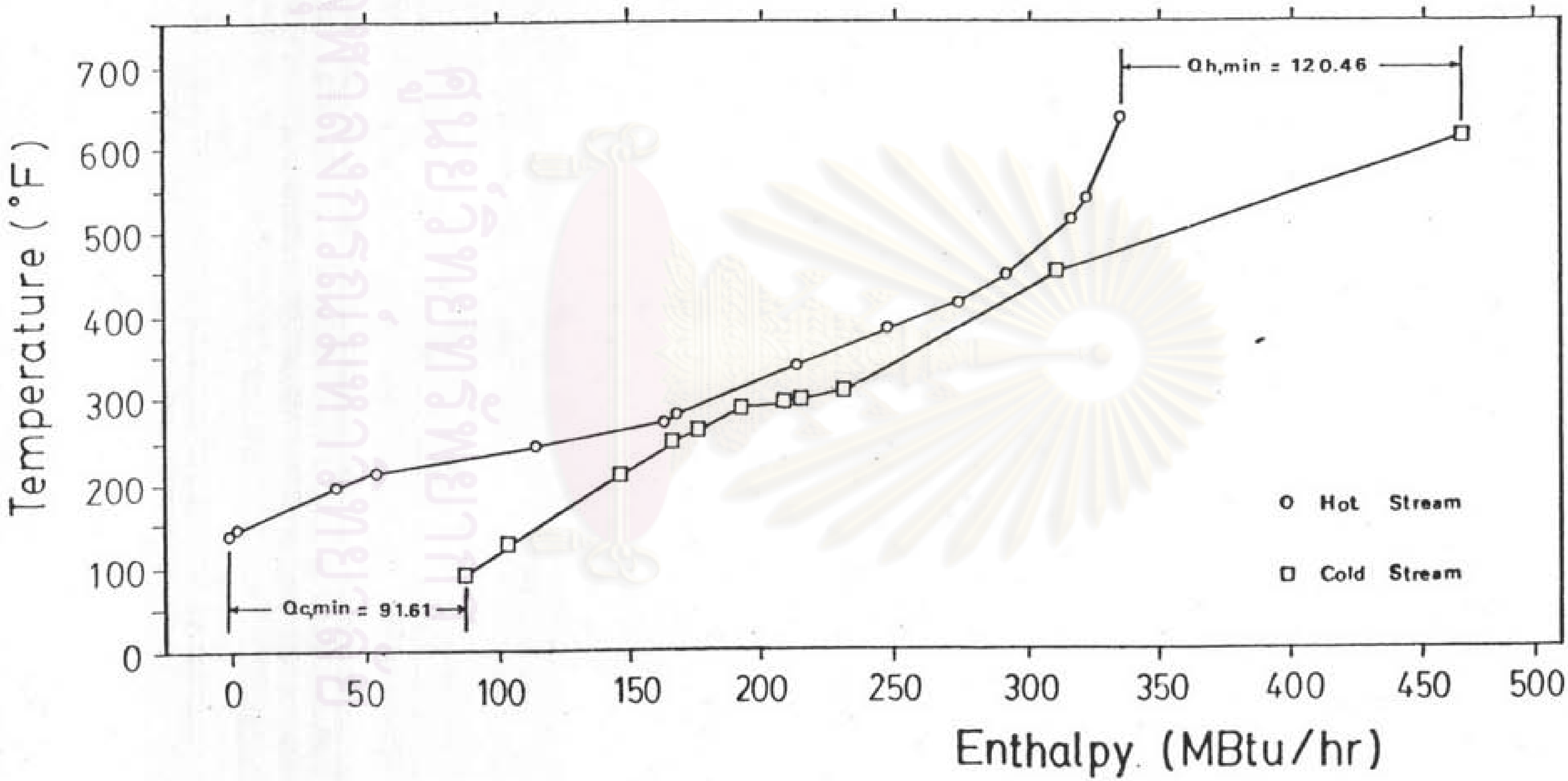


Figure 5.18 (a) Temperature - Enthalpy diagram of the modified plant (MER design)

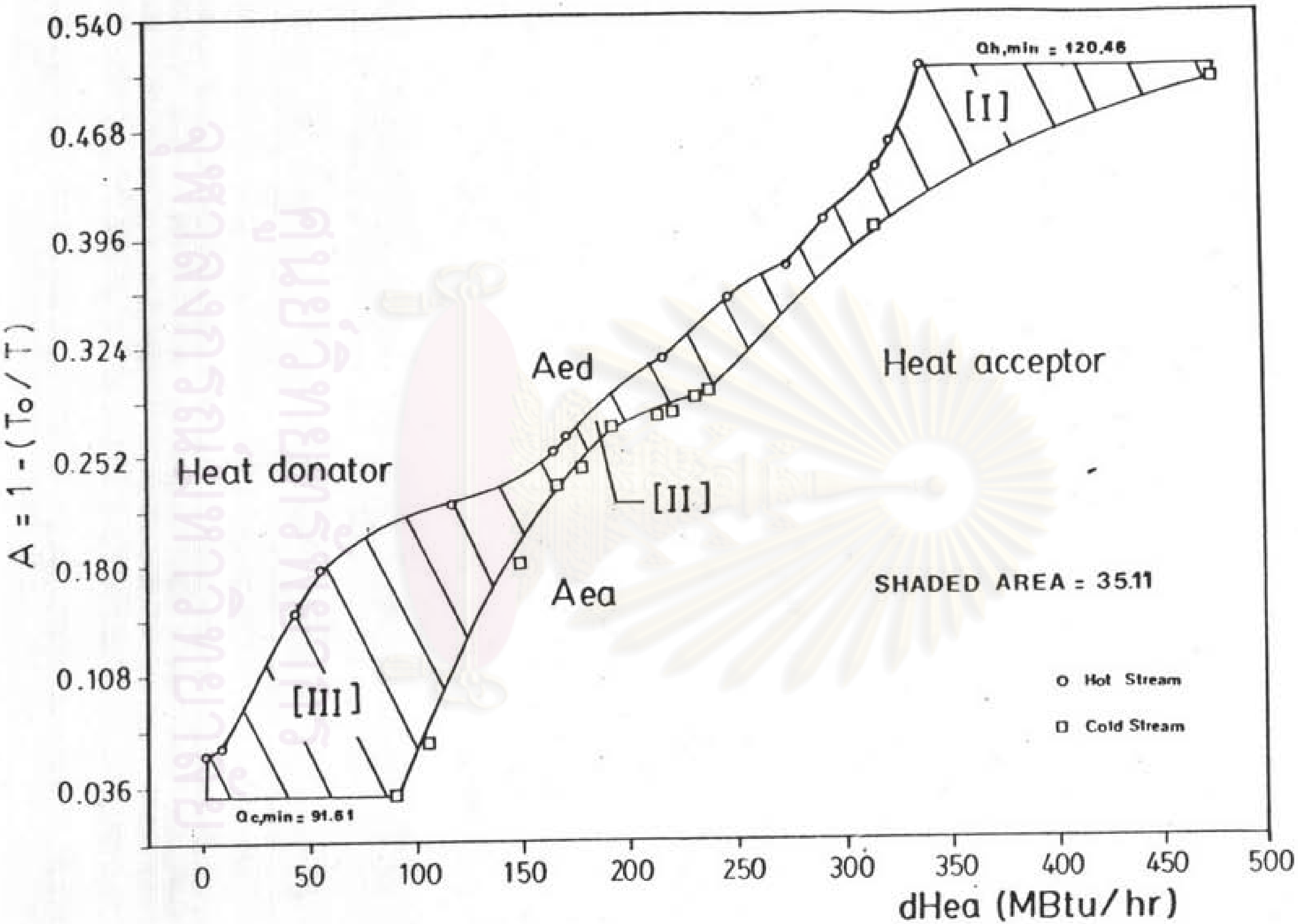


Figure 5.18 (b) EUD of the modified plant (MER design)

3. Summary of the Energy and Exergy Loss

The composite curves and EUD's of the comparing between base case and MER design have been constructed. The comparative analysis illustrated in Table 5.15.

Table 5.15 Summary of the After-Modified plant evaluation

Scheme	Energy Consumption (MBtu/hr)			% Saving		Exergy (MBtu/hr)	
	Hot Utility	Cold Utility	Total	Fuel	Cooling Water	Exergy Losses	Reduction (%)
1. Based Case	126.00	97.54	223.54	0	0	37.99	0
2. MER	120.46	91.61	189.15	4.39	6.08	35.11	7.61

With this result, it is quite obvious that the process system of the modified plant almost satisfies the minimum utility targets and indicate the high efficiency in energy using.

To compare the exergy loss (by MER design) between the after modified plant and the original design is ,respectively, 35.1076 MBtu/hr and 45.58 MBtu/hr. That the value of the after modified plant is lower than the prevailing loss in original plant despite capacity expansion is made possible by process modification involving change in process operating condition and revamping of the topping column itself.