CHAPTER VI

ECONOMIC ANALYSIS

In the previous Chapter, two energy reduction design methods, namely, "MER" and "Relaxation", of the original design (base case) have been pointed out. Generally, the final selection of a Heat-Exchanger-Network (HEN) configuration is devided by comparing the total investment costs or payback periods of competing HENs. In short, the HEN which costs least or earns the shortest payback period will be selected. This chapter is concerned with the economic evaluation of the previous retrofit designs, namely MER design and "relaxed" design.

6.1 Investment Cost

Energy conservation in the design retrofits described in Chapter V will focus on the minimization of fuel consumption in the fired heater plus the cold utility requirements. For this purpose, extra heat exchangers are added to the feed train to recover more heat from the hot effluents. Therefore, the major contributions to the total investment cost of each design retrofit come from the heat exchanger costs, piping costs, and installation costs, whereas the investment costs for the remaining items are either small or vary insignificantly. Thus, our total investment costs will be taken to be the sum of the first three items.

6.1.1 Existing Exchangers

Table 6.1 shows the list of the existing heat exchangers. The characteristics of each exchanger are also described in the table. Note that, from the given entering and exiting temperatures, heat loads, and other characteristics of the streams, we can readily estimated the prevailing overall heat transfer coefficient "U" of each unit using the following rate equation

$$Q = U \times A \times DTLM$$

where Q = heat load (Btu/hr)

A = heat transfer area (ft^2)

U = overall heat transfer coefficient ($Btu/lb\text{-}ft^2\text{-}^oF$)

$DTLM$ = log mean temperature difference (^oF)

Detail of, the calculation procedure is described in Appendix F.

Table 6.1 List of existing heat exchangers

(base case design)

Exchanger		Shell Side		Tube Side		Heat Load	DTLM	AREA	U
NO.	Code	Tin	Tout	Tin	Tout	(MBtu/hr)	(°F)	(ft^2)	(MBtu/hr‡ ft^2‡°F)
1	E-101	80	199	364	176	35.00	119.7	2,628	111.27
2	E-102	199	229	383	229	8.80	75.8	2,356	49.27
3	E-103	229	272	510	272	14.40	114.0	3,262	38.74
4	E-104	272	310	540	390	13.40	167.8	1,760	45.37
5	E-105	697	345	310	452	50.08	107.9	7,574	61.27
6	E-106	252	187	99	115	89.20	110.7	7,635	105.59
7	E-107	187	100	95	100	22.90	28.7	6,703	119.04
8	E-108	270	120	95	115	5.00	71.3	959	73.17
9	E-109	229	120	95	115	5.12	58.7	1,510	57.76
10	E-110	272	120	95	115	7.86	71.8	2,983	36.38
11	E-111	611	120	95	115	14.60	157.6	5,112	18.12
12	E-112	364	180	95	115	22.60	152.6	4,628	32.00
13	E-403	303	314	540	115	11.60	145.6	1,287	61.9

6.1.2 Newly Installed Heat Exchangers

According to Chapter V, we have a total of twenty-five exchangers for the MER design, and twenty exchangers for the relaxed design. The purpose here is to find out the expenditure in installing new exchanger units with the desired heat transfer areas.

One obvious way to minimize the investment costs is to reuse those existing exchangers which can satisfy the heat loads and performances required by the retrofit design. Here we shall determine the investment costs incurred by installing only the necessary new exchangers.

6.1.2.1 MER Design

Table 6.2 (a) gives the list of the reusable exchangers for the MER design. The required new exchangers and their estimated areas are listed in Table 6.2 (b). Figures 6.1 (a) and (b) are the grid diagrams for the base case and the MER design, respectively.

Table 6.2 (a) List of reusable heat exchangers (MER Design)

Existing Unit		Possible Heat Load (MBtu/hr)	Reused Exchanger Code	Required Heat Load (MBtu/hr)
No.	Code			
1	E-101	35.00	E-15	28.01
2	E-102	8.80	E-14	8.19
3	E-103	14.40	E-17	10.10
4	E-104	13.40	E-03	10.30
5	E-105	50.08	E-01	20.45
6	E-106	89.20	C-23	77.30
7	E-107	22.90	C-24	22.90
8	E-108	5.00	C-21	5.00
9	E-109	5.12	C-22	3.08
10	E-110	7.86	C-19	5.60
11	E-111	14.60	C-20	9.60
12	E-112	22.60	C-18	7.51
13	E-403	11.60	E-02	7.70
14	F-101	149.4	H	112.88

Table 6.2 (b) List of newly installed heat exchangers (MER design)

Exchanger		Shell Side		Tube Side		Heat Load	DTLM	U (MBtu/hr*ft2°F)	AREA
No.	Code	Tin	Tout	Tin	Tout	(MBtu/hr)	(°F)		(ft^2)
1	E-04	611.0	339.0	303.0	474.0	8.10	75.6	60.00	1,786.42
2	E-05	540.0	390.0	303.0	474.0	17.30	76.0	60.00	3,792.86
3	E-06	561.0	339.0	303.0	474.0	32.75	57.8	60.00	9,441.85
4	E-07	383.0	339.0	304.3	306.7	2.50	52.8	50.00	947.15
5	E-08	346.0	339.0	303.0	304.3	1.40	38.8	50.00	722.39
6	E-09	339.0	308.0	272.0	303.0	3.80	36.0	50.00	2,111.11
7	E-10	339.0	308.0	272.0	303.0	0.90	36.0	50.00	500.00
8	E-11	339.0	308.0	272.0	303.0	1.90	36.0	50.00	1,055.56
9	E-12	339.0	308.0	272.0	303.0	1.80	36.0	50.00	1,000.00
10	E-13	339.0	326.8	272.0	303.0	2.50	44.7	50.00	1,117.57
11	E-16	252.0	243.3	114.3	154.8	11.90	112.4	50.00	2,118.38

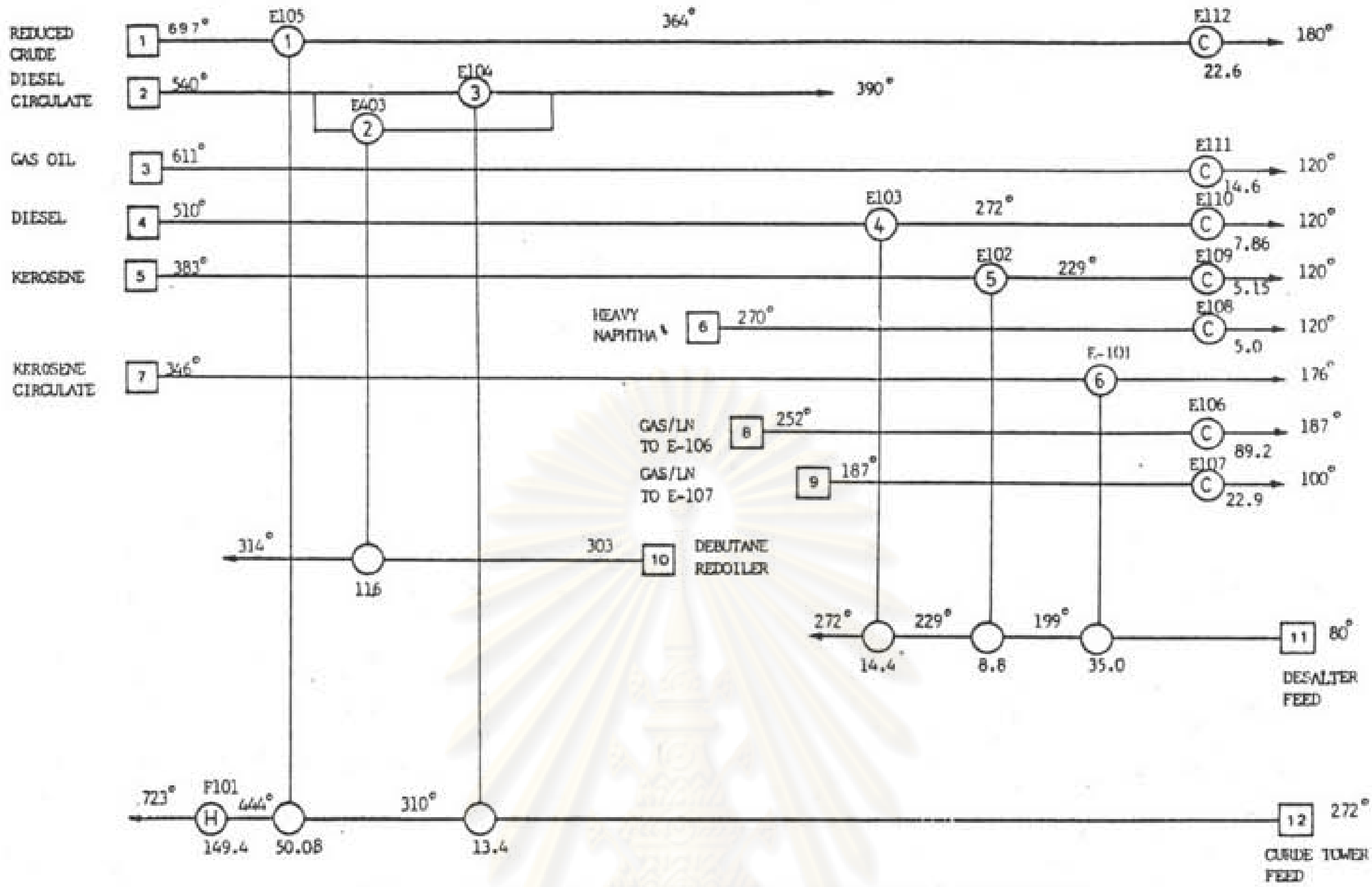

Figure 6.1 (a) Grid diagram of the base case

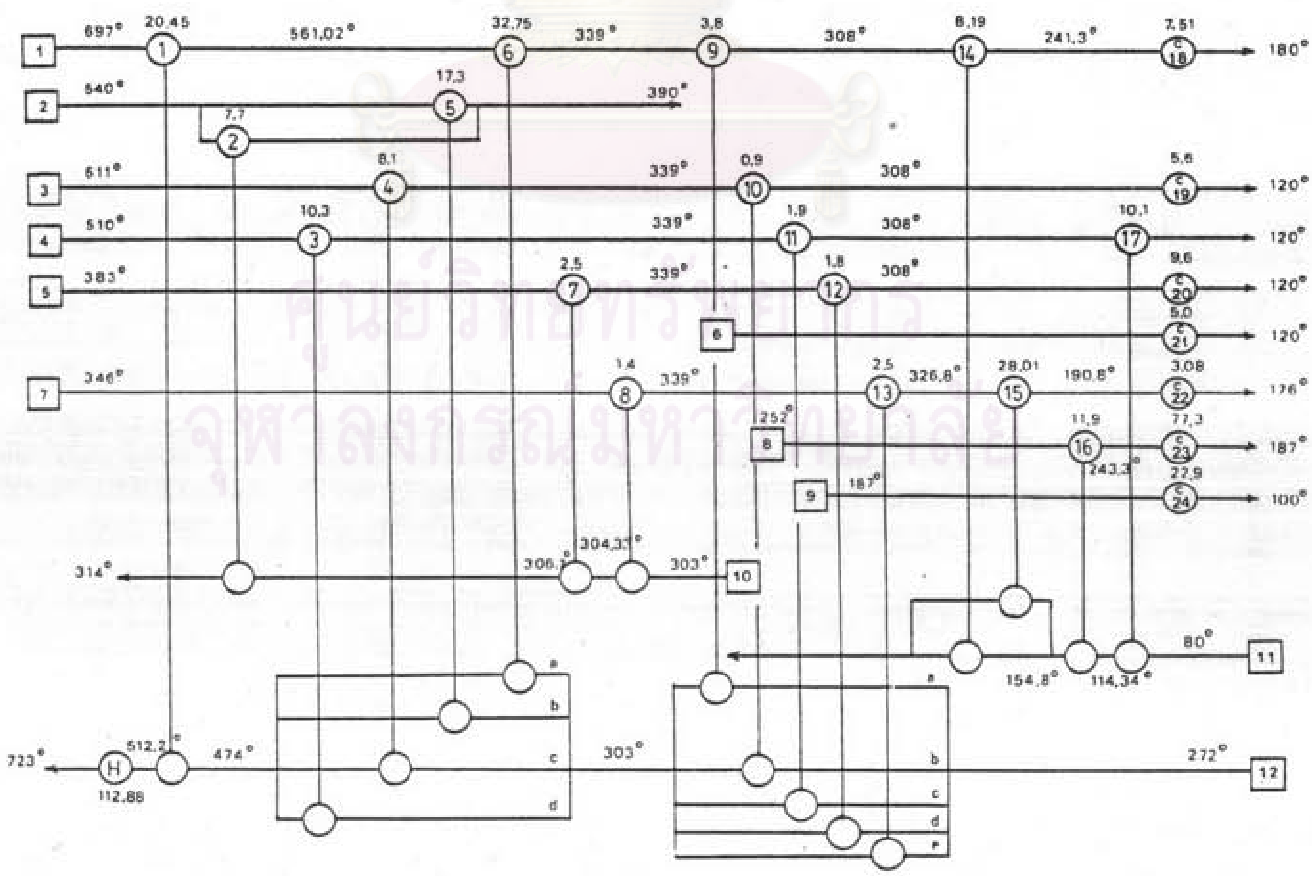

Figure 6.1 (b) Grid diagram of the MER design

6.1.2.2 Relaxed Design

As in the case of the MER design, Table 6.3 (a) give a list of the reusable exchangers for the relaxed design. The required new exchangers and their estimated areas are listed in Table 6.3 (b). Figures 6.2 (a) and (b) are the grid diagrams of the base case and the relaxed design, respectively.

Table 6.3 (a) List of reusable heat exchangers (relaxed design)

Existing Unit		Possible Heat Load Heat Load	Reused Exchanger Code	Required Heat Load (MBtu/hr)
No.	Code			
1	E-101	35.00	E-10	28.01
2	E-102	8.80	E-09	8.19
3	E-103	14.40	E-12	10.10
4	E-104	13.40	E-03	8.50
5	E-105	50.08	E-01	20.45
6	E-106	89.20	C-19	77.31
7	E-107	22.90	C-20	22.90
8	E-108	5.00	C-17	5.00
9	E-109	5.12	C-14a	5.00
10	E-110	7.86	C-15	5.60
11	E-111	14.60	C-16	11.40
12	E-112	22.60	C-13	7.51
13	E-403	11.60	E-02	7.70
14	F-101	148.4	H	126.18

Table 6.3 (b) List of newly installed heat exchangers (relaxed design)

Exchanger		Shell Side		Tube Side		Heat Load	DTLM	U	AREA
No.	Code	Tin	Tout	Tin	Tout	(MBtu/hr)	(°F)	(MBtu/hr* ft²*°F)	(ft^2)
1	E-04	272.0	430.0	510.0	308.0	12.20	55.1	60.00	5,690.00
2	E-05	272.0	430.0	611.0	308.0	9.00	89.8	60.00	1,670.00
3	E-06	272.0	430.0	561.0	308.0	36.55	73.6	70.00	7,099.00
4	E-07	304.3	306.7	383.0	339.0	2.50	52.8	50.00	947.00
5	E-08	303.0	304.3	346.0	339.0	1.40	38.8	60.00	601.00
6	E-11	114.3	154.8	252.0	243.3	11.90	112.3	60.00	1,765.00
7	E-14b	95.0	115.0	442.0	390.0	3.70	310.7	60.00	198.46
8	E-18	95.0	115.0	203.0	176.0	5.58	84.5	60.00	1,101.24

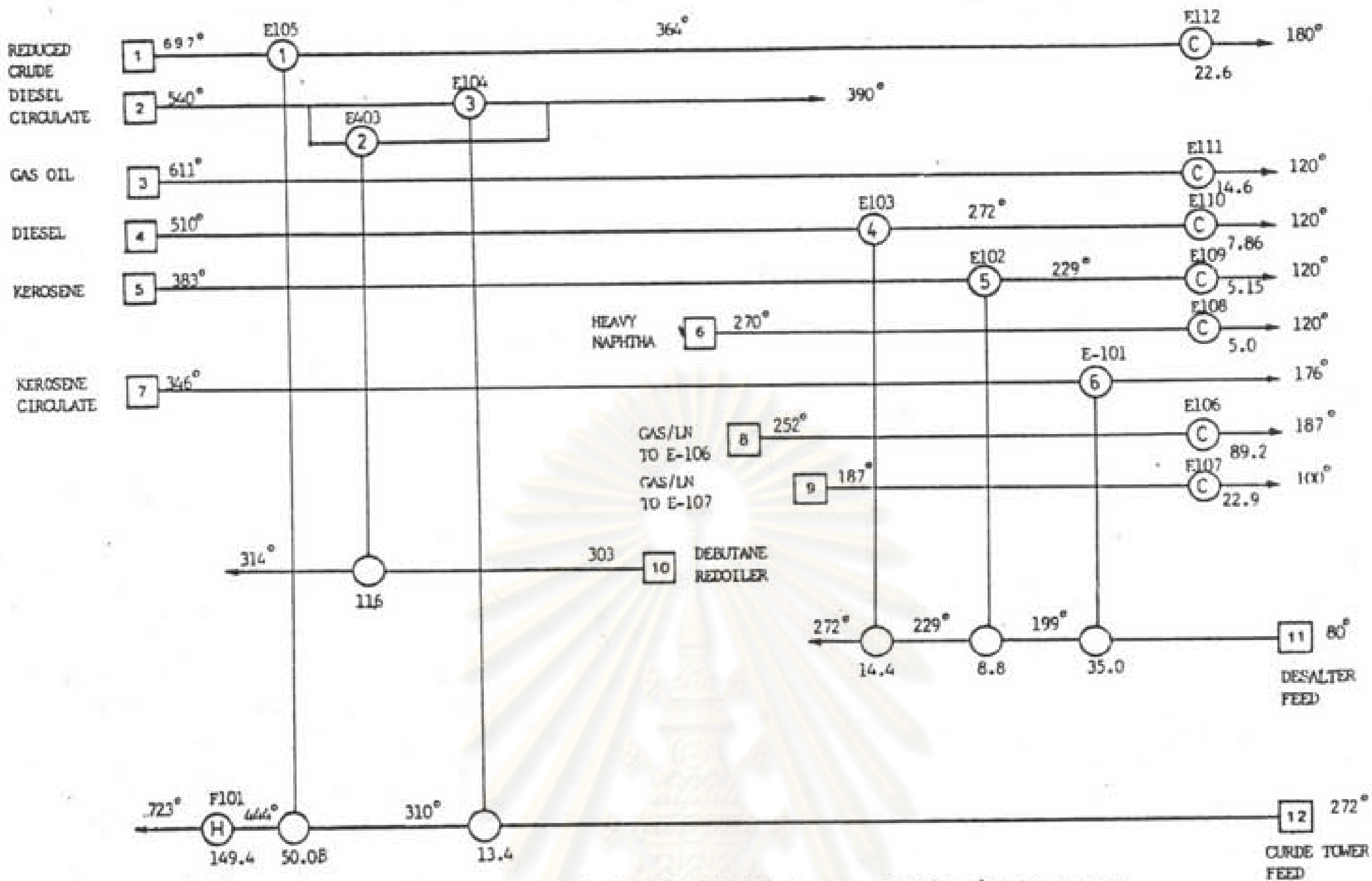

Figure 6.2 (a) Grid diagram of the base case

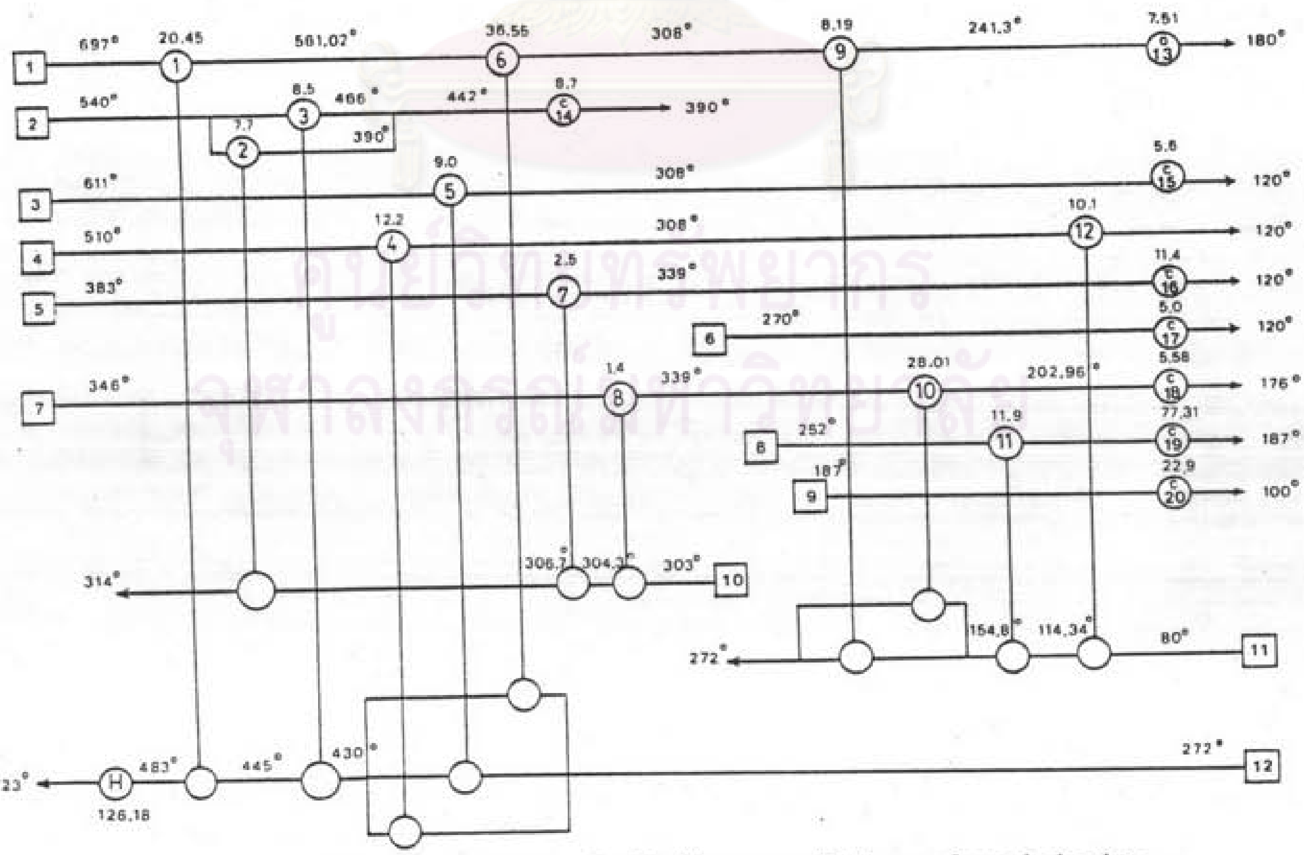

Figure 6.2 (b) Grid diagram of the relaxed design

6.1.3 Investment Costs Related to Heat Exchangers

In the retrofit design, additional heat exchangers are installed to recover more process heat. The costs of these extra exchangers are a major factor. For simplicity, the costs of piping, installation, taxes, etc., will be considered to be proportional to the basic costs of the exchangers.

Most cost data of process equipment, which are available for ready use in estimating the costs of a preliminary or conceptual design are based on known conditions at certain time in the past. To estimate the present costs, the cost data of the past may be corrected by using the current published cost indexes. The cost index at a given time is defined as the ratio of the equipment cost at that time to the cost a certain past time. Therefore, certain base if the equipment cost at the some point time is known or can be estimated, the equivalent cost at the present time can be determined by multiplying the original cost with the ratio of the present cost index to the applicable cost index at the time the original cost is estimated.

$$\text{present cost} = \text{original cost}\ \frac{(\text{ index value at present time })}{(\text{index value at time of original cost})}$$

As in most refinery and process plants, most of the existing exchangers in the base case design are the floating head type. So the same type of exchanger is selected for the additional units. The cost of the floating head heat exchanger in 1958, which is assigned an index value of 100, is used as the original cost. With the aid of Figure 6.3, the present cost of any floating head exchanger can readily be estimated by multiply the original cost with the prevailing index value. Note that the present cost index (September, 1989) of the heat exchanger is 360.5. (See Appendix F)

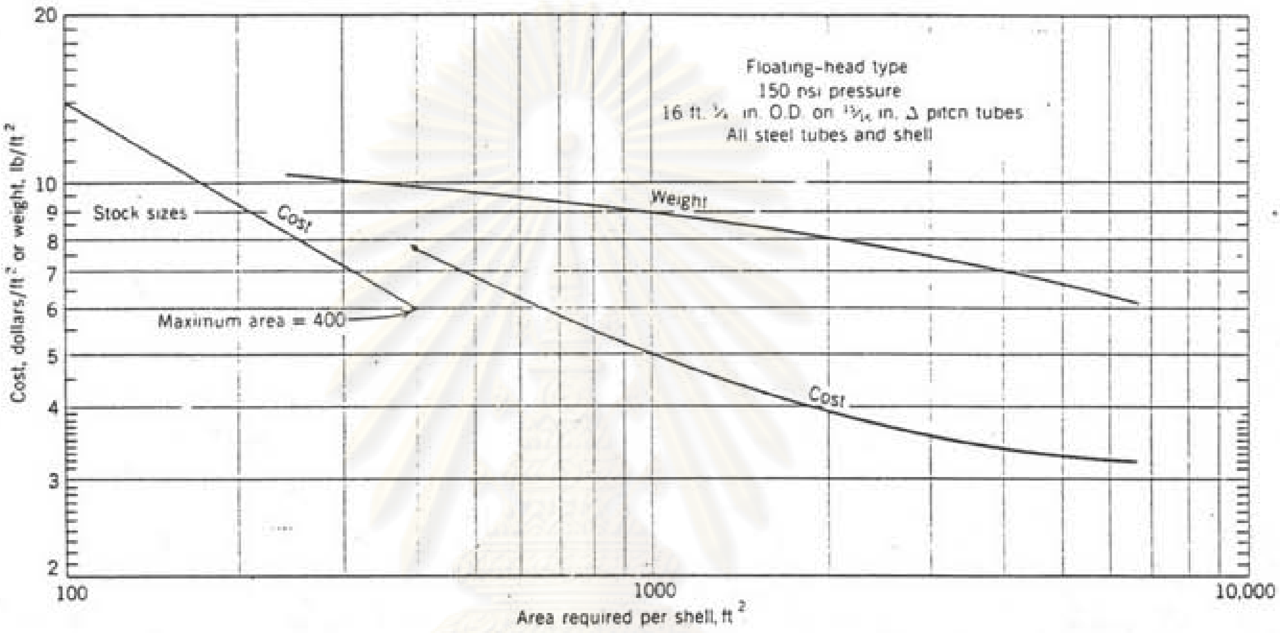

Figure 6.3 Reference costs of heat exchanger (floating head type)

The other best in reliability of cost estimation is to obtain firm bids from approved fabricators of suppliers. According to the design retrofit of plant No. 3, some actual cost of heat exchangers (floating heat type) were known. Table 6.4 shows the correlation between cost of heat exchangers and their heat transfer areas of the knowning exchanger payments.

Table 6.4 List of exchanger costs

No.	Heat transfer area (ft^2)	Cost (US$)	Cost, US$/ft^2
1	1,496.0	29,680	19.84
2	2,723.2	39,900	14.65
3	6,608.0	104,580	15.83
4	8,201.0	112,680	13.74
5	9,170.0	152,630	16.64
6	14,186.0	173,200	12.21
7	18,082.0	228,550	12.64

By this correlation, we can plot the obtained data to the cost of heat exchanger reference chart (Figure 6.3). The comparison chart of exchanger cost developed from Figure 6.3 was obtained as Figure 6.4. Curve A is the original cost data stated in 1958 (index = 100) whereas curve B is the corrected data of curve A using the present cost index of 360.5. The actual cost plotted by using the actual data in Table 6.4 is represented by curve C.

We can see that the currently exchanger cost received from contractor is higher than those shown in the reference curve despite corrected with the present cost index. As mentioned earlier, the cost estimatation seems to be more reliable if the actual cost data is known. Thus, the following estimation of heat exchanger costs will be based on curve C.

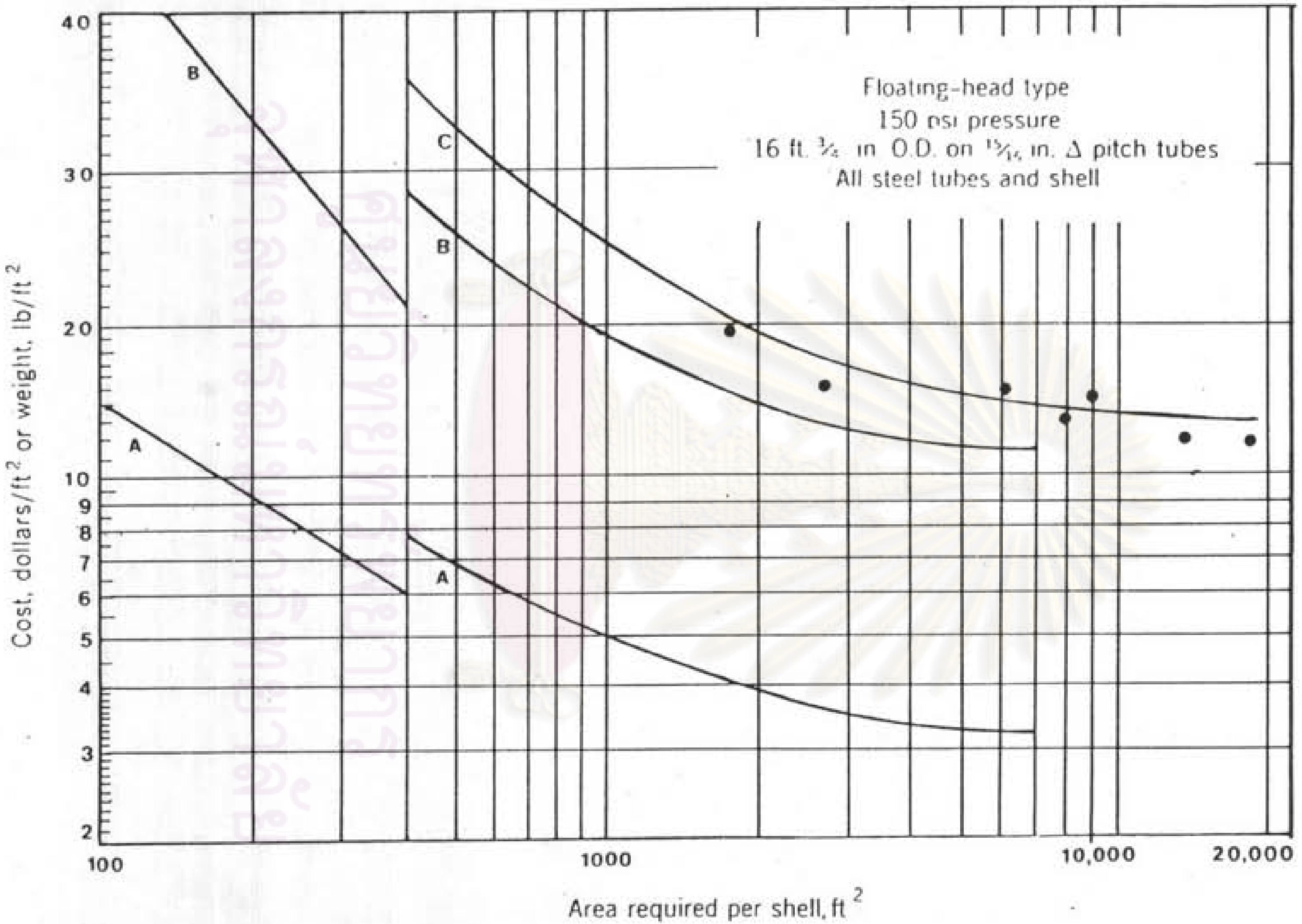

Figure 6.4 Correlation of exchanger costs

6.1.4 Total Investment Cost

The present costs of the additional exchangers required by the MER and relaxed design are determined by Figure 6.4 and showed in Table 6.5 and 6.6, respectively.

Table 6.5 Cost estimatation of newly installed heat exchangers (MER design)

Exchanger		Heat Load	Required AREA	Cost per ft^2	Present Cost
No.	Code	(MBtu/hr)	(ft^2)	(US$)	(US$)
1	E-04	8.10	1,960	20.70	40,572
2	E-05	17.30	4,100	15.00	61,500
3	E-06	32.75	10,500	14.00	147,000
4	E-07	2.50	1,100	24.00	26,400
5	E-08	1.40	900	27.80	25,020
6	E-09	3.80	2,280	18.70	42,636
7	E-10	0.90	600	33.00	19,800
8	E-11	1.90	1,210	22.30	26,983
9	E-12	1.80	1,100	24.00	26,400
10	E-13	2.50	1,260	22.20	27,972
11	E-16	11.90	2,350	18.00	42,300
				Total	486,583.00

Table 6.6 Cost estimation of newly installed heat exchangers (relaxed design)

Exchanger		Heat Load	Required AREA	Cost per ft^2	Present Cost
No.	Code	(MBtu/hr)	(ft^2)	(US$)	(US$)
1	E-04	12.20	3,720	15.1	56,172
2	E-05	9.00	1,700	20.9	35,530
3	E-06	36.55	7,140	14.0	99,960
4	E-07	2.50	980	24.5	24,010
5	E-08	1.40	625	28.0	17,500
6	E-11	11.90	1,800	20.8	37,440
7	E-14b	3.70	210	30.0	6,300
8	E-18	5.58	1,170	22.4	26,208
				Total	303,120.00

To come up with the total investment cost the other relevants are include as proportional to the basic costs of heat exchangers. The below percentages are more or less based on the data of Bangchak Oil Refinery Restructing Project Carried out by TOYO Engineering Cooperation (1989). The parallel investment cost estimations of the two design alternatives is determined as follow.

(a) Equipment & Material Cost	MER design	Relaxed design
1. Basis Heat Exchanger	486,583.00	303,120.00
2. Shipping & Transportation (20 %)	97,316.60	60,624.00
3. Pump (40 %)	194,633.20	121,248.20
4. Piping (50 %)	243,291.50	151,560.00
5. Instrument (10 %)	145,970.90	90,936.00
6. Installing	145,974.90	90,936.00
7. Contingency	24,239.15	15,156.00
Total	1,338,103.25	833,580.00
(b) Import Duty		
1. Heat Exchanger (22.38 %)	108,897.27	67,838.26
2. Pump (22.38 %)	43,558.91	27,135.30
3. Piping (21.85 %)	53,159.19	33,115.86
4. Instrument (21.85 %)	31,895.52	19,869.52
Total	237,510.89	147,958.93
Total investment costs	1,575,614.14	981,538.93

6.2 Energy Saving and Payback Periods

Energy savings in the two retrofit designs is accomplished by minimizing the fuel consumption in the fired heater. In other words, additional heat exchangers are installed in the feed train to recover more heat from the hot effluents to the extent economically justified. Meanwhile, from the view point of hot process streams that need to be cooled down, their consumption of cooling water will simultaneously be reduced as more process heat is recovered. Therefore, the savings in utility consumptions of the retrofits designs will be based on the original demands of the base case design. The payback time is next determined as

$$\text{payback period} = \frac{\text{(total investment costs of retrofiting)}}{\text{(energy saving costs - rise in operating costs)}}$$

Thus, the payback periods of two retrofit designs can be determined in parallel form as belows.

(a) Saved Energy	Base case	MER design	Relaxed design
a.1 Hot Utilities			
Absorbed Duty, MBtu/hr	149.40	112.88	126.18
Efficiency, %	82.50	82.50	82.50
Fired Duty, MBtu/hr	181.09	136.84	152.95
Saved Energy, MBtu/hr	-	44.25	28.14
Unit Cost = 4.3 US$/MBtu, Operating time = 8,000 hr/yr			
Saved Cost, US$	-	1,521,939.39	968,203.64

(a) Saved Energy (continued)	Base case	MER design	Relaxed design
a.2 Cold Utilities			
Required, MBtu/hr	167.31	130.99	144.0
Saved Energy, MBtu/hr	-	36.32	23.31
Saved Cooling Water, m^3/hr	-	823.74	528.67
(See Appendix F)			
Unit Cost = 0.021 US$/$m^3$, Operating time = 8,000 hr			
Saved Cost	-	138,388.32	88,816.56
Total cost of energy saving in US$/yr (a.1 + a.2)	-	1,660,327.71	1,057,020.20
(b) Rise in Operating Cost (estimated for 40 % of Saving)		664,131.09	422,808.28
(c) Total investment cost of retrofiting		1,575,614.14	981,538.93
(d) Payback Periods, years		1.58	1.55

<u>Remark</u> :

1. Payback period of MER design

$$= \frac{(1,575,614.14)}{(1,660,327.71-664,131.09)} \quad \frac{(US\$)}{(US\$/yr)}$$

$$= 1.582 \quad \text{years}$$

2. Payback period of relaxed design

$$= \frac{(981,538.93)}{(1,057,020.20-422,808.28)} \quad \frac{(US\$)}{(US\$/yr)}$$

$$= 1.547 \quad \text{years}$$

6.3 Design Finalization

The above economic analysis indicates that both the MER and the relaxed designs merit serious consideration for implementation, the slight difference in their payback period being insignificant, i.e., 1.58 and 1.55 years, respectively. As mentioned earlier, all the designs which have attractive payback peroids should be seriously considered for selection.

In addition to economic return, it is an important design strategy to carefully check the equipment performance, and system operability, including rationalization of labor costs. The relaxed design is found to require twenty exchangers compared to the twenty-five of the MER design. It is reasonable to conclude that the MER design pays a high penalty in terms of more complex layout, more circuitous piping, more operators, and so on. For example, the MER design configuration calls for a five-way split of stream No. 12 (whereas only a three-way split suffices for the relaxed design).

For these reasons, the relaxed design is strongly recommended over the MER design. The flowsheet of the final retrofit design is represented in Figure 6.5.

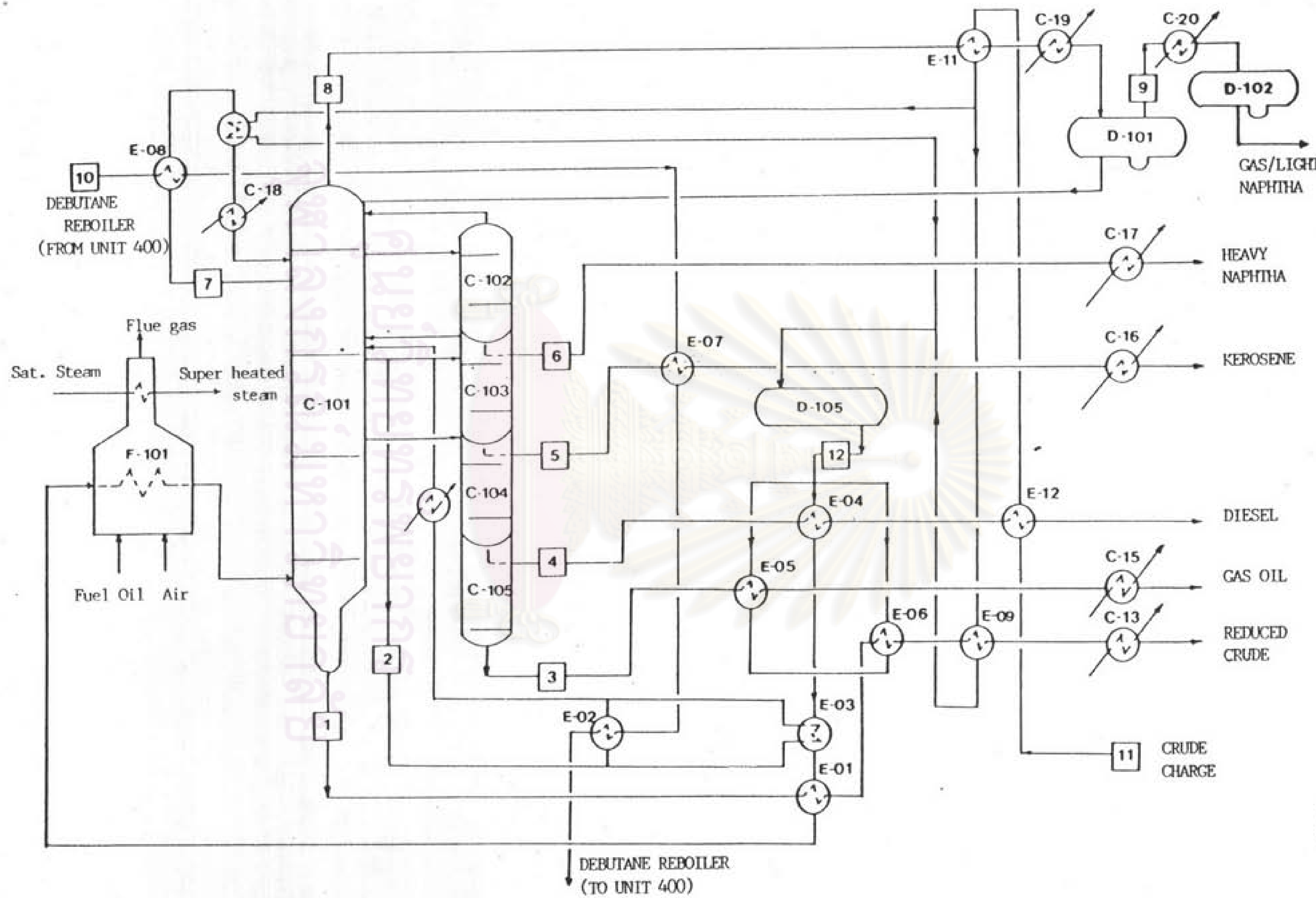

Figure 6.5 Process flow sheet of proposed retrofit