CHAPTER IV
RESULTS AND DISCUSSION

4.1 Column Targeting of Reformer Area

4.1.1 The Collected Data and Heat Exchanger and Stream Data Modeling

In this study, seventeen hot and ten cold streams were selected. The location and information of each stream are described in Appendix A.

The heat exchanger network design is usually done on grid diagram because of its simplicity. For the design case of existing plant, the grid diagram can be constructed by using the above data as shown in table 4.1.

Table 4.1 The Result from Simulation of Pro II of Reformer Area

STREAM	stream in name	stream out name	flowrate kg/hr	mCp kW/C	Tin C	Tout C	total duty MW
H1	346	351	71144.00	38.220	234.02	49.00	7.071
H2	540	544	19333.00	14.496	104.23	38.00	0.960
H3	511	565	35173.00	25.437	116.00	38.00	1.984
H4	006	008	242137.00	169.200	220.00	60.00	27.072
H5	131	132	148267.00	150.224	343.00	131.00	31.847
H6	136	137	153252.00	109.330	121.37	49.00	7.912
H7	341	399	146465.00	105.491	222.21	109.00	11.942
H8	194	195	208.90	0.176	524.00	179.90	0.060
H9	167	181	176380.00	273.448	103.20	48.53	14.949
H10	1204	1212	22648.00	29.394	132.90	55.00	2.289
H11	1122	1123	4080.00	5.589	111.80	8.00	0.580
H12	1164	1165	153530.00	120.223	46.86	37.91	1.076
H13	1214	1215	137680.00	100.141	56.19	37.78	1.842
H14	1254	1265	2519.00	4.172	59.54	37.78	0.090
H15	1474	1469	126970.00	82.032	209.54	103.40	8.706
H16	1411	-	985.80	2.452	37.77	8.00	0.073
H17	1154	1162	29600.00	34.195	131.00	56.11	2.560
C1	109	110	265176.00	167.283	118.00	143.00	4.014
C2	517	513	19690.00	15.291	45.02	78.00	0.504
C3	525	527	357.00	1.045	23.46	42.00	0.022
C4	302	305	49679.00	34.963	52.28	76.00	0.864
C5	-	-	242137.08	232.056	184.50	220.00	8.238
C6	-	002	241836.00	159.144	36.80	188.70	24.174
C7	112	115	148267.00	138.031	63.00	339.00	38.096
C8	151	306	146965.00	91.964	49.00	157.00	9.932
C9	190	193	263.60	0.299	111.00	315.60	0.060
C10	1438	1420	131800.00	74.354	37.00	154.10	8.706

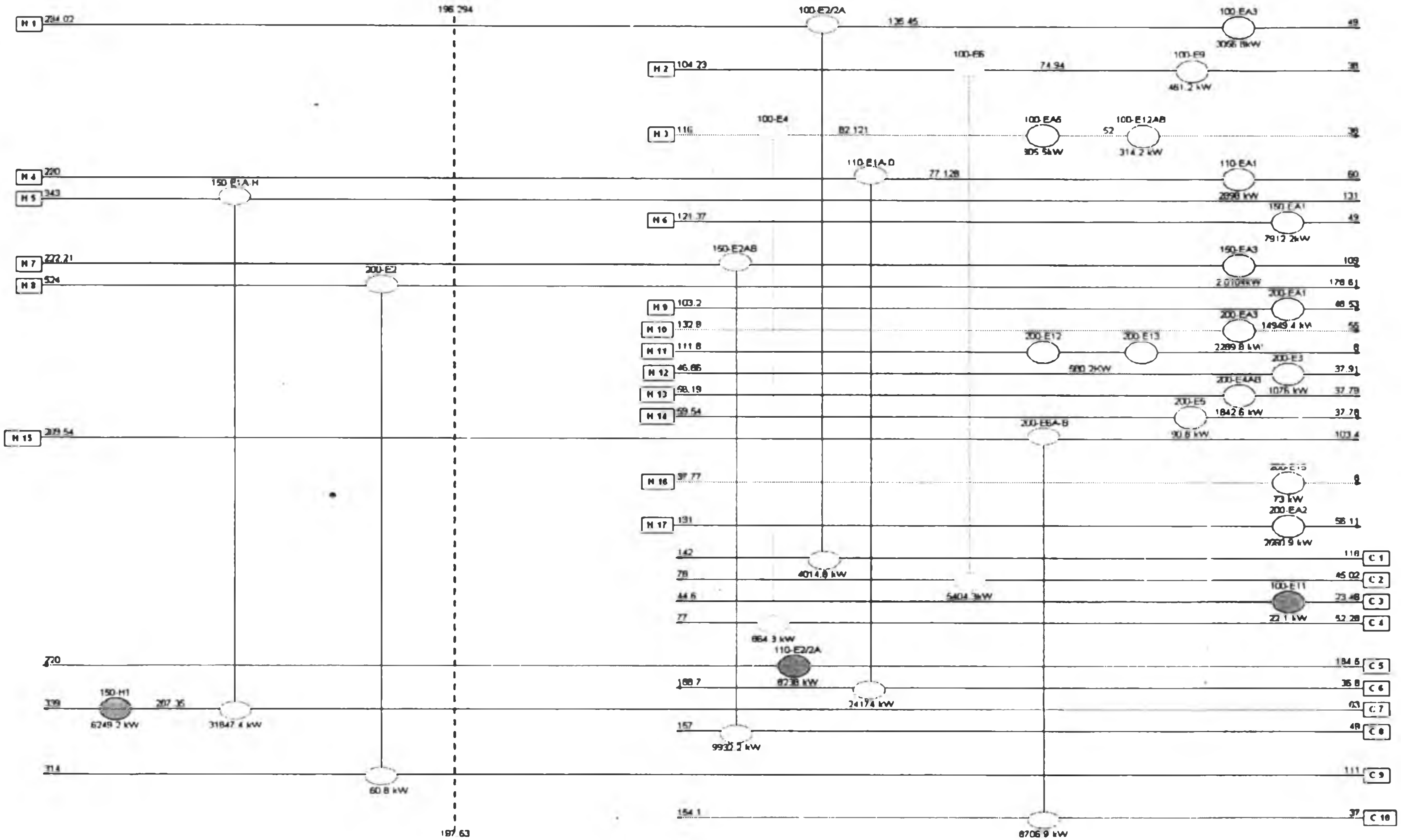


Figure 4.1 Grid Diagram of Existing Plant of Reformer Area.

4.1.2 Energy Target

The problem table analysis and grand composite curves at any minimum approach temperatures had been done as in the procedure in section 3.4. The data extracted from grand composite curve will give the minimum utility requirement at any ΔT_{min}. The Problem Table Algorithm for any ΔT_{min} is shown in Appendix B and the result of PTA is shown in Table 4.2.

Table 4.2 Result of PTA at any ΔT_{min} of Reformer Area

ΔTmin	QHmin	Qcmin	Pinch
C	KW	KW	C
40	12309.60	38716.22	200.00
45	13797.00	40203.62	197.50
47	14392.00	39627.64	196.50
47.412	14514.50	40921.10	196.29
48	14689.40	41096.02	196.00
50	15284.40	46191.02	195.00

The existing plant uses the hot utility in the process 14514.5 KW and use the cold utility in the process 40921.1 KW. This values of both utilities tell that ΔT_{min} of the process is 47.412 °C. The ΔT_{min} of this process when compares with the similar process in many literature which is about 10-20 °C (Linnhoff, 1998) is very high. This can be conclude that the utility usage in the process is too high and can be reduced by recovery process to process energy.

From The Problem Table Algorithm can plot composite curve and grand composite curve is shown in Figure 4.2 and 4.3.

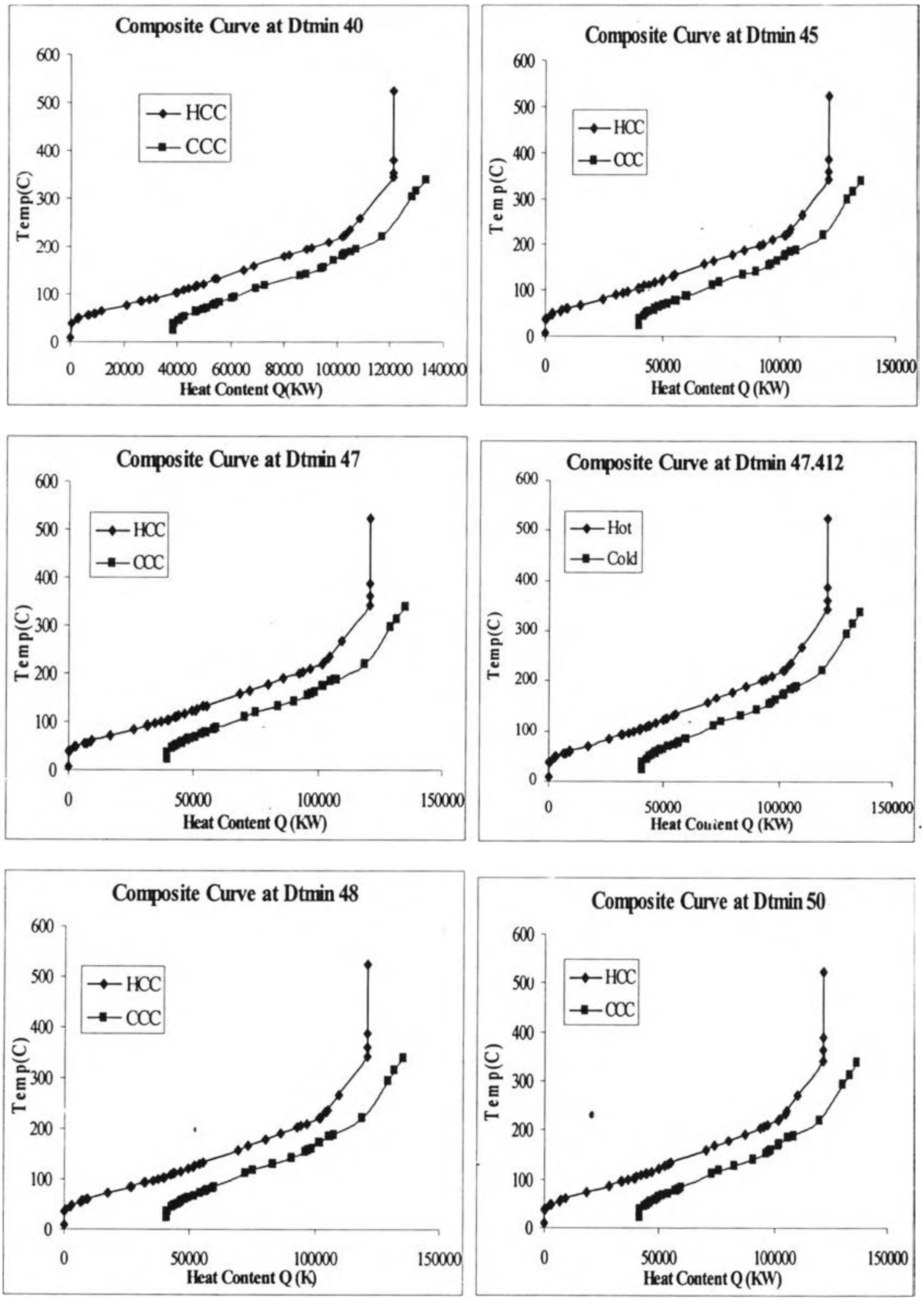


Figure 4.2 Hot and Cold Composite Curves at any ΔT_{min} of Reformer Area.

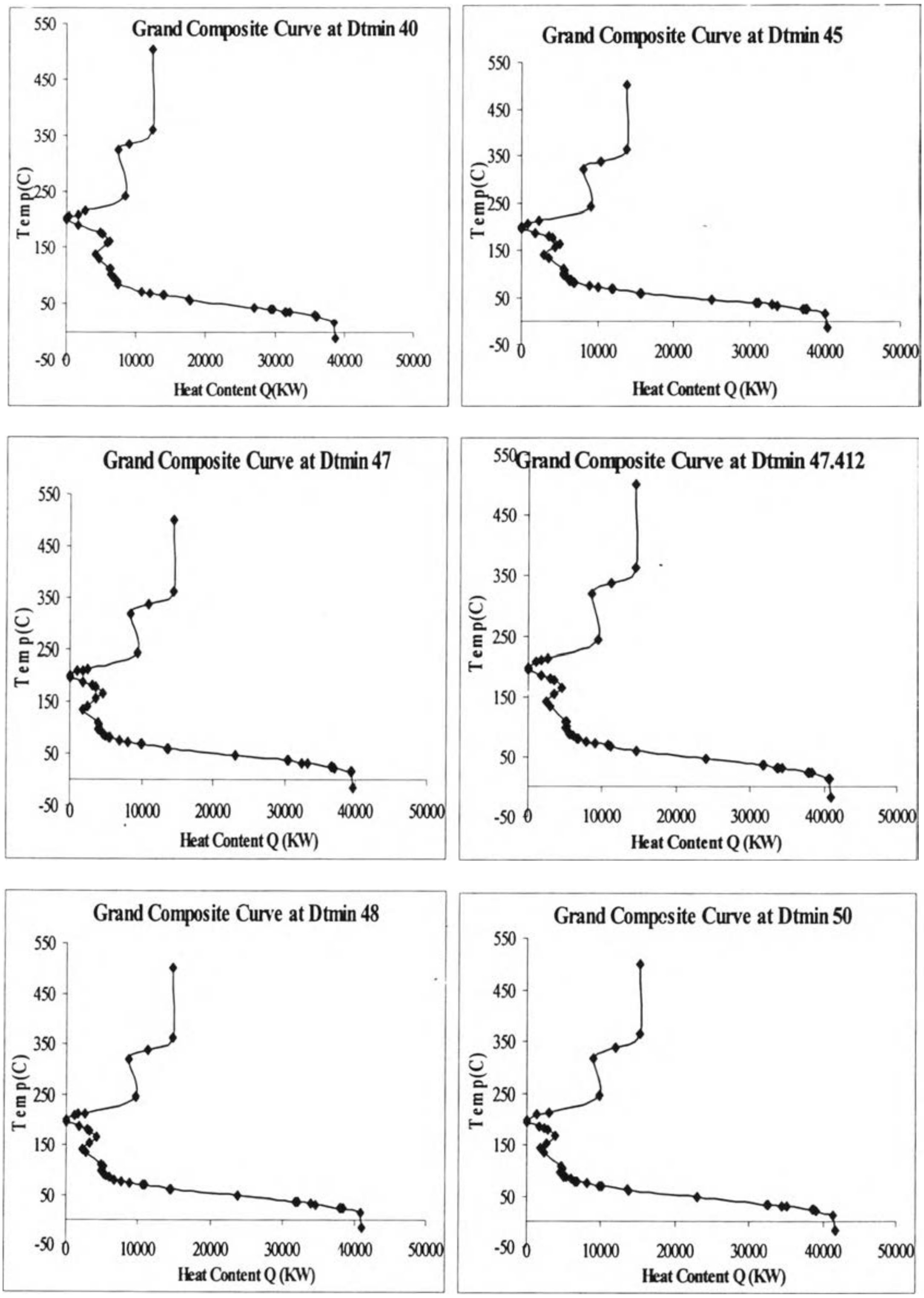
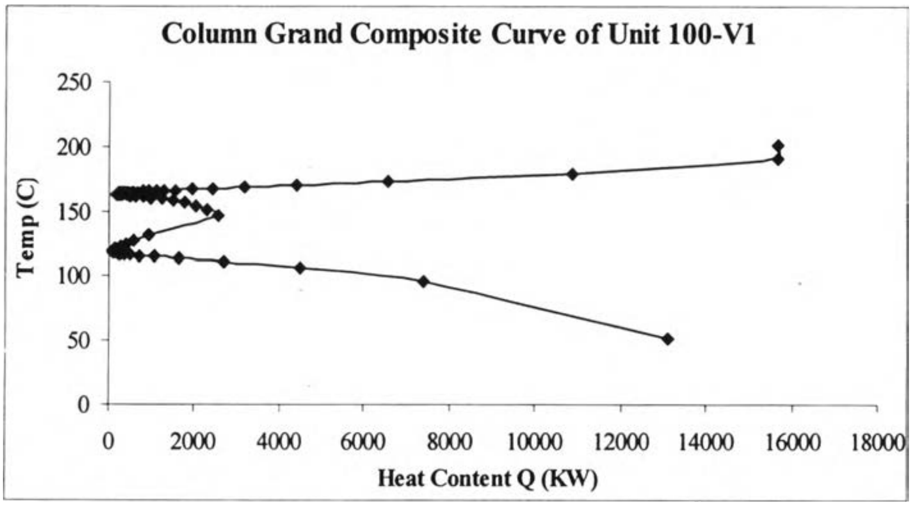


Figure 4.3 Grand Composite Curves at any ΔT_{min} of Reformer Area.

4.1.3 Plotting of Column Grand Composite Curve

In this research have 6 columns of reformer area of aromatics plant. Simulate distillation column by using ProII program and get the result to plotting the column grand composite curve. The column grand composite curve has been done as in the procedure in section 3.5. The data extracted from column grand composite curve will give profile of enthalpy change at each stage. The column grand composite curves are shown in Figure 4.4. The result of simulation of distillation column by using ProII program is shown in Appendix C.



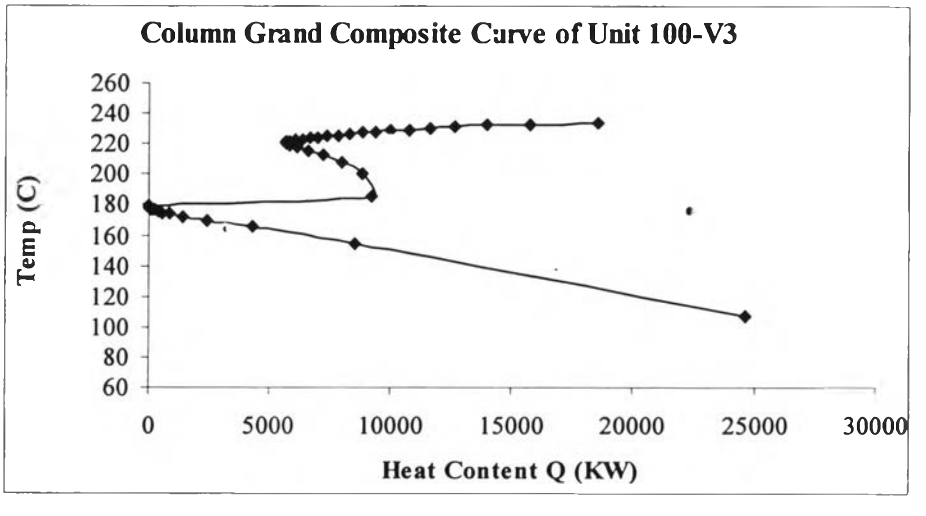
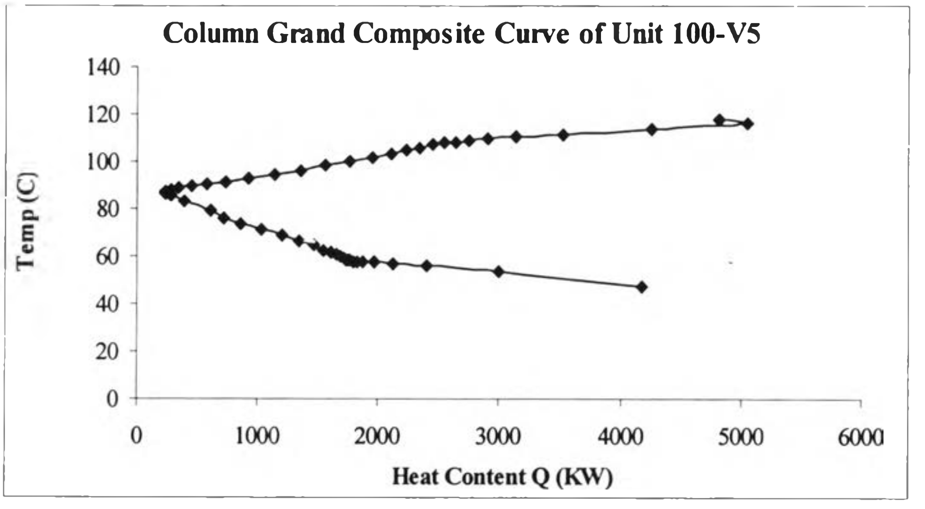
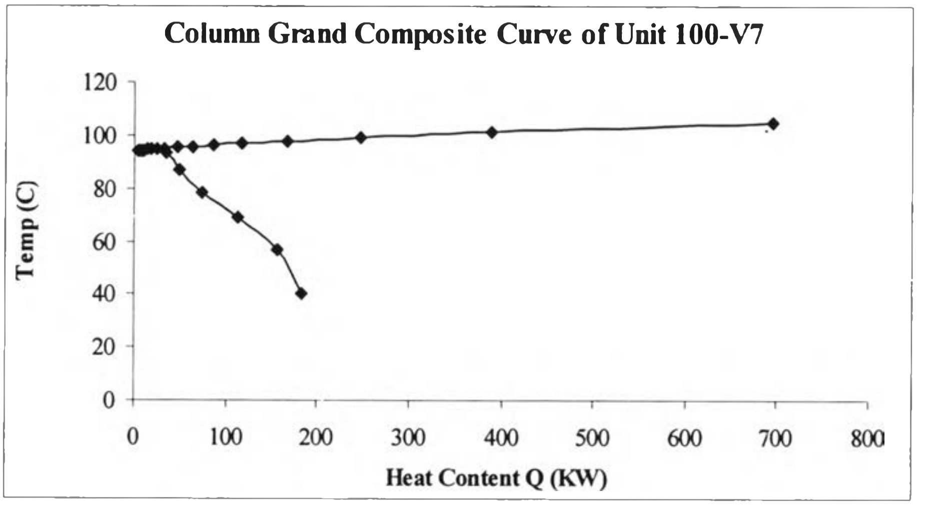


Figure 4.4 The Column Grand Composite Curve at any Distillation Column.





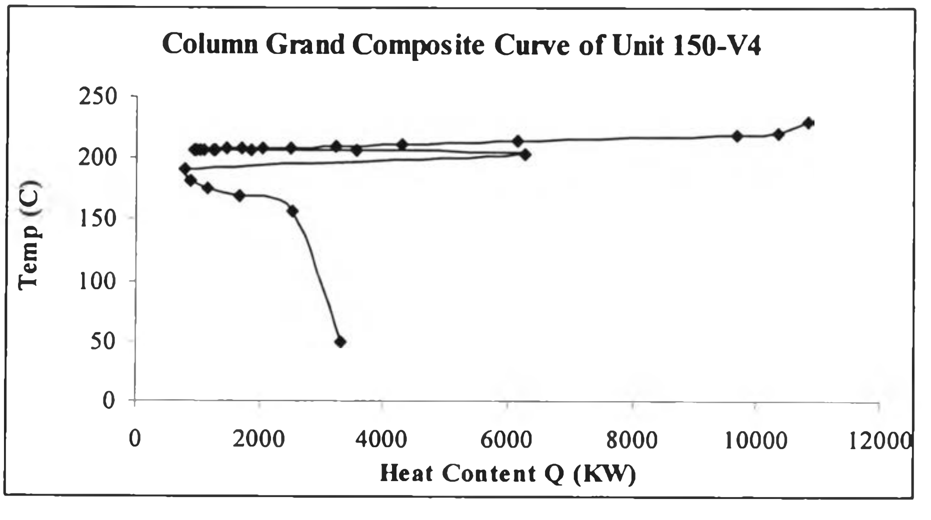


Figure 4.4 (Con't) The Column Grand Composite Curve at any Distillation Column.

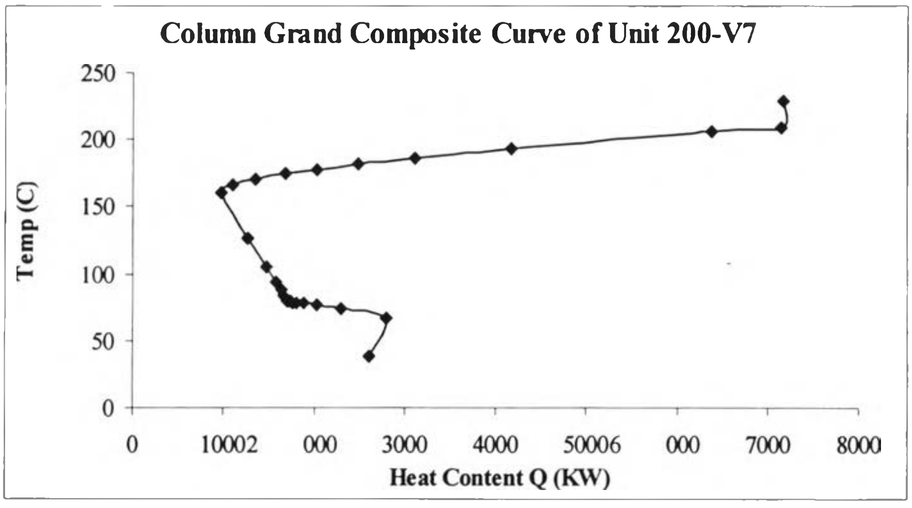


Figure 4.4 (Con't) The Column Grand Composite Curve at any Distillation Column.

4.1.4 Process Integration

GCC and CGCC were plotted in the same graph and the possibility in transferring heat among each other to save energy in the plant was considered. The grand composite curve and column grand composite curve on the same graph are shown in Figure 4.5.

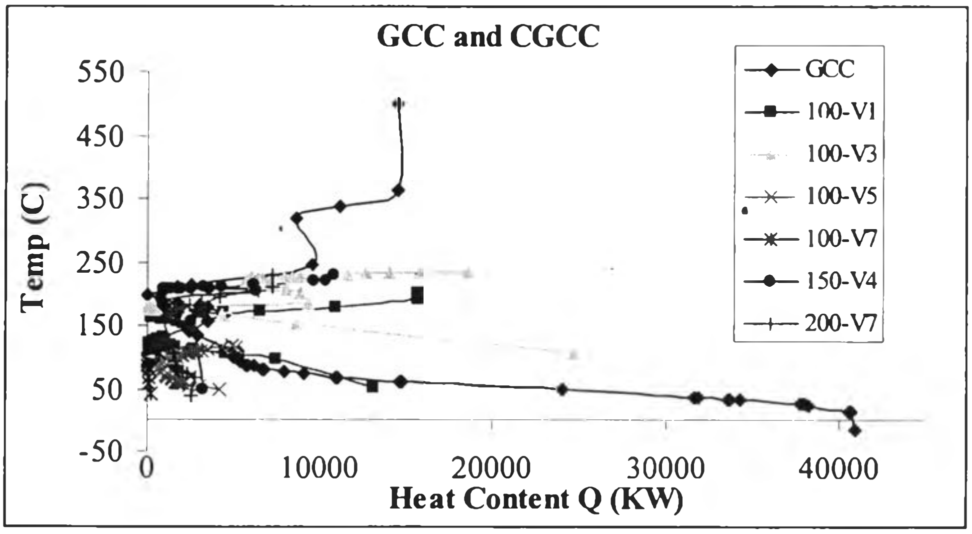


Figure 4.5 Grand Composite Curve and Column Grand Composite Curve.

Alternative 1

From figure 4.6, it was observed that heat transfer between unit 100V5 and background process could be achieved.

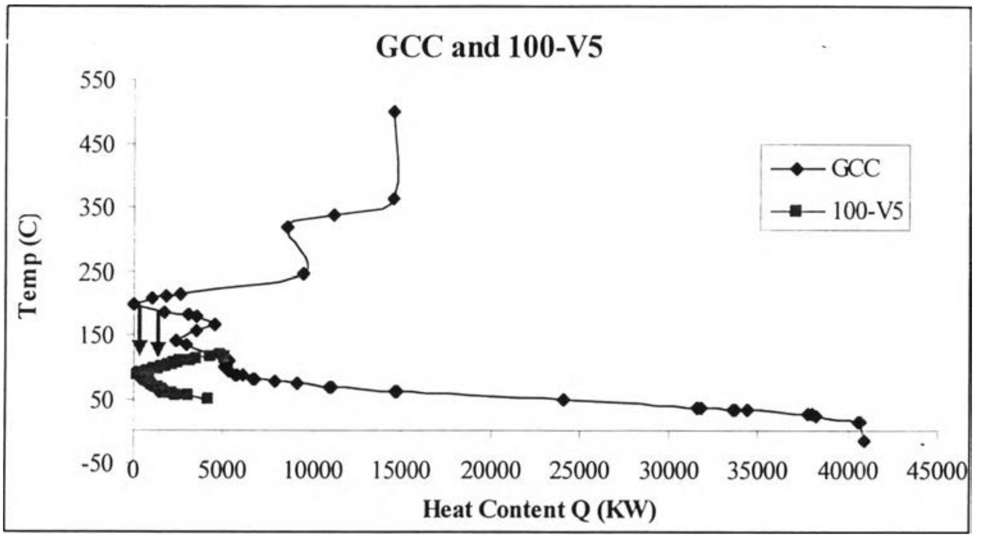


Figure 4.6 Grand Composite Curve and Unit 100V5.

From this graph, adding stream 1 by adding side reboiler at tray 36 of unit 100V5 and checking energy saving by using ProII simulate. The result after adding side reboiler is shown in table 4.3.

Table 4.3 Result of Unit 100V5 and Unit 100EA3

100-V5	Before(MW)	After(MW)	save	overall save
condenser	4.238	4.247		
reboiler	4.981	3.690	25.93%	13.91%
100-EA3	Before(MW)	After(MW)	save	
duty	3.056	1.756	42.53%	

This target duty at reboiler of unit 100V5 can be saved from 4.981 MW to 3.690 MW it about 25.93 % and overall energy saving of this distillation column is about 13.91% and unit 100-EA3 can save energy from 3.056 MW to 1.756 MW which is about 42.53%.

Alternative 2

From figure 4.7, it was observed that heat transfer between unit 100V7 and Background Process could be achieved.

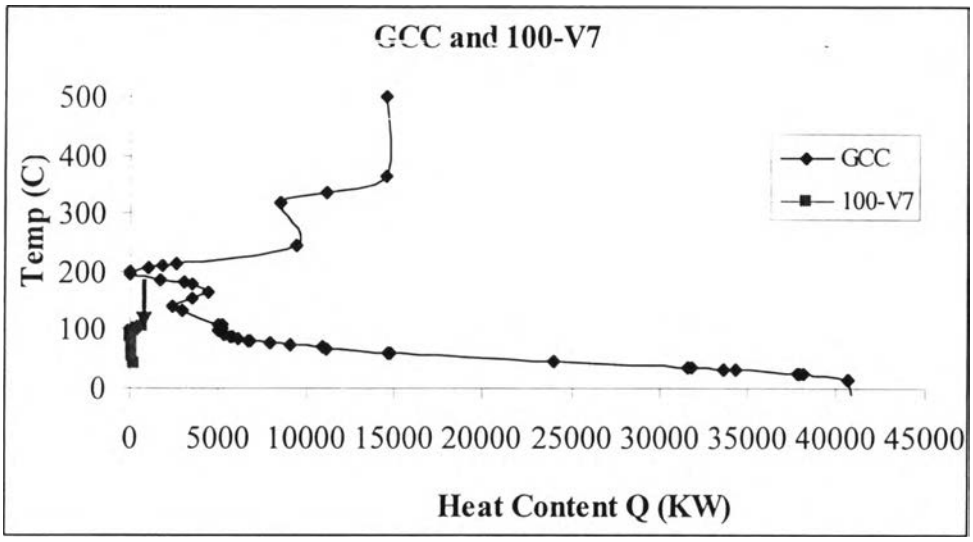


Figure 4.7 Grand Composite Curve and Unit 100V7.

From this graph we can transfer heat between unit 100V7 and Hot stream 1 by adding side reboiler at tray 25 of unit 100V7 and using ProII program to check. The result after adding side reboiler is shown in table 4.4.

Table 4.4 Result of Unit 100V7 and Unit 100EA3

100-V7	before(MW)	after(MW)	save	overall save
condenser	0.183	0.183		
reboiler	0.680	0.280	58.81%	46.33%
100-EA3	before	after	save	
duty	3.056	2.656	13.09%	

This target can save reboiler duty of unit 100V7 from 0.680 MW to 0.280 MW (about 58.81 %) and overall energy saving in this distillation column is about 46.33%. And it can save energy conservation of unit 100-EA3 from 3.056 MW to 2.656 MW (about 13.09%).

4.2 Retrofit of Aromatics Area

4.2.1 Process Data

The temperature and flow rate of streams can be measured by the instruments and are concluded in Table 3.2 and 3.3 in Chapter III. These data were concluded in Table 4.5 and 4.6. The location and information of each stream are described in Appendix D.

Table 4.5 Process Data of Aromatics Area (Hot Streams)

STREAM	stream in		stream out		phase	Tdew	Tbubble	flowrate	Cp in	Cp out	Cp avg	mCp		Tin	Tout	Temp change for sensible heat (C)	total duty
	name	phase	name	phase	change	C	C	kg/hr	kWhr/kgC	kWhr/kgC	kWhr/kgC	sensible heat	latent heat	C	C		MW
H1	120	LIQ	122	LIQ	×	-	-	83576.50	0.000585	0.000509	0.000547	48.450		96.801	36.784	96.801-36.784	2.908
H2	147	LIQ	148	LIQ	×	-	-	67043.00	0.000656	0.000649	0.000653	43.839		199.765	194.117	199.765-194.117	0.248
H3	186	VAP	180	LIQ	✔	124.591	104.748	175187.00	0.000478	0.000587	0.000532	93.279	927.977	133.614	96.801	133.61-124.591,104.48-96.8011.7	19.997
H4	114	MIX	116	MIX	✔	-	-	30431.10	0.000997	0.000967	0.000982	23.588		85.566	32.328	85.566-32.328	1.256
H5	257	MIX	259	MIX	✔	-	-	394972.00	0.000539	0.000515	0.000527	196.046		145.014	83.000	145.014-83	12.158
H6	164	VAP	166	MIX	✔	115.174	-	47718.60	0.000478	0.000669	0.000574	27.378	103.893	118.890	32.761	118.89-115.174	8.664
H7	112	LIQ	113	LIQ	×	-	-	88075.00	0.000656	0.000465	0.000560	48.693		195.470	55.950	195.47-55.95	6.794
H8	206	VAP	210	LIQ	✔	82.632	82.580	133706.00	0.000352	0.000454	0.000403	53.907	280292.260	85.100	56.833	85.1-82.632,82.58-56.833	16.096
H9	239	LIQ	242	LIQ	×	-	-	38000.00	0.000485	0.000426	0.000456	17.361		83.495	33.480	83.495-33.48	0.868
H10	304	VAP	310	LIQ	✔	112.417	112.393	222353.00	0.000414	0.000519	0.000466	103.681	934498.696	116.000	95.348	116-112.417,112.393-95.348	24.567
H11	170	LIQ	172	LIQ	×	-	-	127.74	0.000512	0.000442	0.000477	0.061		89.983	29.649	89.983-29.649	0.004
H12	259	MIX	264	LIQ	✔	-	219.420	189199.00	0.000653	0.000521	0.000587	110.991	691.676	230.772	98.410	219.42-98.41	21.283
H13	209	MIX	212	LIQ	✔	-	84.536	45101.00	0.000569	0.000510	0.000540	24.351	61.534	145.674	32.776	84.536-32.776	5.023
H14	240	LIQ	242	LIQ	×	-	-	15000.00	0.000647	0.000469	0.000558	8.329		193.275	37.693	193.275-37.6934	1.296
H15	736-732	LIQ	734	LIQ	×	-	-	151090.00	0.000735	0.000735	0.000735	105.273		254.284	197.242	254.284-197.242	6.005
H16	608	VAP	610	LIQ	✔	145.893	145.880	50835.30	0.000473	0.000587	0.000530	26.926	376834.000	147.456	137.187	147.456-145.893,145.88-137.187	5.175
H17	404	VAP	410	LIQ	✔	172.858	171.787	79967.00	0.000507	0.000607	0.000557	44.569	6660.917	174.479	154.959	174.479-172.858,171.787-154.959	7.956
H18	320	LIQ	322	LIQ	×	-	-	8248.40	0.000586	0.000465	0.000525	4.327		137.187	24.124	137.187-24.124	0.489
H19	474	LIQ	477	LIQ	×	-	-	8306.50	0.000696	0.000491	0.000594	4.929		222.359	33.400	222.359-33.4	0.931
H20	1254	LIQ	1255	LIQ	×	-	-	32548.00	0.000808	0.000671	0.000739	23.834		297.465	201.916	297.465-201.916	2.277
H21	254	LIQ	255	LIQ	×	-	-	218833.00	0.000679	0.000655	0.000667	146.070		207.122	186.764	207.122-186.764	2.974
H22	421	VAP	423	LIQ	✔	138.853	132.109	239117.00	0.000456	0.000488	0.000472	112.875	3670.518	139.910	55.804	139.91-138.853,132.109-55.8042	33.486
H23	241	LIQ	245	LIQ	×	-	-	84049.20	0.000676	0.000655	0.000665	56.104		204.511	186.261	204.511-186.261	1.024
H24	311	VAP	313	LIQ	✔	142.595	142.416	143262.00	0.000456	0.000557	0.000507	72.614	76232.078	144.554	120.945	144.554-142.595,142.416-120.945	15.347
H25	352	LIQ	359	LIQ	×	-	-	53310.00	0.000590	0.000461	0.000526	28.023		150.060	33.576	150.06-33.576	3.264
H26	325	VAP	327	LIQ	✔	111.207	111.042	54977.96	0.000409	0.000484	0.000446	24.531	34404.061	111.501	66.034	111.501-111.207,111.042-66.034	6.788
H27	-	LIQ	-	LIQ	×	-	-	59093.10	0.000784	0.000629	0.000706	206.753		189.126	164.100	189.126-164.1	5.174
H28	204	LIQ	205	LIQ	×	-	-	322480.00	0.000652	0.000614	0.000633	204.279		185.932	152.164	185.932-152.164	6.898
H29	123	LIQ	124	LIQ	×	-	-	140050.00	0.000570	0.000473	0.000521	115.108		128.351	41.492	128.351-41.492	9.998
H30	110	LIQ	111	LIQ	×	-	-	140050.00	0.000592	0.000583	0.000588	82.486		147.097	139.583	147.097-139.583	0.620
H31	171	LIQ	172	LIQ	×	-	-	202300.00	0.000701	0.000628	0.000664	134.095		229.398	177.842	229.398-177.842	6.913
H32	263	LIQ	269	LIQ	×	-	-	131180.00	0.000709	0.000583	0.000646	84.254		235.806	140.436	235.806-140.436	8.035
H33	208	MIX	212	LIQ	✔	-	139.651	78917.60	0.000577	0.000448	0.000513	40.454	120.472	160.723	37.533	139.651-37.533	6.670
H34	562	LIQ	567	LIQ	×	-	-	9343.40	0.000741	0.000452	0.000597	5.349		212.518	41.216	212.518-41.216	0.916
H35	-	LIQ	-	LIQ	×	-	-	30013.00	0.000735	0.000681	0.000708	21.217		254.284	213.472	254.284-213.472	0.866
H36	261	LIQ	264	LIQ	×	-	-	40133.20	0.000700	0.000579	0.000639	25.512		227.228	135.862	227.228-135.862	2.331
H37	210	MIX	211	LIQ	✔	-	77.541	14245.20	0.000535	0.000517	0.000526	7.498	22.846	125.633	44.786	77.541-44.786	1.344

Table 4.6 Process Data of Aromatics Area (Cold Streams)

STREAM	stream in	phase	stream out	phase	phase	Tdew	Tbubble	flowrate	Cp in	Cp out	Cp avg	mCp		Tin	Tout	Temp change for sensible heat (C)	total duty
	name		name		change	C	C	kg/hr	kWhr/kgC	kWhr/kgC	kWhr/kgC	sensible heat	latent heat	C	C		MW
C1	198	LIQ	192	LIQ	✗	-		34000.00	0.000513	0.000574	0.000543	18.457		30.000	82.131	30-82.131	0.962
C2	101	LIQ	195	LIQ	✗	-	-	163117.00	0.000592	0.000609	0.000600	96.135		124.268	136.791	124.268-136.791	1.204
C3	135	LIQ	136	VAP	✓	205.881	200.695	340450.00	0.000660	0.000535	0.000597	203.400	5664.925	199.765	210.186	199.765-200.695,205.881-210.186	30.443
C4	151	MIX	154	MIX	✓	-	-	537759.00	0.000497	0.000528	0.000512	257.604		64.435	111.630	64.435-111.63	12.158
C5	105	LIQ	109	LIQ	✗	-	-	117351.00	0.000447	0.000659	0.000553	63.901		40.605	197.850	40.6054-197.85	10.048
C6	139	LIQ	204	MIX	✓	-	112.651	190400.00	0.000494	0.000591	0.000543	103.323	223.127	49.115	178.614	49.115-112.651	21.283
C7	284	LIQ	285	MIX	✓	-	269.377	433598.00	0.000738	0.000660	0.000699	302.916	3473.403	254.284	276.615	254.284-269.377	29.712
C8	331	LIQ	338	MIX	✓	-	201.189	210000.00	0.000660	0.000647	0.000653	137.233	1686.467	189.260	203.779	189.26-201.189	6.005
C9	1156	LIQ	1160	LIQ	✗	-	-	67043.00	0.000650	0.000720	0.000685	45.815		191.143	240.849	191.143-240.849	2.277
C10	1284	LIQ	1285	MIX	✓	-	310.499	1100239.30	0.000787	0.000799	0.000793	872.803	12103.406	289.735	312.000	289.735-310.499	36.290
C11	411	LIQ	412	LIQ	✗	-	-	343000.00	0.000637	0.000653	0.000645	221.126		174.878	188.326	174.878-188.326	2.974
C12	309	LIQ	310	LIQ	✗	-	-	139500.00	0.000637	0.000651	0.000644	89.745		177.228	188.637	177.228-188.637	1.024
C13	322	LIQ	324	LIQ	✗	-	-	55300.40	0.000557	0.000575	0.000566	31.273		120.945	136.038	120.945-136.038	0.472
C14	365	LIQ	367	MIX	✓	-	151.392	167740.00	0.000592	0.000551	0.000572	95.911	5046446.000	150.060	151.393	150.06-151.392	5.174
C15	362	LIQ	364	MIX	✓	-	151.093	105770.00	0.000592	0.000503	0.000547	57.893	2279432.333	150.060	151.096	150.06-151.093	6.898
C16	164	LIQ	206	LIQ	✗	-	-	138440.00	0.000473	0.000703	0.000588	80.159		41.492	225.270	41.492-225.27	14.731
C17	273	LIQ	276	LIQ	✗	-	-	131180.00	0.000629	0.000693	0.000661	86.501		178.165	223.657	178.165-223.657	3.935
C18	242	LIQ	247	MIX	✓	-	235.882	340049.00	0.000714	0.000664	0.000689	234.184	79530.525	235.806	236.000	235.806-235.882	9.402
C19	502	MIX	504	MIX	✓	-	-	11273.00	0.000538	0.000590	0.000564	8.429		39.493	132.683	39.493-132.683	0.786
C20	541	LIQ	548	MIX	✓	-	212.712	55359.00	0.000735	0.000707	0.000721	39.922	528.629	210.911	214.214	210.911-212.712	0.866
C21	201	LIQ	204	LIQ	✗	-	-	45368.00	0.000481	0.000596	0.000539	24.364		40.754	136.422	40.754-136.422	2.331
C22	245	LIQ	246	MIX	✓	-	229.466	106100.00	0.000701	0.000660	0.000681	72.222	858.464	227.228	232.782	227.228-229.466	3.008
C23	231	LIQ	238	MIX	✓	-	132.326	688602.00	0.000566	0.000508	0.000537	369.770	43583.411	132.021	133.000	132.02-132.326	29.488
C24	331	LIQ	338	MIX	✓	-	162.941	769584.00	0.000608	0.000575	0.000592	455.349	60016.007	162.898	163.242	162.898-162.941	18.084

4.2.2 Energy Target

The problem table analysis and grand composite curves at any minimum temperature approach had been done following the procedure in section 3.4. The data extracted from grand composite curve will give the minimum utility requirement which results in minimum total cost and minimum heat exchanger capital investment cost at any ΔT_{min}. The problem table algorithm (PTA) for any ΔT_{min} is shown in Appendix E and the result of PTA is shown in Table 4.7.

Table 4.7 Result of PTA at Various ΔT_{min} of Aromatics Area

ΔTmin	$Q_{cu,min}$	$Q_{hu,min}$	pinch
°C	kW	kW	°C
5	112739.586	105654.000	134.826
10	124212.608	117127.000	137.595
20	147111.586	140026.000	137.097
30	152876.586	145791.000	147.021
40	163401.586	156316.000	152.326
41.017	167725.000	160639.000	152.530

The actual case of existing plant uses 160,639 kW of hot utility and 167,725 kW of cold utility in the process. The reduced utility is from removing some exchangers that can not be modified. These values of both utilities tell that ΔT_{min} of the process is 41.017 °C. The ΔT_{min} of this process, comparing with the similar process in many literatures which is about 10-20 °C (Linnhoff, 1998), is very high. This can be concluded that the utility usage in the process is too high and can be reduced by recovering process to process energy.

The Problem Table Algorithm can generate composite curve and grand composite curve, shown in Figure 4.8 and 4.9.

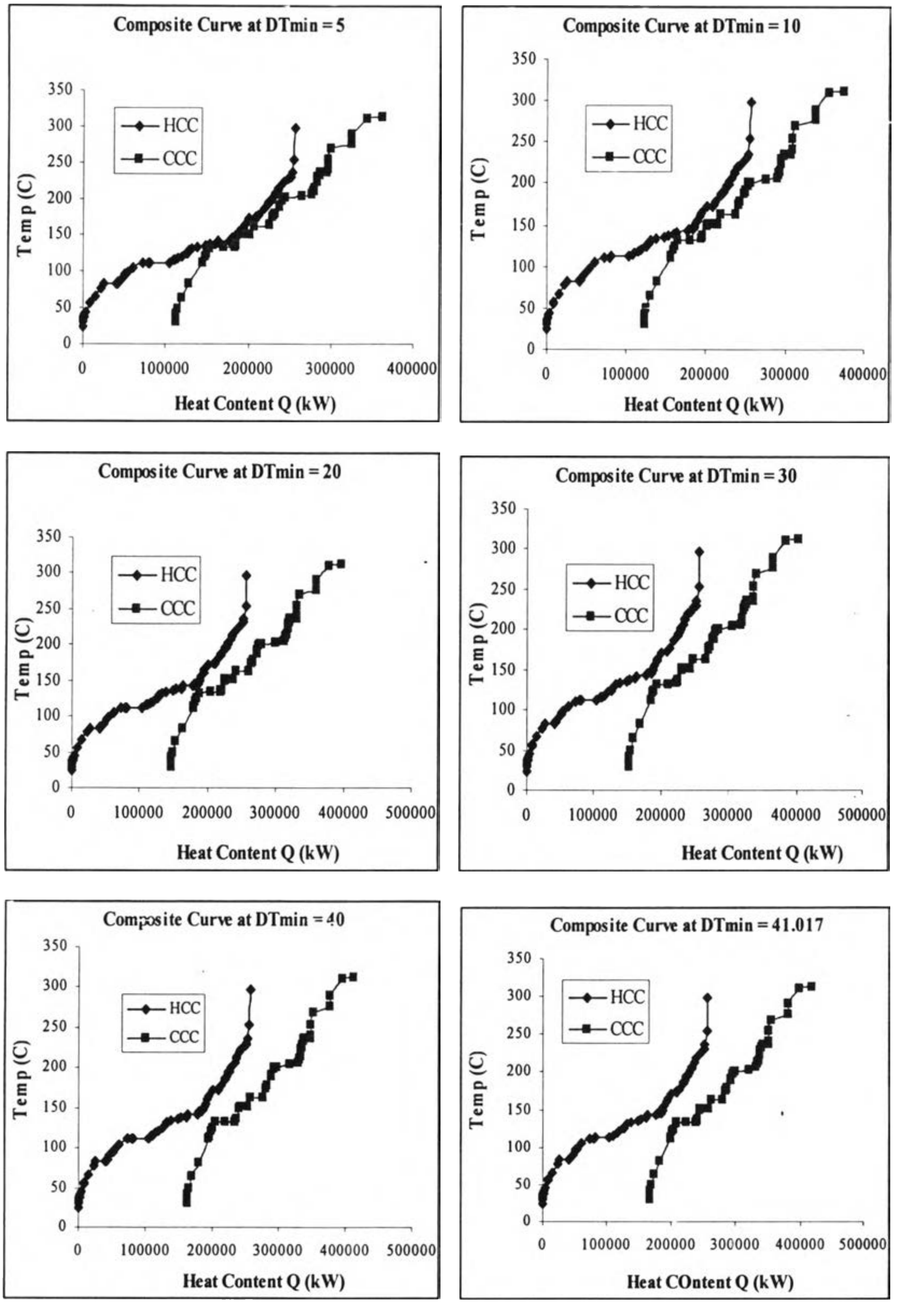


Figure 4.8 Hot and Cold Composite Curves at Various ΔT_{min} of Aromatics Area.

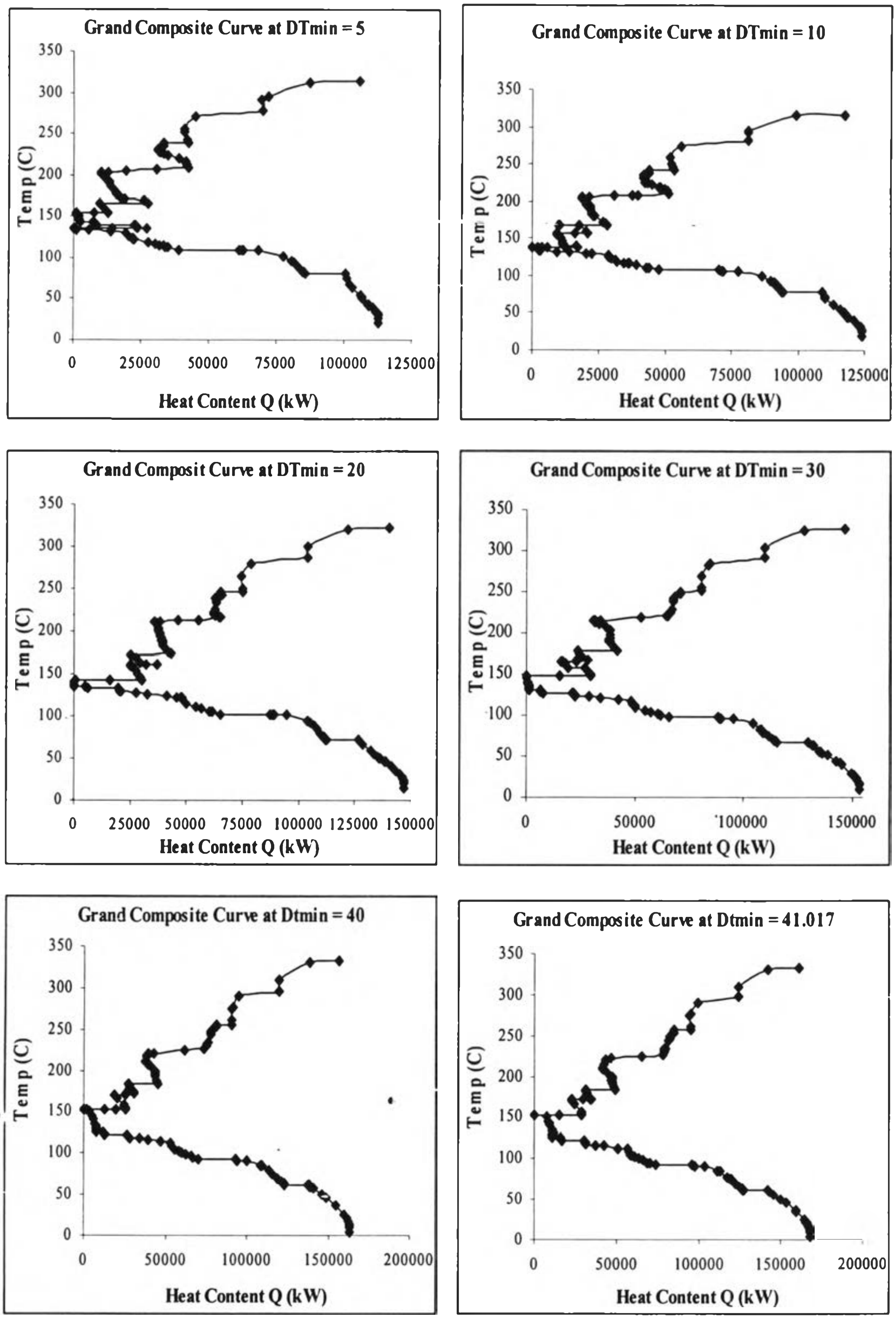


Figure 4.9 Grand Composite Curves at Various ΔT_{min} of Aromatics Area.

4.2.3 Target Area

The surface area of overall and each of existing heat exchanger is shown in Table 4.8. The hot and cold composite curves for calculating minimum area at any ΔT_{min} are shown in Figure 4.8. The procedure to construct the curves as in section 3.5 is shown in Appendix F. The result from this analysis is in Table 4.9.

Table 4.8 Surface Area of Existing Heat Exchangers in the Process

unit	steam	surface area	unit	steam	surface area
		m^2			m^2
430-E3	H1	48.00	500-E15	H28	103.00
	C1			C14	
430-E1	H2	36.30	500-E16	H29	741.00
	C2			C15	
540-E1	H5	1874.70	320-E1	H31	233.60
	C4			C16	
431-E2	H7	427.20	320-E6	H32	1498.80
	C5			C16	
380-E4	H13	245.80	320-E7	H33	602.40
	C6			C17	
432-E8	H16	283.00	320-E5	H33	98.20
	C8			C16	
432-E1	H21	171.90	320-E8	H34	349.10
	C9			C16	
500-E6	H22	487.70	320-E17	H35	54.00
	C11			C19	
500-E9	H24	238.20	320-E16	H36	108.00
	C12			C20	
500-E12	H26	81.90	390-E3	H37	72.00
	C13			C21	
				total area	7754.80

Table 4.9 Result from Target Area at Various ΔT_{min}

ΔTmin	A_{ideal}
°C	m^2
5	18430.92
10	10895.15
20	4943.36
30	4128.75
40	3089.65
41.017 (existing case)	2765.16

4.2.4 Setting Retrofit Targets

Step1. Calculation of Target Area for Various Energy Levels and Area Efficiency of Existing network

The existing HEN has an area efficiency of 0.3565, where the existing area ($A_{existing}$) and target area (A_{ideal}) for the existing energy recovery are 7754.80 and 2765.16 m^2, respectively.

Step 2. Calculation of the Retrofit Curve

The utility demands and area requirement for each global ΔT_{min} which were calculated in sections 4.2.2 and 4.2.3 are concluded in Table 4.10 and the area-energy plot is in Figure 4.10.

Table 4.10 Area-Energy Data for Various ΔT_{min}

ΔTmin	$Q_{cu,min}$	$Q_{hu,min}$	A_{ideal}	$A_{max,retr}$	$A_{max,retr}$
C	kW	kW	m2	$\Delta\alpha = 1$	$\Delta\alpha = 0.3565$
5	112739.586	105654.000	18430.919	23420.563	51688.971
10	124212.608	117127.000	10895.153	15884.797	30555.137
20	147111.586	140026.000	4943.360	9933.004	13863.508
30	152876.586	145791.000	4128.746	9118.389	11578.946
40	163401.586	156316.000	3089.645	8079.289	8664.818
41.017 (existing case)	167725.000	160639.000	2765.157	7754.800	7754.800

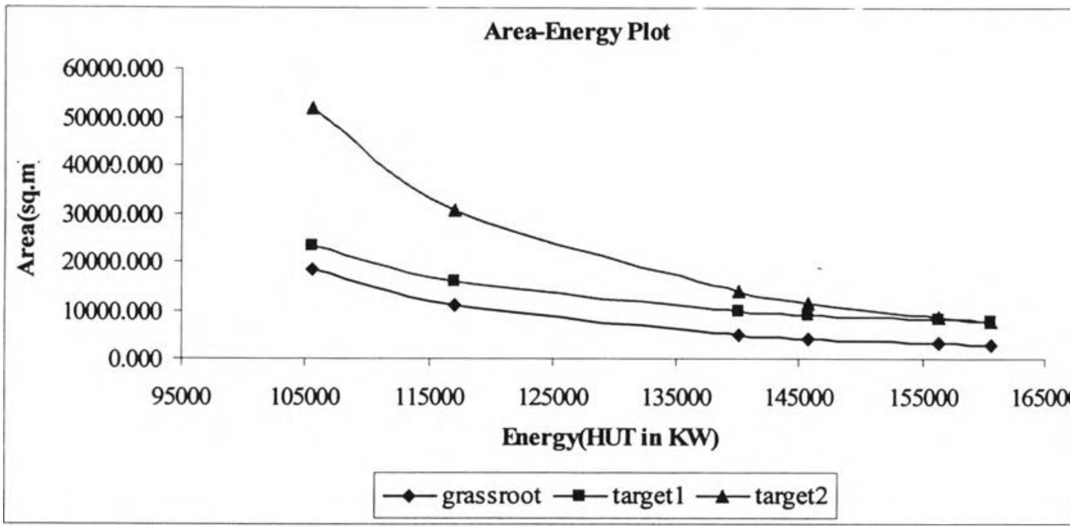


Figure 4.10 Retrofit Curve on Area-Energy Plot.

Step3. Calculation of Energy Savings and Extra Area Required

Before calculation of the energy saving, the utility usage for multiple utility levels is required and Problem Table Analysis will be very useful in this step as shown in Appendix G. The data of target utility usage for various ΔT_{min} was concluded in the Table 4.11 where

Table 4.11 Data of Target Utility Usage for Multiple Utilities

utility i	Current uility usage		Target utility required							
			ΔTmin=5		ΔTmin=10		ΔTmin=20		ΔTmin=30	
	in kW	in \$	in kW	in \$	in kW	in \$	in kW	in \$	in kW	in \$
MP	48529	10494816	13321	2880778	23023	4978910	39608	8565626	41701	9018192.8
HP	3254.5	724587								
RE			806.89	0	2206	0	5881.9	0	11041	0
ELEC	108856	47935045	92333	40658889	94104	41438885	100417	44218827	104089	45835799
CW	4071.8	0	1226.6	0	1336.6	0	2475.4	0	3793.8	0
AIR	163653	0	110706	0	120670	0	138754	0	138041	0
Sum		59154448		43539667		46417795		52784452		54853992

Step4. Economic Analysis of Investment vs. Savings

The calculated data for energy cost savings and investment cost is shown in Table 4.12. The investment-saving plot is in Figure 4.11

Table 4.12 Calculated Data for Energy Cost Savings and Investment Cost

ΔTmin	Energy Saving	Extra Area	Extra Area	Savings	Investment	Investment	payback
		Δα=1	Δα=0.35657		Δα=1	Δα=.35657	yr
C	kW	m^2	m^2	10^3\$/yr	10^3\$	10^3\$	Δα=1
5	87024.392	15665.763	43934.171	15614.782	4619.060	8487.613	0.296
10	41226.414	8129.997	22800.337	12736.653	3136.790	5763.914	0.246
20	29696.414	2178.204	6108.708	6369.996	1442.149	2649.978	0.226
30	8646.414	1363.589	3824.146	4300.456	1093.945	2010.145	0.254

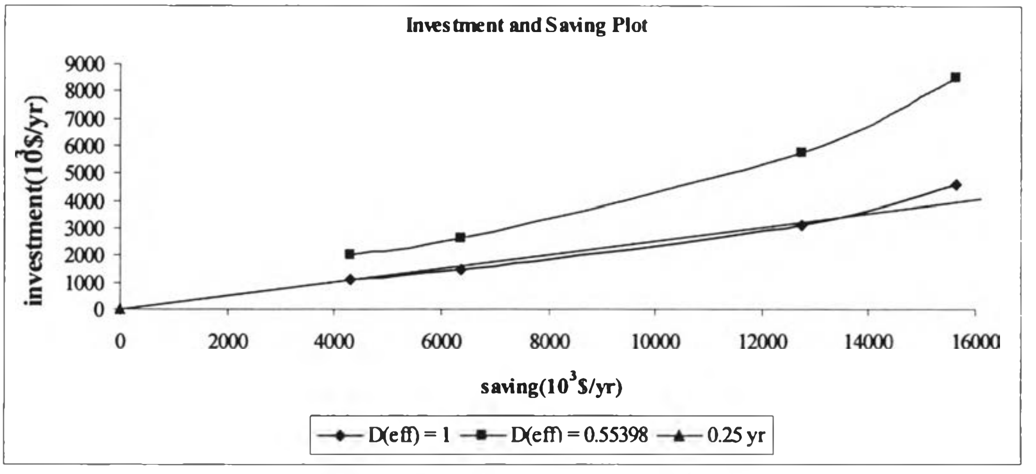


Figure 4.11 Investment-Saving Plot.

<u>Step5.</u> Identification of Target ΔT_{min}

Based on the specified payback period of 2 years the required target is the point where the investment is twice of the savings. From the table 4.12, any ΔT_{min} gives payback period less than 2 years. Therefore, the payback period is now chosen to be 0.25 year which corresponds to ΔT_{min} = 10 °C.

4.2.5 <u>Design Procedure</u>

The grid for existing network (using ΔT_{min} identified in the targeting stage) was shown in the Figure 4.12 and the heat exchangers crossing the pinch are reported in Table 4.13.

Table 4.13 Heat Exchangers, Heater and Cooler which Transfer Heat Across the Pinch

HEX no.	HEX name	Hot stream	Cold Stream	Heat load (kW)
4	430-E1	1	1	247.60
6	430-E2	mp	2	956.30
12	431-E2	7	5	6793.60
20	380-E4	12	6	21282.90
24	432-EA3	14	Air	1278.90
31	432-EA10	19	Air	931.30
38	500-E12	25	13	472.00
46	320-E6	31	16	6913.40
49	320-E8	33	16	3098.00
52	320-E17	34	19	785.50
56	390-E3	36	21	2330.90
59	431-E4	mp	23	29488.00

At the targeting stage, the potential for energy savings is set by the economics of the process. The optimum energy recovery corresponds to a minimum temperature approach of 10 °C, and the minimum energy consumption of the process is given by the composite curves.

In the diagnosis stage, inspections for topology changes, which increases energy savings by shifting heat from below to above the network pinch, are carried out. The modifications considered include resequencing, repiping and the

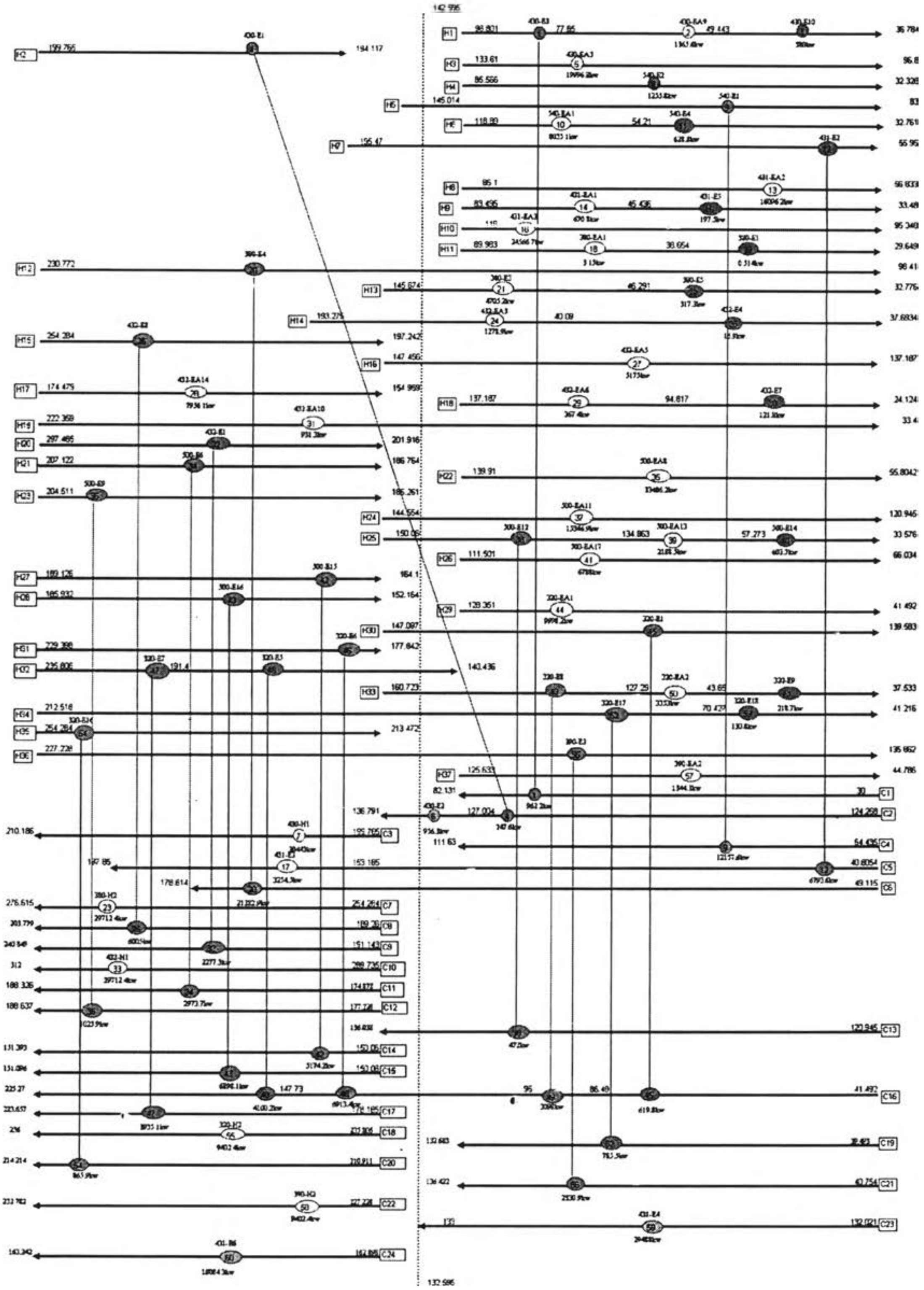


Figure 4.12 Grid Diagram of Existing Plant with Pinch Temperature.

addition of new heat exchangers. Split heuristics modifications are implemented whenever the network pinch and process pinch coincides. With these modification methods the across pinch exchanger will be eliminated and the heat flow across pinch will be reduced.

4.2.5.1 Diagnosis Stage

The purpose of this stage is to identify design options that overcome the network pinch and increases the energy recovery of the network. The inspection for potential topology changes is sequential. Each step resequencing is considered first, followed by repiping, and finally by adding of a new heat exchanger. As the area efficiency method was used for targeting, the optimum value of the minimum temperature approach of 10 °C was used for the retrofit design in this study. The design objective in the diagnosis stage was set for minimum energy consumption. A summary of the steps taken in the diagnosis stage for the different design options is shown in Figure 4.13.

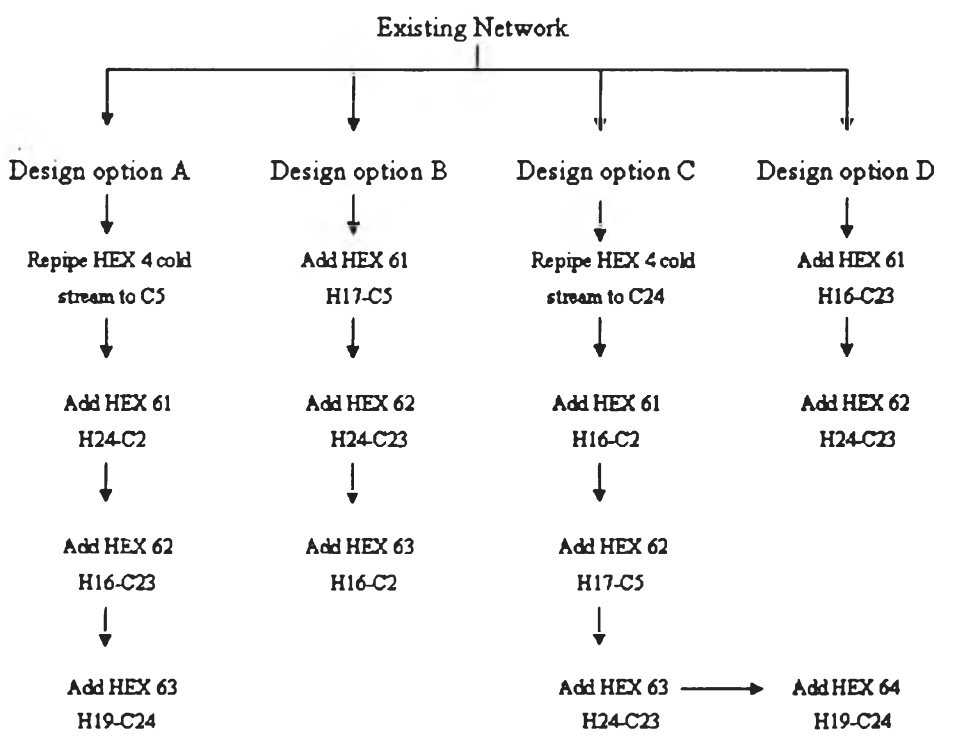


Figure 4.13 The Design Solution Search Tree for Diagnosis Stage of HEN.

Design Option A

1) There is no beneficial resequencing modification, repiping was considered. The first modification is the repiping of HEX 4's cold stream to C5 that gives HP steam duty savings of HEX 17 about 247.60 kW.

2) The next modifications for this design option is the addition of new heat exchanger. Since repiping of HEX 4, the stream C2 now needs heating with the hot stream having high enough temperature and this results is use HEX 6 and add HEX 61 between H24and C2 and saving MP steam duty about 956.30 KW of HEX 6 and saves energy about 1203.90 KW of HEX 37.

3) The modification continues with the addition of new heat exchanger HEX 62 between H16-C23 with the maximum energy recovery of cold stream C23, which saves energy about 10000 KW.

4) The further modification is the addition of new heat exchanger HEX 63 between H19-C24 with the maximum energy recovery of cold stream C24. This modification gives 486.53 KW of energy savings.

Design Option B

1) This search begins with the addition of new heat exchangers. The first modification is match of HEX 61 between H17-C5. The result is 1443.39 KW of energy savings.

2) The next modification is the addition of HEX 62 which gives two options with maximum energy recovery of stream H24. The two matches are H24-C23 and H24-C2. The match of H24-C23 is selected as in this case since there is large driving force with 23673.40 KW.

3) The next modification is use HEX 6 and add new heat exchanger HEX 63 between H16-C2 with the maximum energy recovery of cold stream C2. This modification gives 1912.60 KW of energy savings.

Design Option C

1) The first modification is the repiping of HEX 4's cold stream to C24 that gives MP steam duty savings of HEX 60 about 247.60 kW.

2) The next modification is the addition of HEX 61 which gives two options with maximum energy recovery of stream H16. The two matches are H16-C2 and H16-C3. The match of H16-C2 is selected as in this case since there is large driving force with 2160.20 KW.

3) The addition of new heat exchanger HEX 62 between H17-C5 with the maximum energy recovery of cold stream C5. This modification gives 1443.40 KW of energy savings.

4) The addition of new heat exchanger HEX 63 between H24-C23 with the maximum energy recovery of cold stream C23. This modification gives 23673.40 KW of energy savings.

5) Further modification is addition of HEX 64 between H19-C24, which give the best energy recovery.

Design Option D

1) This search begins with the addition of new heat exchangers. The first modification is match of HEX 61 between H16-C23. The result is 10089.66 KW of energy savings.

2) The addition of new heat exchanger HEX 62 between H24-C23 with the maximum energy recovery of cold stream C23. This modification gives 13598.02 KW of energy savings.

4.2.5.2 Optimized Design Options Results

After all the modifications of each design option have been completed, grid diagrams of the modified network of design options A, B, C and D are generated, and shown in Figures 4.14, 4.15, 4.16 and 4.17, respectively. The retrofit network cost report of all design options are in Appendix H. A summary of the design options modifications are:

Design Option A

- 12.894 MW of energy savings correspond to a utility cost saving about 1.395 M US$ and investment cost of 1.068 M US$ gives a payback period of 0.765 year.
- One hot utility units using MP steam are removed. The duty of other hot utility unit using HP steam and MP steam is reduced.

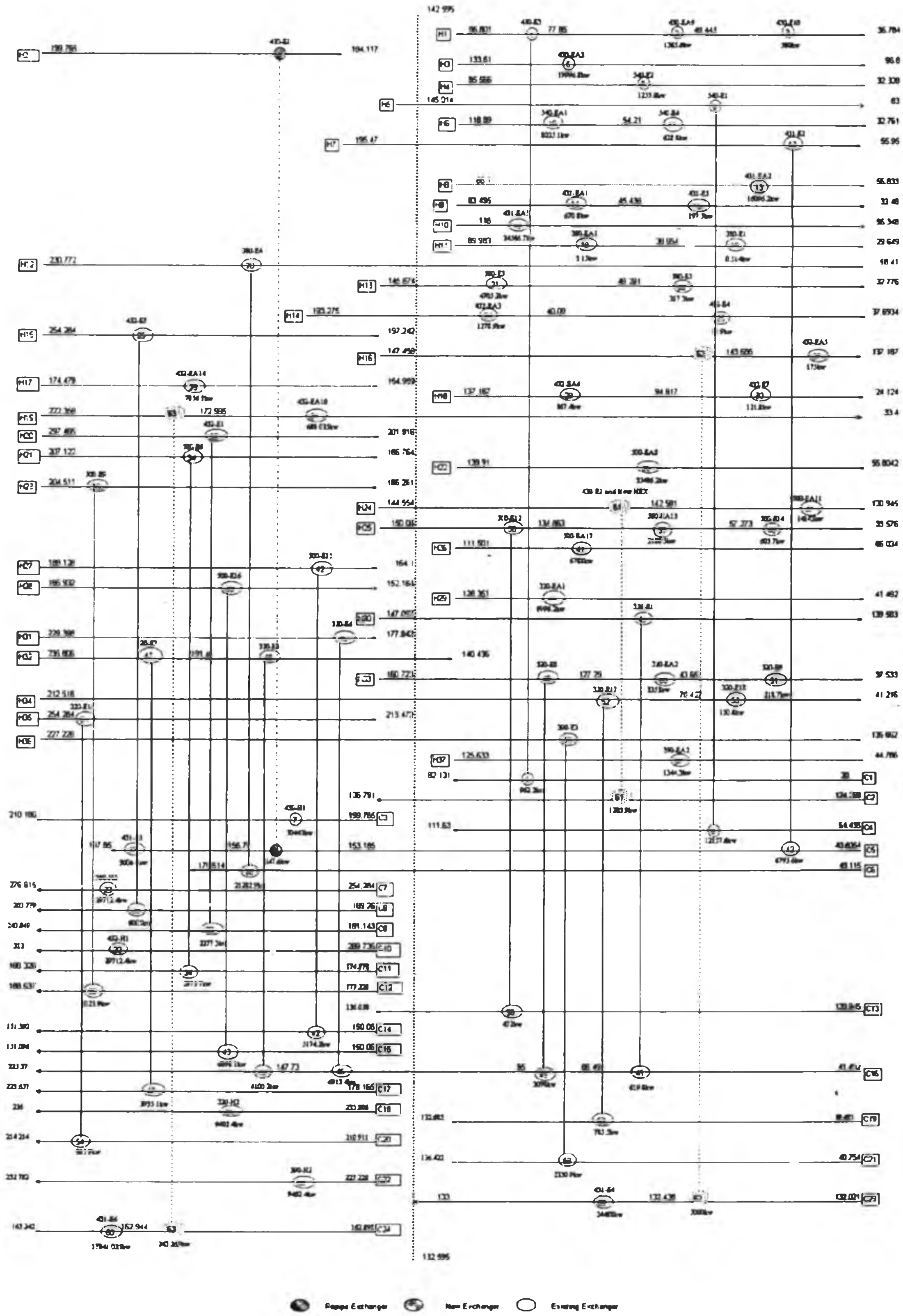


Figure 4.14 Grid Diagram for Design Option A.

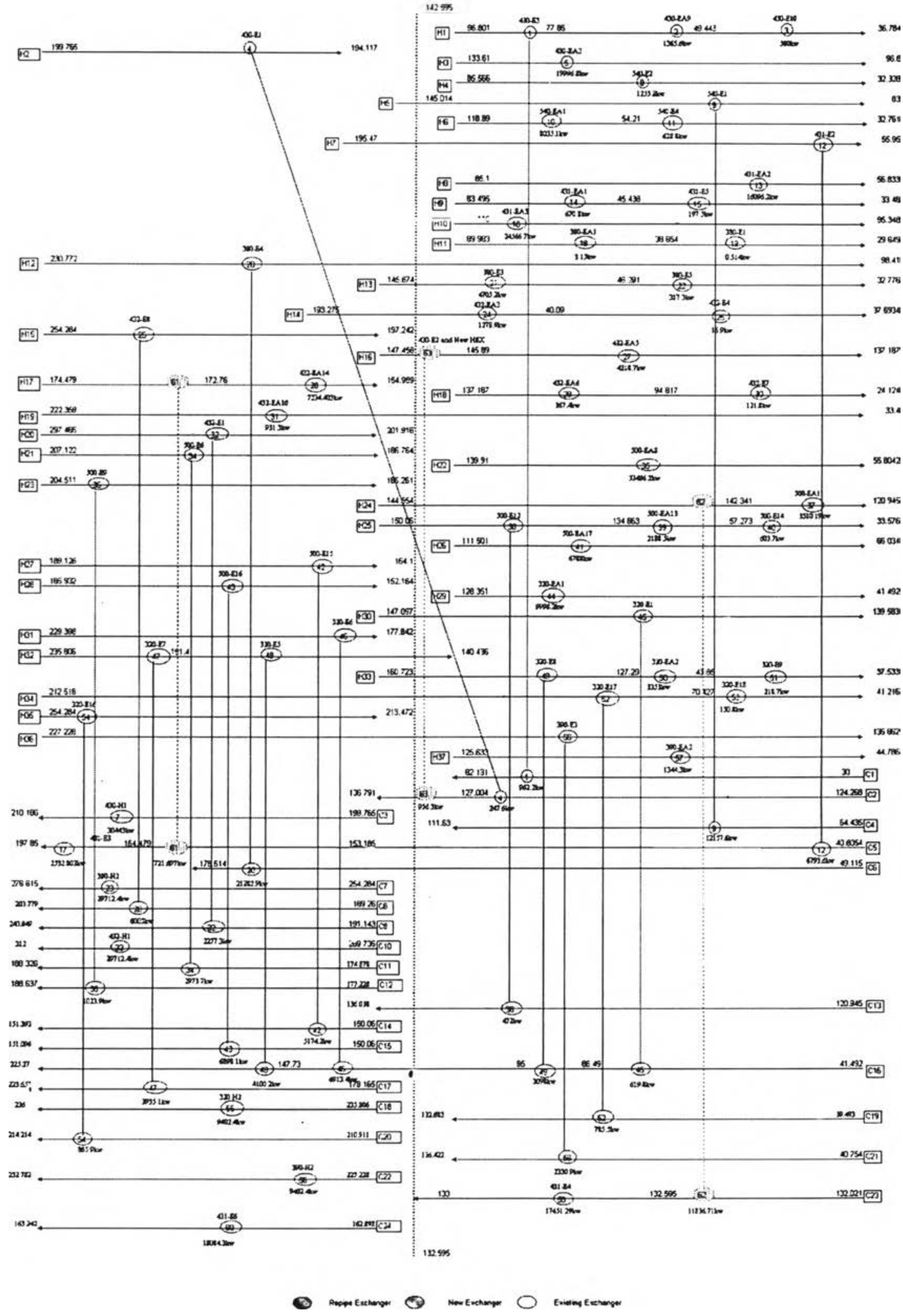


Figure 4.15 Grid Diagram for Design Option B.

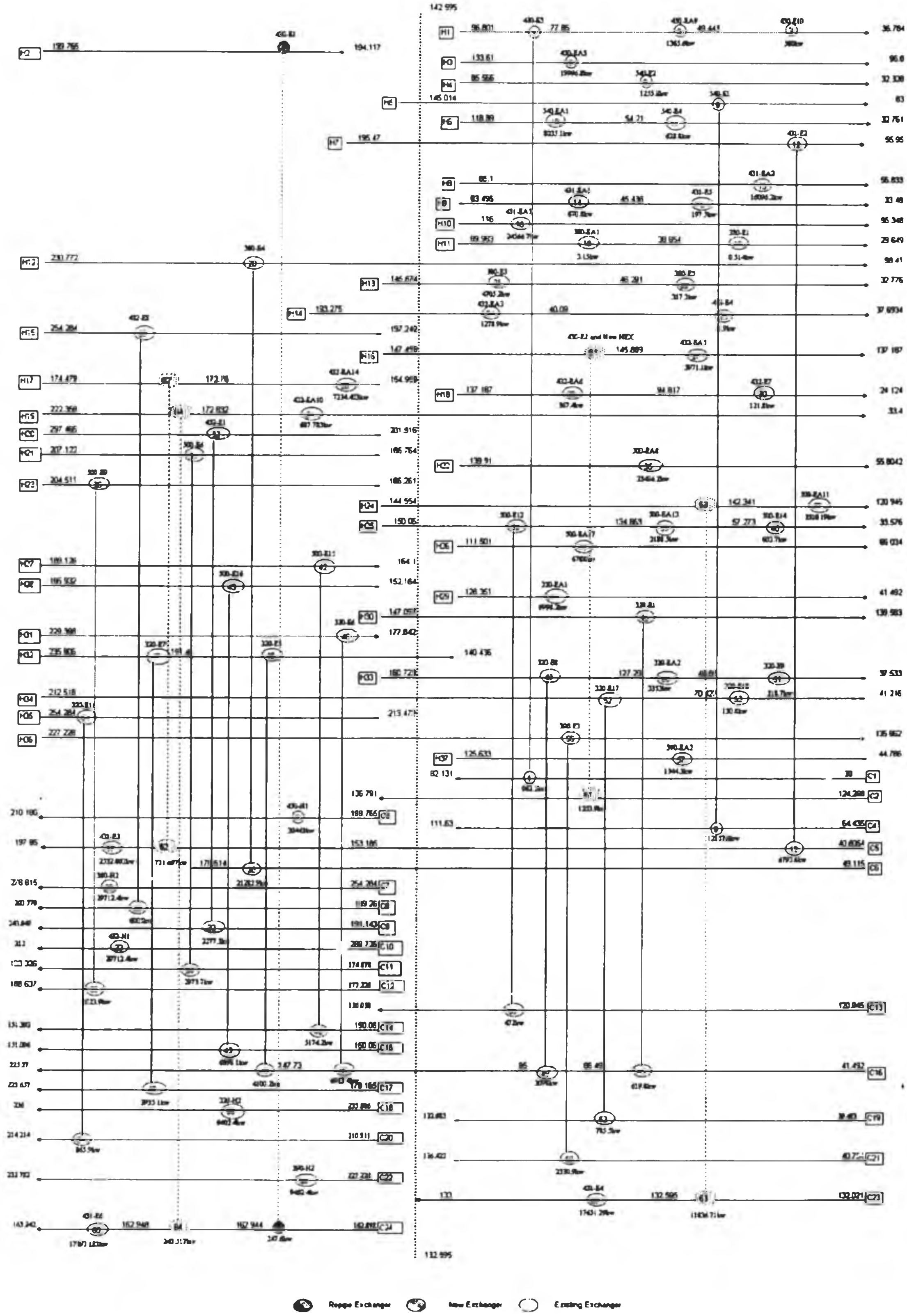


Figure 4.16 Grid Diagram for Design Option C.

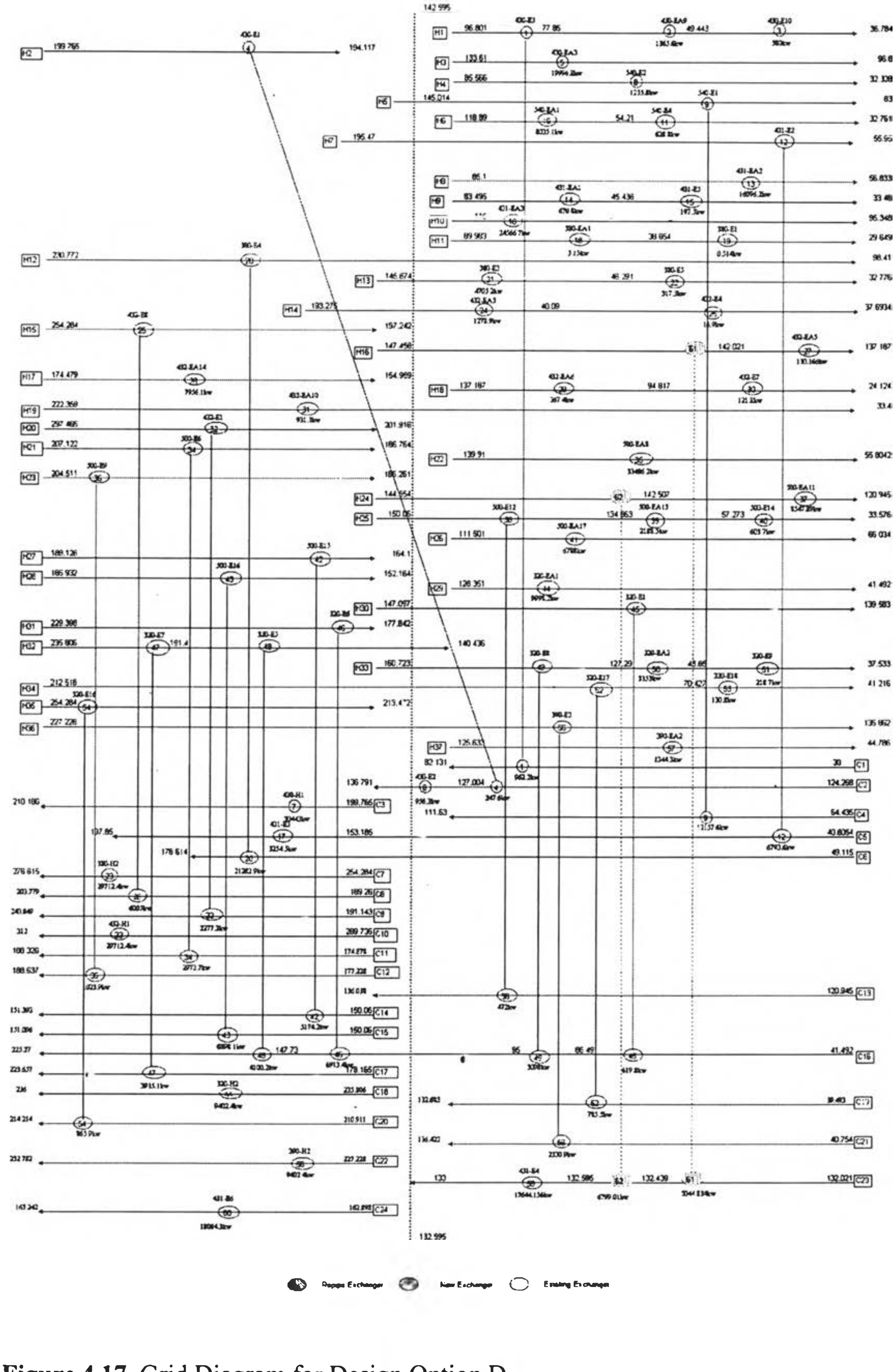


Figure 4.17 Grid Diagram for Design Option D.

Design Option B

- 27.029 MW of energy savings correspond to a utility cost saving about 2.927 M US$ and investment cost of 1.759 M US$ gives a payback period of 0.601 year.
- One hot utility units using MP steam are removed. The duty of other hot utility unit using HP steam and MP steam is reduced.

Design Option C

- 27.767 MW of energy savings correspond to a utility cost saving about 3.030 M US$ and investment cost of 1.891 M US$ gives a payback period of 0.624 year.
- One hot utility units using MP steam are removed. The duty of other hot utility unit using HP steam and MP steam is reduced.

Design Option D

- 23.687 MW of energy savings correspond to a utility cost saving about 2.561 M US$ and investment cost of 1.842 M US$ gives a payback period of 0.719 year.
- The duty of hot utility unit using MP steam is reduced.

These three designs option can reduced hot utility units using MP stream to zero load. Two design options had three new heat exchangers added to them and one design option had four new heat exchangers and the last one just add two new heat exchangers. The number of extra units was limited to keep investment costs low.

A number of modifications identified for the different design options are similar. There were two repiping options identified, which is repiping of HEX 4 which transfers heat across the pinch. The repiping of HEX 4 moves heat from below to above the pinch and reduced the utility cost significantly since it also reduced the amount of MP steam or HP steam. The rest of the modifications are the addition of new exchangers. The new exchangers include matches between hot streams and cold streams that violate the pinch.

Design C seems to give a good energy saving overall. The comparison of the results of the design options together with the existing design is given in Table 4.14.

Table 4.14 Comparison of Design Option Parameter with Existing Design

Design	Utility cost (M$/y)	Area (m^2)	ΔA (m^2)	no. of units	Payback (y)
Existing	59.154	7754.80		60	
Option A	57.758	8611.40	856.60	63	0.765
Option B	56.227	10009.02	2254.22	63	0.601
Option C	56.120	10049.02	2294.22	64	0.624
Option D	56.593	9810.22	2055.42	62	0.719