CHAPTER IV
RESULTS AND DISCUSSION

The information of gas separation unit was collected on 1 July 2004. The data consists of design and actual data. The design data is used first because there are unmeasured values of actual data. Moreover, the design case can estimate the energy saving possibility in process heat integration.

4.1 Retrofitting of Gas Separation Unit (Design Case)

4.1.1 Heat Exchanger Networks of Gas Separation Unit

In the data extraction and plant simulation steps, the flow diagram of gas separation unit and data of seven hot and six cold streams in the process simulated by PROII simulator are illustrated in appendix A. The second step is calculation and design by pinch analysis. The minimum temperature approach (ΔT_{min}) of existing process is figured out first. Pinch design method is applied to obtain minimum utility requirements at different of ΔT_{min} and a trial–and-error procedure to ascertain the ΔT_{min} for the existing utility level. Threshold problem was observed in range between 0-8.18 ^{O}C. Figures 4.1 and 4.2 present minimum energy requirement of each ΔT_{min}. The energy requirement is constant in range of ΔT_{min} between 0-8.18 ^{O}C and rising up as ΔT_{min} higher than 8.18 ^{O}C. Figure 4.3 presents the GCC with varying value of ΔT_{min}. From the previous work (Rongsayamanon, 2004), ΔT_{min} of existing process is chosen from the reference of Linnhoff March (1983). However, in this research, utilities pinch technique is used to solve for ΔT_{min} of this threshold problem.

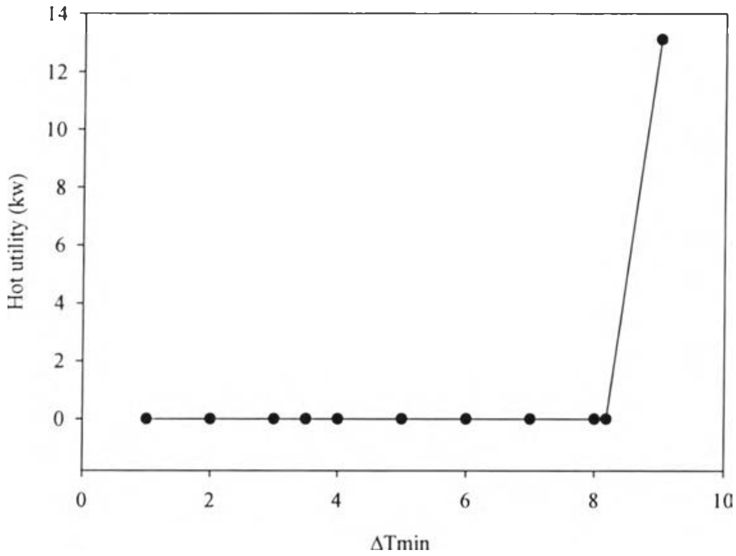


Figure 4.1 Threshold problem in hot utility.

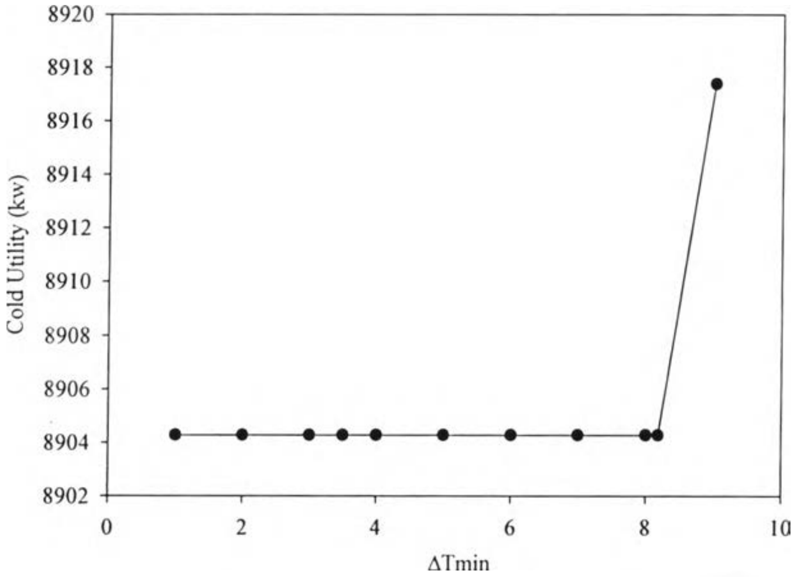


Figure 4.2 Threshold problem in cold utility.

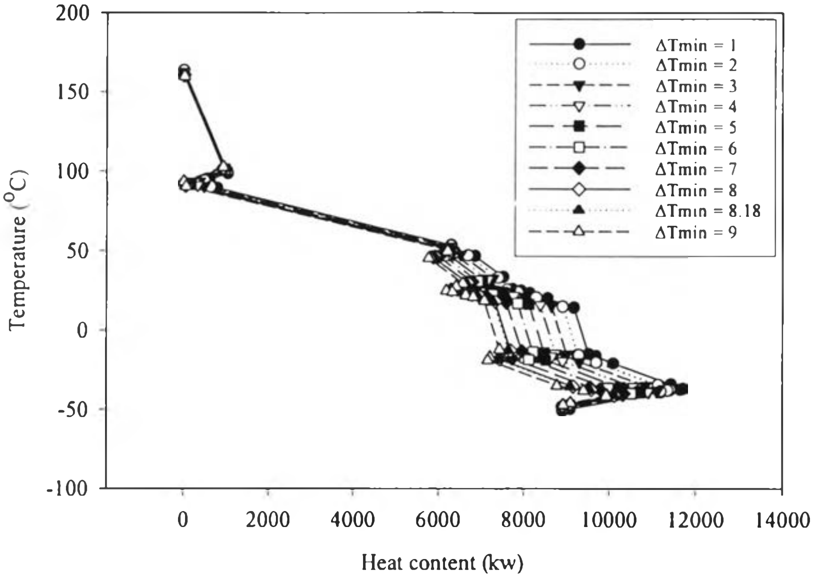


Figure 4.3 The grand composite curve of various ΔT_{min} in range of threshold problem.

From the literature survey, Querzoli and Hoadley (2002) apply this idea to find the ΔT_{min} of the process. It can be observed that minimum utility is constant (the last point of curve is the same) for unpinch problem but the profile of heat transfer is different. Thus, the utilities, refrigerant and air cooler, used in this unit are the utility pinch which help find the ΔT_{min} of the existing process. Air cooler temperature is applied to match energy consumption in the GCC with different ΔT_{min}. The reason for not using the refrigerant to match is the phase change problem in the refrigerant. Table 4.1 summarises the gas seperation utility usages in various ΔT_{min} and is used to match them with the existing utility using of design case. Matching design utility usages with targets indicates ΔT_{min} of process around 3.083 ^{O}C. The GCC of ΔT_{min} of existing process (design case) is shown in Figure 4.4 and grid diagram is shown in Figure 4.5.

Table 4.1 Utility usage summary of gas separation plant (GSPII) for ΔT_{min} between 1 to 9 ^{O}C

ΔT_{min}	Air Cooler(kw)	Refrigerant (kw)	Hot Utility (kw)
1.00	6323.87	2580.42	0
2.00	6307.88	2596.41	0
3.00	6288.78	2615.50	0
3.50	6211.79	2692.49	0
4.00	6134.81	2769.48	0
5.00	5980.83	2923.45	0
6.00	5826.85	3077.43	0
7.00	5672.88	3231.41	0
8.00	5518.90	3385.38	0
8.18	5491.19	3413.10	0
9.00	5378.03	3539.36	13.11
Design case	6276.02	2628.37	0

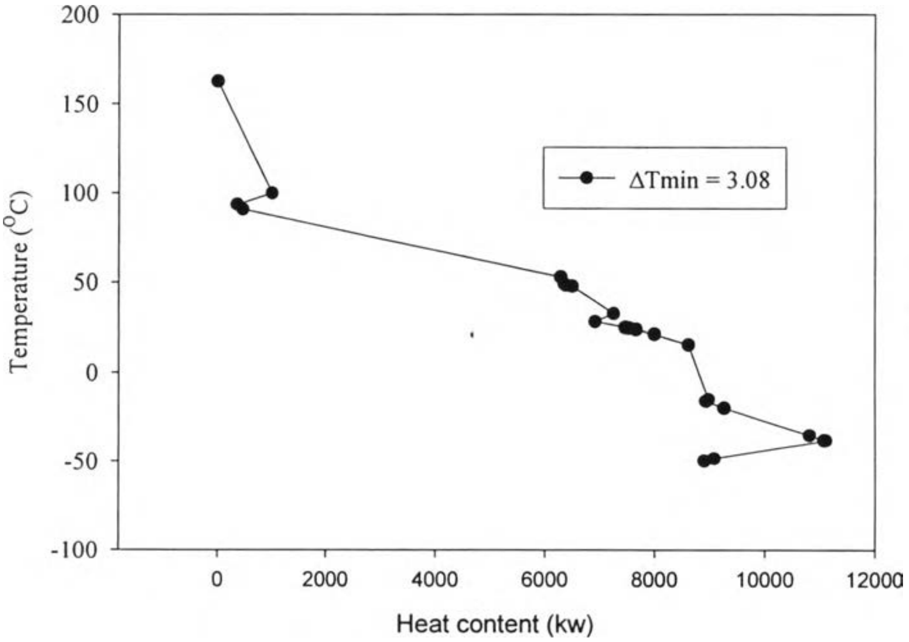


Figure 4.4 Grand composite curve at ΔT_{min} of existing process (design case).

Figure 4.5 Grid diagram of existing gas separation unit (design case).

From Figure 4.5, the modifications of heat exchanger networks cannot be done because process has no process pinch (unpinch problem), resulting in no heat transfer across pinch, no wrong position utility and no temperature crossover.

4.1.2 Distillation Column Targeting of Gas Separation Unit

There are three distillation columns in the unit, C2 plus separator, deethanizer and depropanizer columns. The design data and information of these columns are depicted in appendix A. The description of these column are shown below

- C2 separator (T78202) is the column used to separate methane as a product (sales gas). There are two feed streams, stream 78213 and 78216 to the column. Feed stream 78213 is at tray no.6 and feed stream 78216 is at tray no.26. The top and bottom products are stream 78218 and 78901, respectively.
- Deethanizer column is used to separate ethane as a product. Because of the large pressure drop occuring in the column and limitation of simulator, the column is divided into two columns (T78901-1 and T78901-2) as shown in the diagram. The feed stream is stream 78901 that comes from C2 plus separator and is fed at tray 5. Stream 78904 is the top product from T78901-1 and fed in T78901-2 at the bottom tray. The top and bottom products of this unit are stream 78902 and stream 78301.
- Depropanizer column, used to produce LPG, is fed at tray 43 by stream 78302. The top and bottom products are stream 78311 and stream 78305 respectively.

The distillation column targeting method is applied to generate column grand composite curve (CGCC). Figure 4.6 presents the CGCC of C2plus separator. The carbon dioxide (CO_2) is selected as light key component to generate CGCC. From this figure, there are two pinches because of two feed points. The reboiler and condenser duties are 7411.2 and 3142.57 kw, respectively. The reflux modification of this column cannot be done because of proper energy consumption (pinch point are nearly zero) and the scope of feed preheating is not observed. Like the C2 plus separator column, the CGCC of deethanizer and depropanizer are presented in Figure

4.7 and 4.8. Propane (T78901-1) and ethane (T78901-2) are the light key components to generate CGCC of deethanizer column while heptane is selected as key component to generate CGCC of depropanizer column.

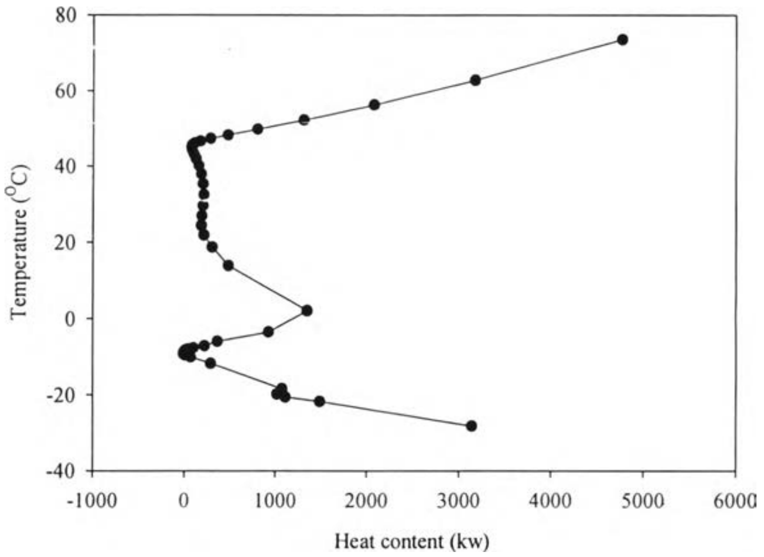


Figure 4.6 CGCC of C2 plus separator.

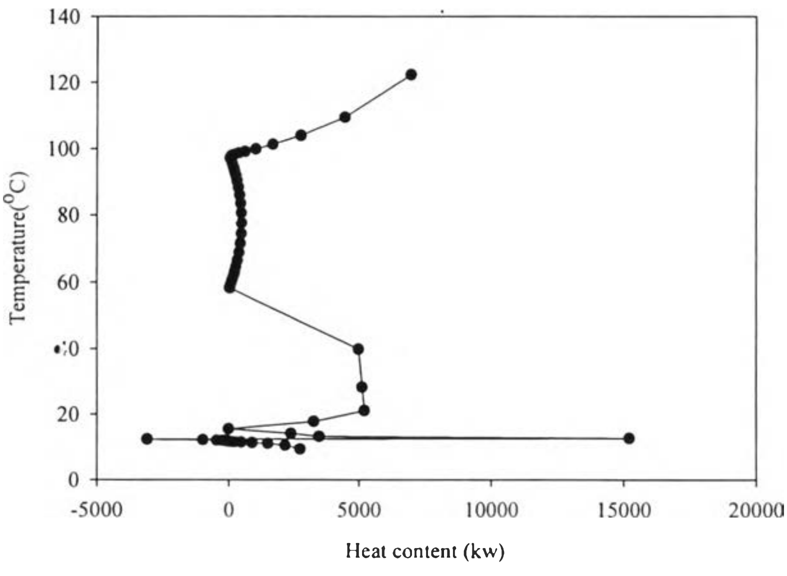


Figure 4.7 CGCC of deethanizer column.

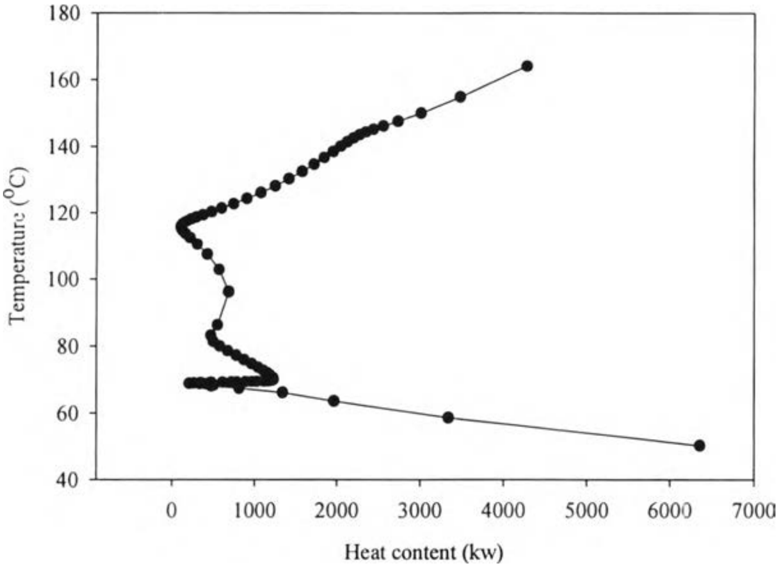


Figure 4.8 CGCC of depropanizer column.

From Figure 4.7, there are two pinches because of feed (stream 78901 and stream 78904). The reboiler and condenser duties are 6961.48 and 2752.8 kw, respectively. The error of this curve comes from the calculation model and choosing of light key component. From Figure 4.8, there are two pinch points not corresponding to one feed tray, because choosing light and heavy keys affect the shape of CGCC. The reboiler and condenser duties are 4272.75 and 6357.65 kw, respectively.

4.1.3 Energy Integration of Gas Separation Unit

As a result of distillation column targeting, the modification scope of these columns are not observed, the integration between heat exchanger network and three distillation columns is another way to improve energy recovery in the process. Integration with background process, C2 plus separator, deethanizer and depropanizer columns are shown in Figure 4.9. The maximum scope of energy recovery is between background process and C2 plus separator. Two streams, stream 78305 and stream 78603, from unit E78306 and unit E78601 respectively were selected to recover energy.

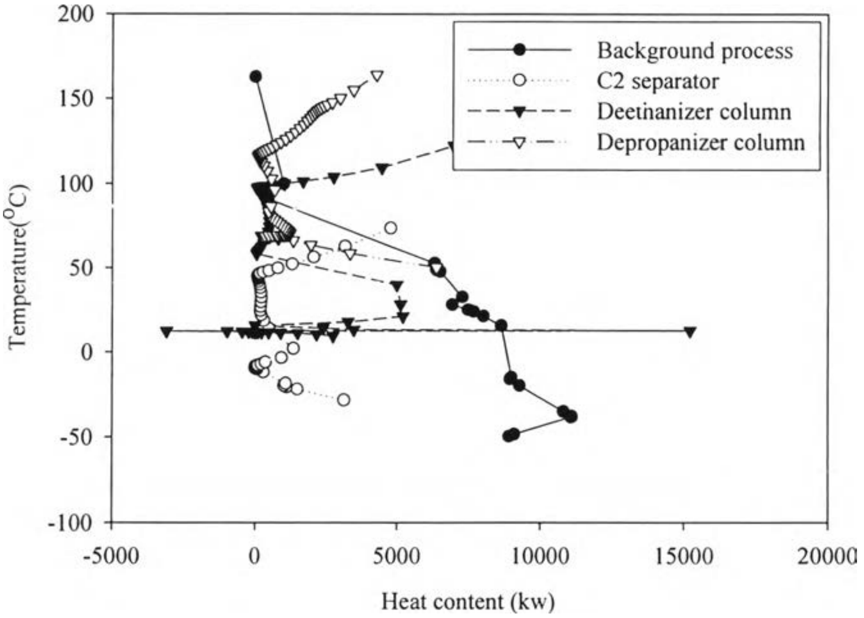


Figure 4.9 The integration of gas separation unit.

By adding side reboiler, Table 4.2 shows the energy savings and %energy recovery of gas separation unit.

Table 4.2 Energy savings and %energy recovery of gas separation unit

Option	Unit	Energy Savings (kw)	% Cold Utility Savings	%Hot Utility Savings
A	E78601	7434.57	35.14	39.87
B	E78306	1093.45	5.17	5.86

4.2 Retrofit of Gas Separation Unit (Actual Case)

Because of unmeasured information, the design model simulation is used as a base case and changed the specified parameters with the actual data to simulate the missing data. The data and information of actual case that are simulated with PROII simulator are shown in appendix B.

4.2.1 Heat Exchanger Network of Gas Separation Unit

Similarly with the design case, the threshold problem is observed in this case. The threshold temperature range is between 0-5.551 ^{O}C and the utility pinch is used to find the ΔT_{min}. Table 4.3 shows the utility summary for ΔT_{min} of 1 to 5.551 ^{O}C and Figure 4.10 shows the GCC with various of ΔT_{min} in the threshold range. By comparing the air cooler utility, the ΔT_{min} of existing unit is around 4.24. The GCC and the grid diagram of existing unit is presented in Figure 4.11 and 4.12 respectively.

Table 4.3 The utility summary for ΔT_{min} of 1 to 5.551 ^{O}C

ΔT_{min}	Air Cooler	Refrigerant	Hot Utility
1.00	5937.82	4341.34	0
2.00	5937.82	4341.34	0
3.00	5937.82	4341.34	0
4.00	5617.60	4661.53	0
5.551	4553.00	5726.17	0
Actual case	4724.42	5554.74	0

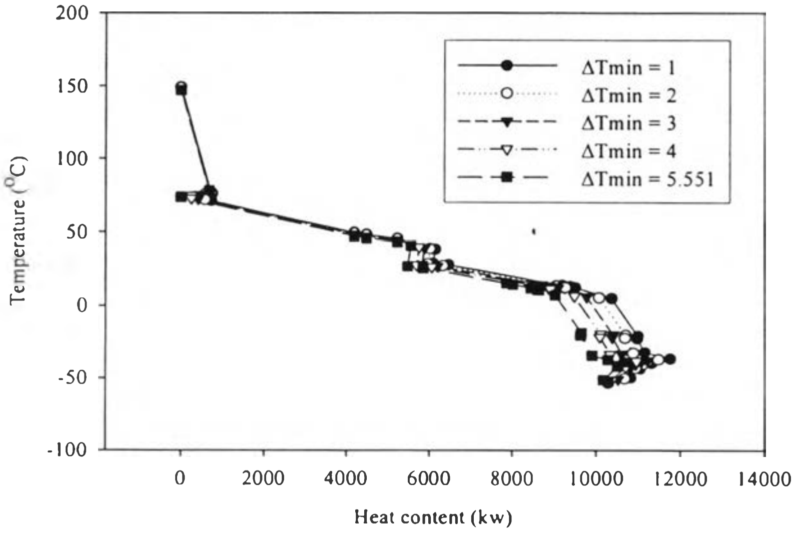


Figure 4.10 The grand composite curve of various ΔT_{min} in range of threshold problem (actual case).

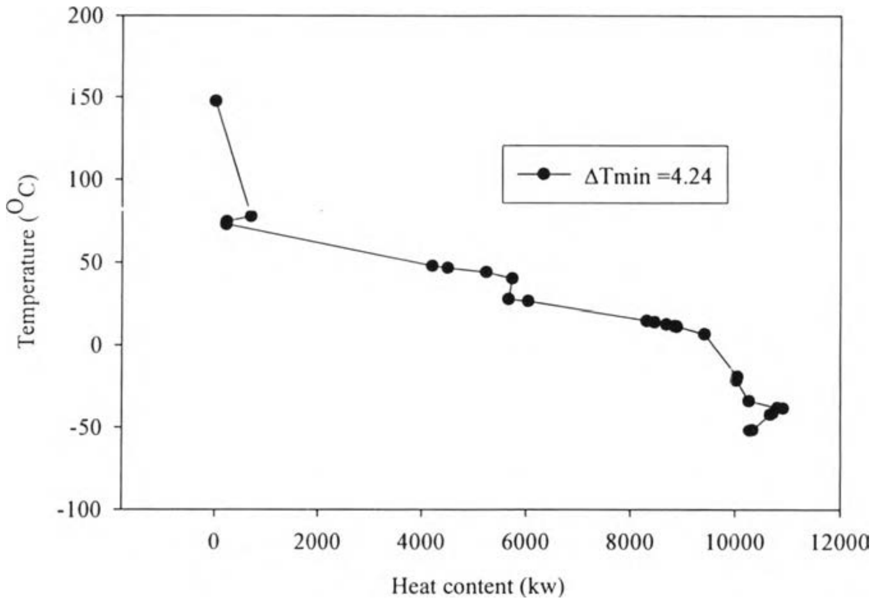


Figure 4.11 The GCC of existing unit (ΔT_{min} = 4.24).

From the observing, the modifications of heat exchanger networks cannot be done because of the optimum energy recovery of the unpinch process which has no process pinch, resulting in no heat transfer across pinch, no wrong position utility and no temperature crossover.

4.2.2 Distillation Column Targeting of Gas Separation Unit

Data and information of actual columns are illustrated in Appendix B. The reboiler and condenser duty of these columns are shown in Table 4.4. The CGCC of three actual columns are shown in Figure 4.13, 4.14 and 4.15, respectively.

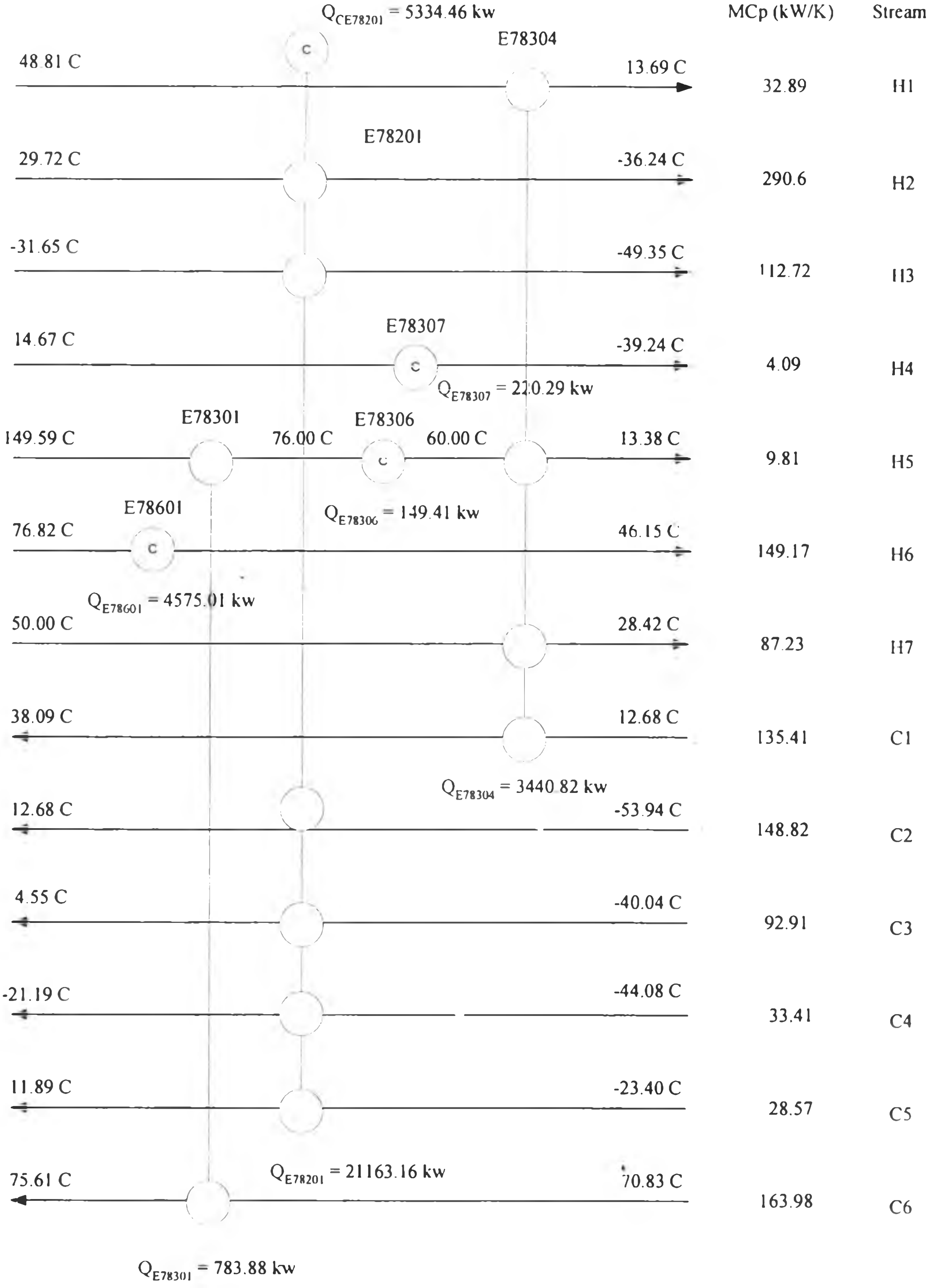


Figure 4.12 The grid diagram of existing unit (actual case).

Table 4.4 Rebolier and condenser duty of C2 separator, deethanizer and depropanizer columns

Column	Unit	Duty (M*KJ/HR)	
		Rebolier	Condenser
C2 separator	T78202	26.88	7.34
Deethanizer	T78901-1	-	8.29
	T78901-2	25.05	14.85
Depropanizer	T78301	13.69	24.36

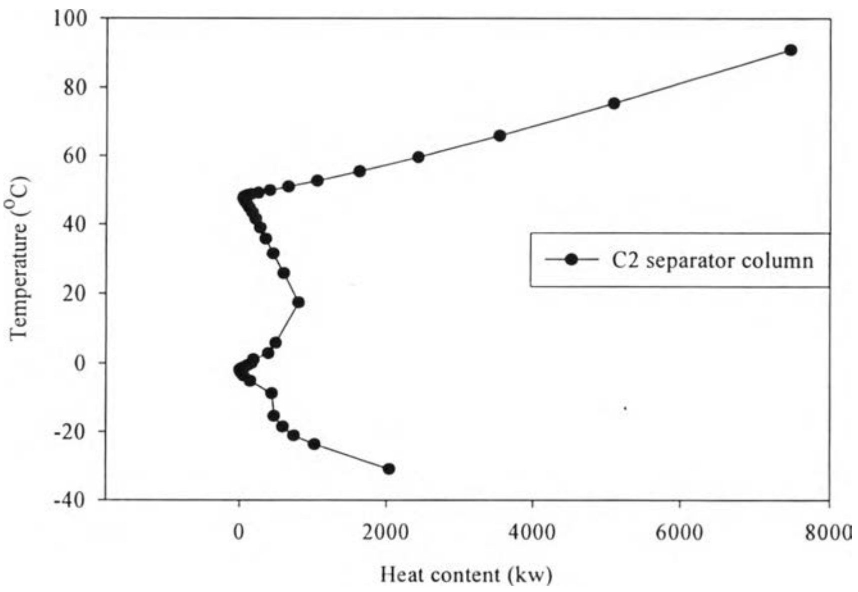


Figure 4.13 CGCC of C2 separator column (actual case).

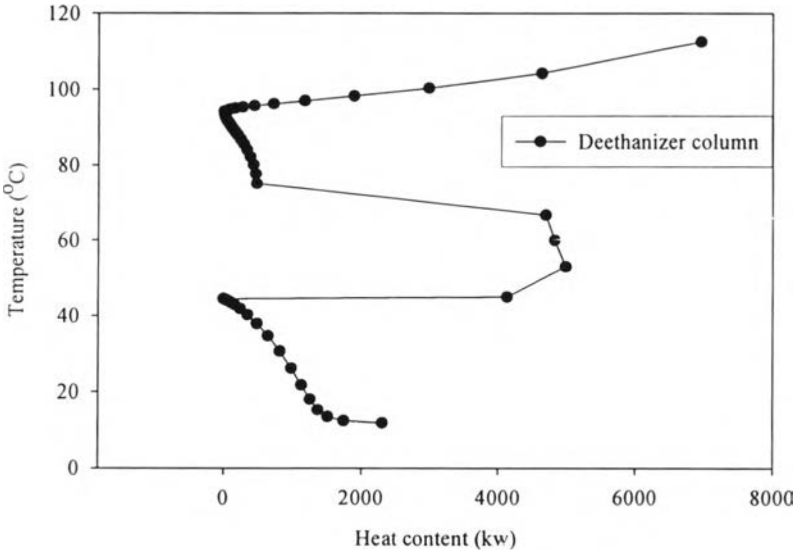


Figure 4.14 CGCC of deethanizer column (actual case).

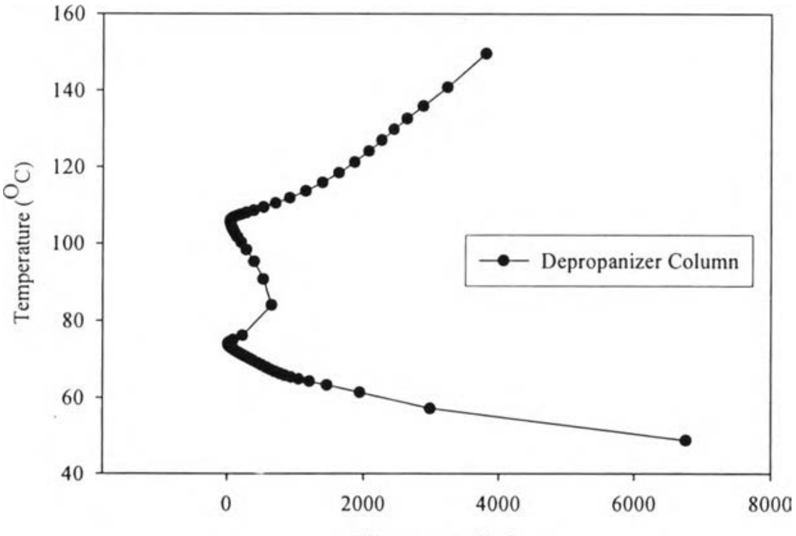


Figure 4.15 CGCC of depropanizer column (actual case).

From the CGCC of these columns, the modification of CGCC is not observed similarly with design case.

4.2.3 Energy Integration of Gas Separation Unit

The modification of these column cannot be done like design case. Energy integration is another way to improve energy recovery in the process. The integration between GCC and CGCC are shown in Figure 4.16.

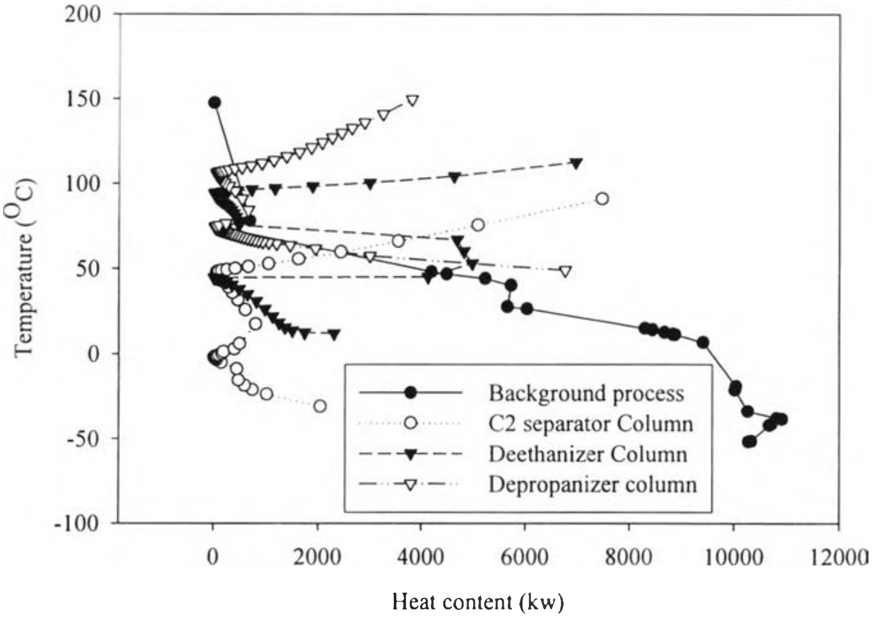


Figure 4.16 The integration of gas separation unit (actual case).

The maximum energy integration is observed between background process and C2 separator column. For clearly, Figure 4.17 shows the integration between background process and C2 separator column. Two streams, 78305 and 78603, from unit E78306 and E78601, respectively were selected to recover energy. By adding side reboiler, Table 4.5 shows the energy savings and %energy recovery of gas separation unit.

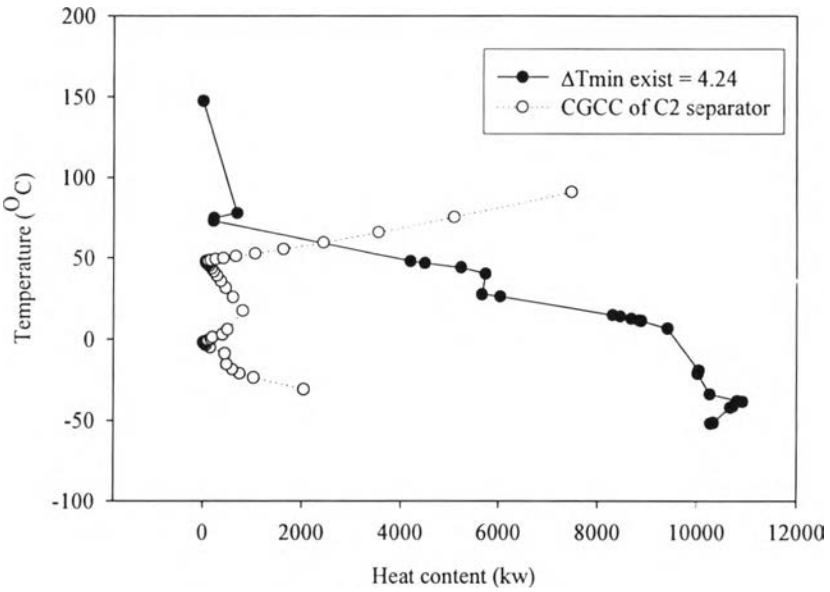


Figure 4.17 The integration between background process and C2 separator.

Table 4.5 Energy savings and %energy recovery of gas separation unit

Option	Unit	Energy Saving (kw)	%Cold Utility Saving	%Hot Utility Saving
A	E78601	1979.28	9.26	10.86
B	E78306	149.41	0.70	0.82

4.3 New Design for stabilizer unit

4.3.1 Heat Exchanger Networks of Stabilizer Unit

Stabilizer unit consists of three hot and one cold streams. Like gas separation, data extraction and simulation with PROII simulator is the first step. The diagram of stabilizer units and streams data are presented in appendix C.

After appling pinch analysis to this unit, threshold problem that refers to matching “very very hot stream” with very very cold stream” is observed in the design. Utilities do not change when varying minimum temperature approach (ΔT_{min}) as shown in Figure 4.18.

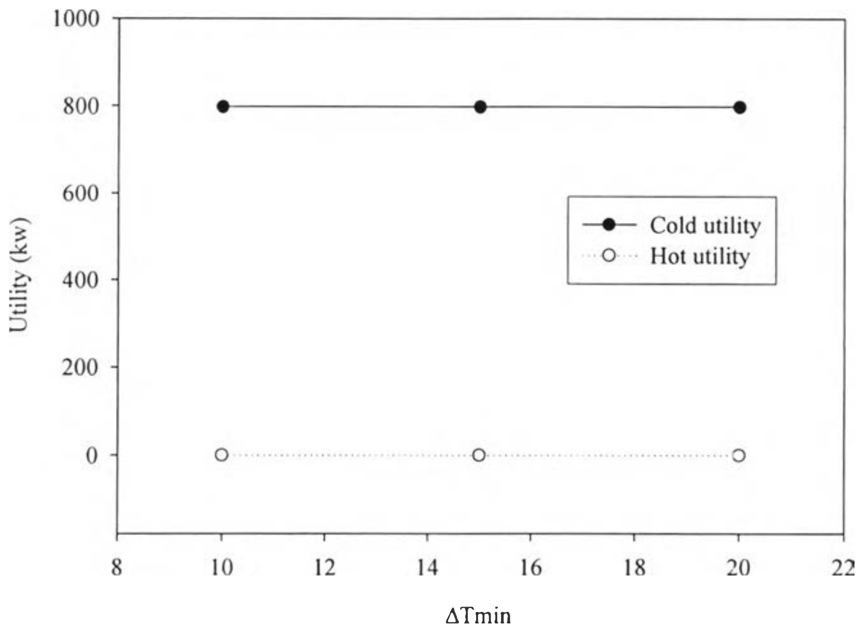


Figure 4.18 Effect of threshold problem in stabilizer unit.

Thus, the suitable ΔT_{min} is not found.. The experience of ΔT_{min} (Linnhoff March) as shown in Table 4.6 is used to select ΔT_{min}. Based on this reference, ΔT_{min} of petrochemical plant is chosen for three values, 10, 20 and 30^{O}C, to generate GCC. From the pinch design method, the GCC of stabilizer unit with various ΔT_{min} is shown in Figure 4.19. The ΔTmin = 10^{O}C is chosen for the design. Grid diagram of stabilizer unit is illustrated in Figure 4.20. The network is designed by using Fast matching algorithm to match the stream exchanger (Ponton and Donalson, 1974).

Table 4.6 ΔT_{min} experience of Linnhoff March (www.linnhoffmarch.com)

Industrial Sector	Experience ΔTmin Values
Oil Refining	20-40 °C
Petrochemical	10-20 °C
Chemical	10-20°C
Low Temperature Processes	3-5 °C

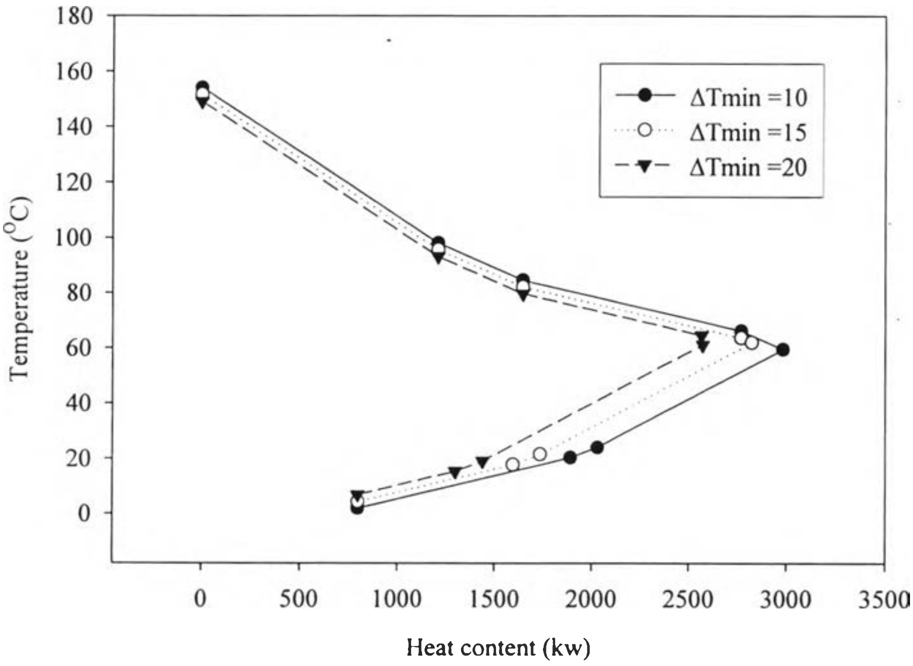


Figure 4.19 The GCC of stabilizer unit with various ΔT_{min}.

4.3.2 Distillation Column Targeting of Stabilizer Unit

In this unit, there is only one distillation column, stabilizer column (2-T-001) with the main feed stream 101/4 at tray no.11. Data of distillation is shown in appendix C. From Figure C1, because of the limitation of simulator, which is stream 108/1 cannot be mixed in the reflux rate. Thus, this stream is used as pseudo feed stream at tray no.2. The top and bottom products are stream 104/1 and 102/1, respectively. The CGCC of stabilizer column is presented in Figure 4.21 using iso-butane as a light key component while reboiler and condenser duties are 4486.42 and 841.62 kw, respectively. From this figure, the reflux modification cannot be done because the pinch point is near zero and scope of preheating is not observed. It means that this column is optimum in energy consumption already.

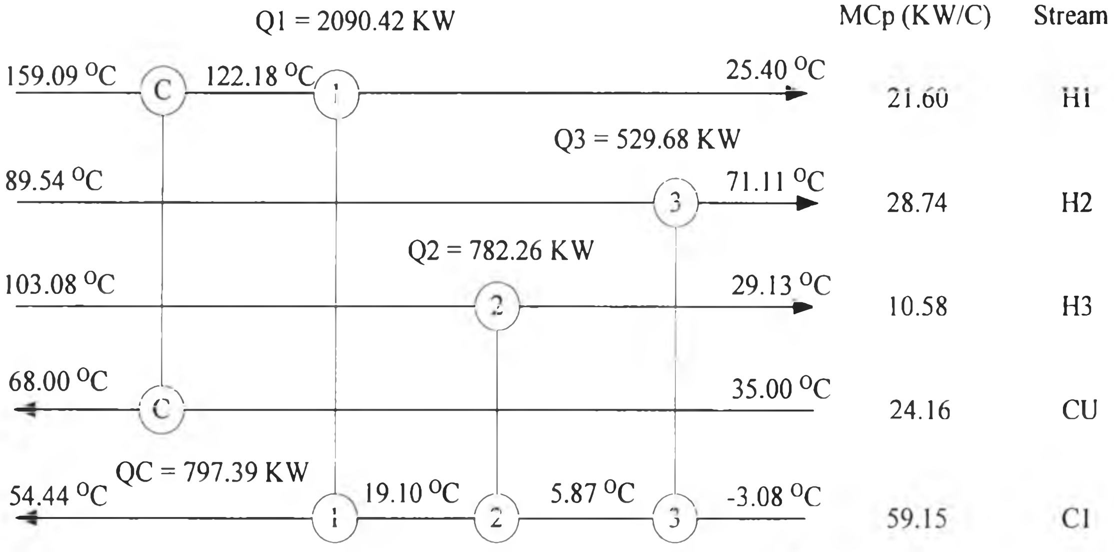


Figure 4.20 Grid diagram of stabilizer unit before integration.

4.3.3 Energy Integration of Stabilizer Unit

The combination between CGCC of stabilizer column and GCC of heat exchanger networks are shown in Figure 4.22. The integration technique helps recover the energy about 780.70 kw or 47.63 and 17.4 % of cold and hot utility usages by adding side reboiler between tray 5-10. Similarly, the network is rearranged by Fast matching algorithm and the grid diagram is shown in Figure 4.23.

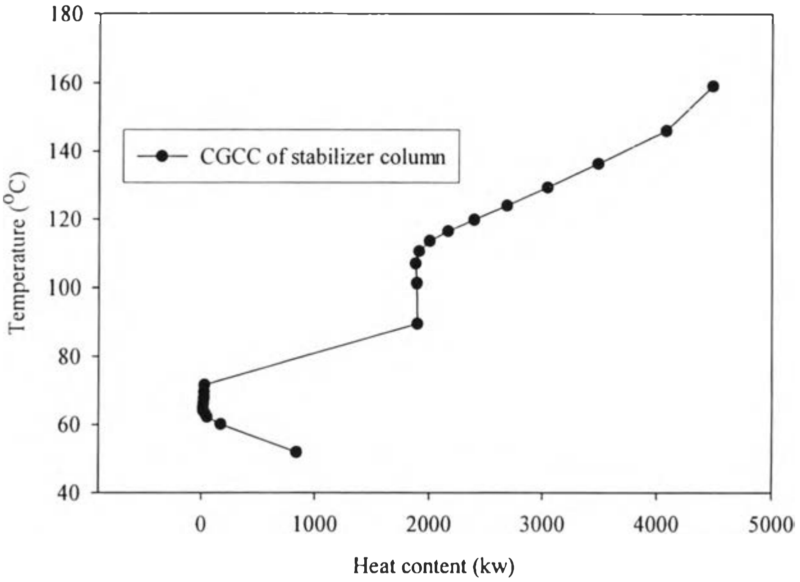


Figure 4.21 CGCC of stabilizer unit.

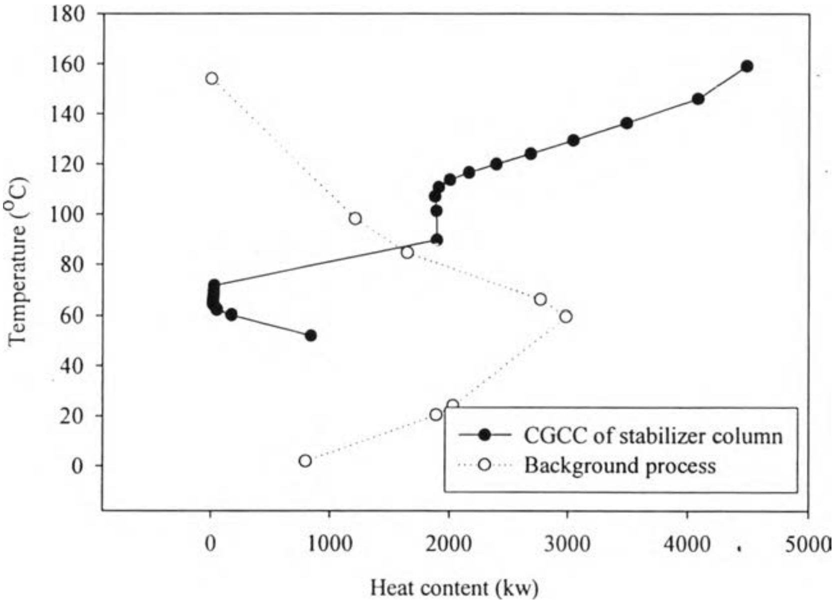


Figure 4.22 The integration of stabilizer unit.

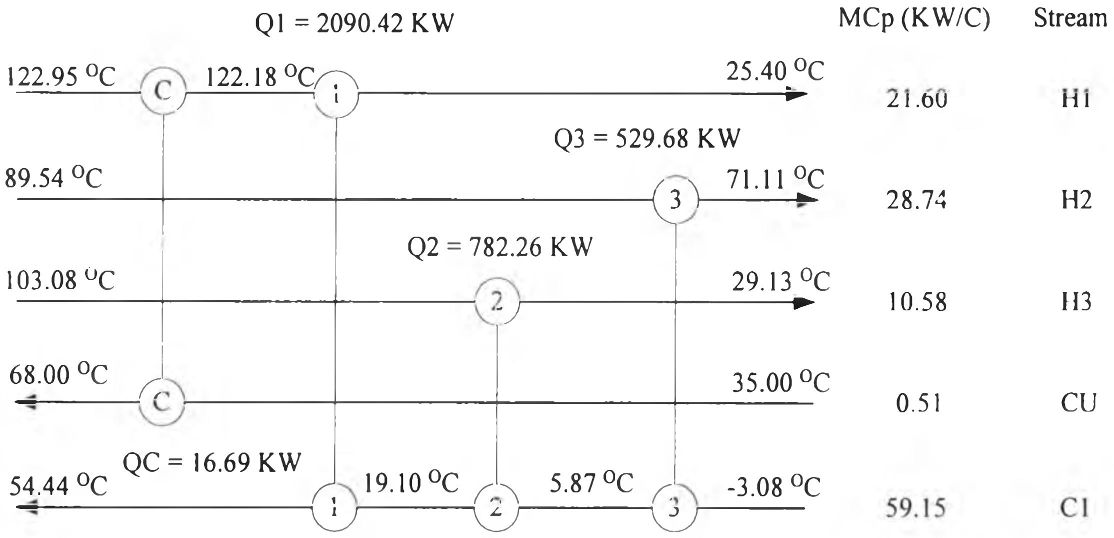


Figure 4.23 The grid diagram of stabilizer unit after integration.

4.4 Sensitivity Analysis of Propane and LPG Production

The main objective of this topic is to minimize the utility of reboiler and condenser and the efficiency of equipment is also concerned. The design data of feed composition of unit E78301 as shown in Figure 1A or 1B is included to prevent the temperature crossover at the reboiler. Figure 4.24 shows a diagram of propane and LPG production.

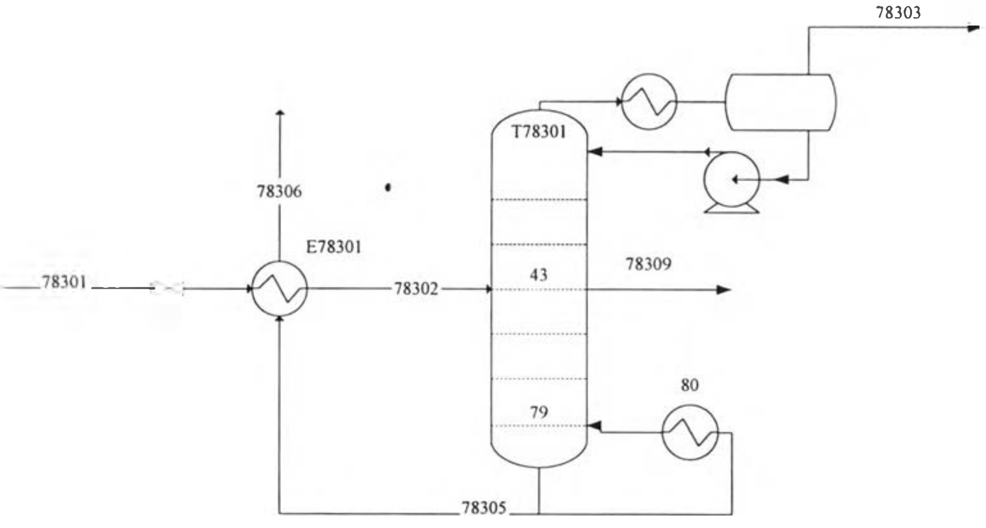
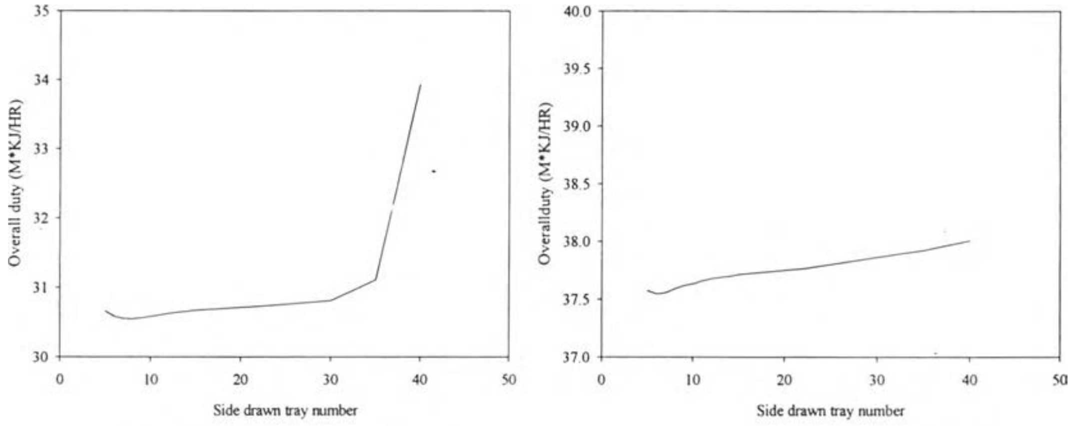


Figure 4.24 Diagram of propane and LPG production.

Stream 78303 and 78309 are propane and LPG flow rates, respectively. Pressure of stream 78302 is reduced to equal the pressure of depropanizer column by expanding with valve. Flow rate of stream 78305, NGL product, is specified constant. Moreover, in the real situation, feed composition of natural gas is always varied. Thus, the design composition is considered as a base case to inspect the effect of composition. Figure 4.25 is the result when varying the side drawn tray number to find the suitable tray to operate.



(a) design composition

(b) actual composition

Figure 4.25 Effect of location of side drawn tray.

From Figure 4.25, overall duty in case of design composition seems constant during side drawn tray no.5 to 30 and rises up dramatically after side drawn tray number 30 while actual composition case is still constant at all side drawn tray. It means that it should be operated at side drawn tray below tray no.30 to avoid the composition effect. Moreover, to consider optimal location of side drawn tray, it depends on the demand of propane and LPG. Table 4.7 shows the data of propane and flow rate when varying the side drawn tray location in actual composition. At each location of side drawn tray gives the difference of product flow rate.

Table 4.7 Data of propane and LPG flow rate of actual composition

Side Drawn Tray	Flow Rate (Kgmol/Hr)	
	LPG	Propane
4	770.00	106.33
5	502.00	374.36
6	385.00	491.36
7	314.00	562.37
8	261.00	615.35
9	220.00	656.33
10	188.00	688.36
11	161.00	715.34
12	139.00	737.32
13	121.00	755.32
14	106.00	770.33
15	93.00	783.31
22	43.00	833.36
30	23.50	852.81

The next parameter is pressure of depropanizer column. Because overall duty has constant trend, side drawn tray no.6 is chosen to study the effect of this parameter. By varying pressure, Figure 4.26 illustrates the result of varying pressure to overall duty at side drawn tray no.6.

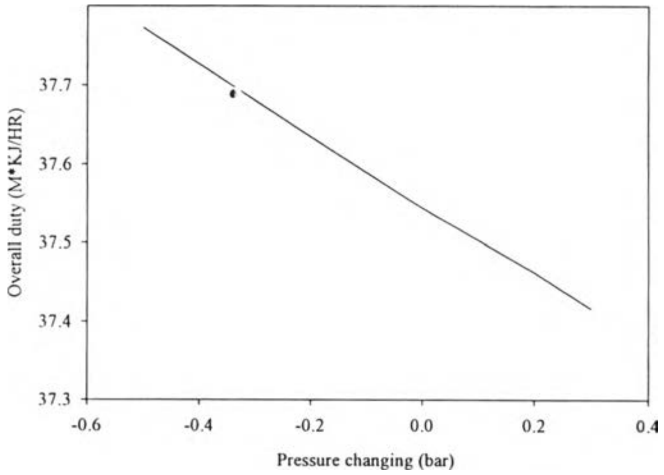


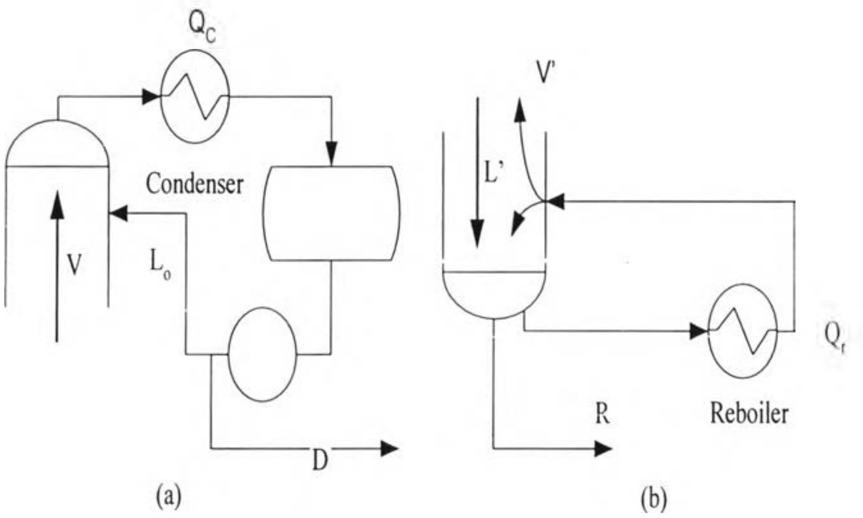
Figure 4.26 The result of varying pressure at side drawn tray no.6.

From this figure, increasing pressure of column will decrease the overall duty. Table 4.8 shows the result of varying of pressure column at side drawn tray no.6.

Table 4.8 Result of varying pressure to produce Propane and LPG at side drawn tray no.6

Pressure	Q Reboiler (M*KJ/HR)	QCondenser (M*KJ/HR)	LPG Flow rate (Kgmol/Hr)	Propane Flow rate (Kgmol/Hr)	NGL Flow rate (Kgmol/Hr)
-0.5	13.529	24.243	335.000	540.189	164.790
0	13.541	24.004	385.000	491.360	163.620
0.2	13.548	23.915	401.000	475.800	163.179
0.3	13.549	23.868	409.000	468.036	162.943

To explain effect of changing pressure, it can be described in term of material and energy balance as shown in Figure 4.27 (a) and (b). Vapor (V) rate will decrease and liquid (L') flow rate will condense more when increasing pressure of depropanizer column. Thus, reboiler duty will increase and condenser duty will decrease as shown in equation in Figure 4.27. However, condenser effect is more dominates than reboiler effect because of feed temperature. As mentioned above, pressure of feed stream 78302 will be reduced by expanding with valve. Table 4.9 shows the temperature of stream 78302 when changing pressure. Temperature of stream 78302 will increase when increasing depropanizer column pressure. This effect helps reduce overall energy utility consumption.



$V = L_o + D$

$Q_c = VH_c$

where, Q_c = Condenser duty

V = Vapor flow to condenser

L_o = External reflux flow

D = Head product flow

H_c = Heat of condensation of V

$L' = V' + R$

$Q_r = V'H_r + h_R - h_L \sim V'H_r$

where, Q_r = Reboiler duty

V' = Vapor flow from reboiler

h_R = Heat of bottom product

h_L = Heat of liquid from the last tray

R = Bottom product flow

H_r = Heat of vaporisation of V'

Figure 4.27. Material and Energy balance (a) for condenser (b) for reboiler.

Table 4.9 The temperature of stream 78302 when changing pressure

Pressure (bar)	Temperature of Stream 78302 (^{O}C)
-0.5	73.99
0	75.58
0.2	76.20
0.3	76.50

The effect of increasing pressure is limit on 0.3 bars because the UA of unit E78301 is larger than 10 % as mentioned in chapter III. The effect between increasing pressure and UA of E78301 at side drawn tray no. 6 is shown in Figure 4.28. The other results of this sub-topic are shown in appendix D.

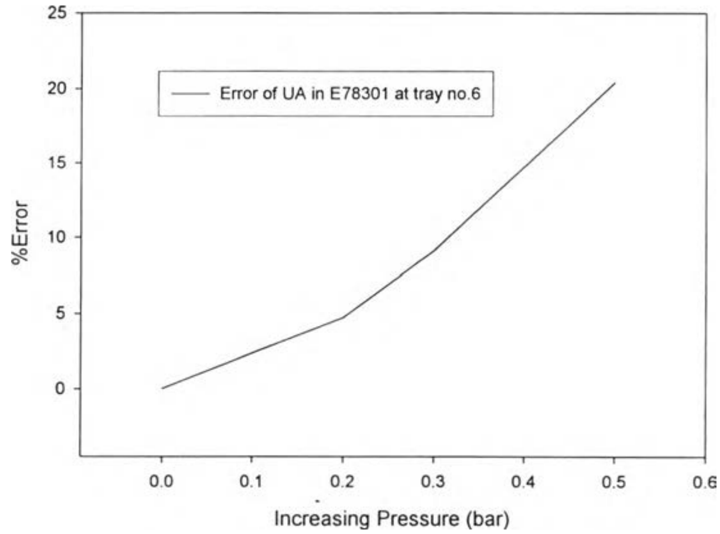


Figure 4.28 The effect between increasing pressure and %error of UA.