CHAPTER IV
RESULTS AND DISCUSSION

4.1 Distillation Column

This part was divided into two parts. The first one was about column parameters and the second one was about column targeting on heat integration

4.1.1 Column Parameters

The column parameter such as feed location, reflux ratio were studied to observe column optimization

Demethanizer

Feed tray location between first tray (tray No.1) and the last tray (tray No.40) was varied to study the purification of methane at the top of the column. The result showed that the most appropriate tray for feeding was the first tray because from Figure 4.1 this feed tray could give methane fraction around 0.936 but in the other trays the fraction of methane was around to 0.796. Therefore feed location at the first tray was the most suitable for operation. In the actual operation, feed location of the demethanizer was already at the first tray so it was not necessary to change. In summarily, the actual feed tray had been already an optimum tray.

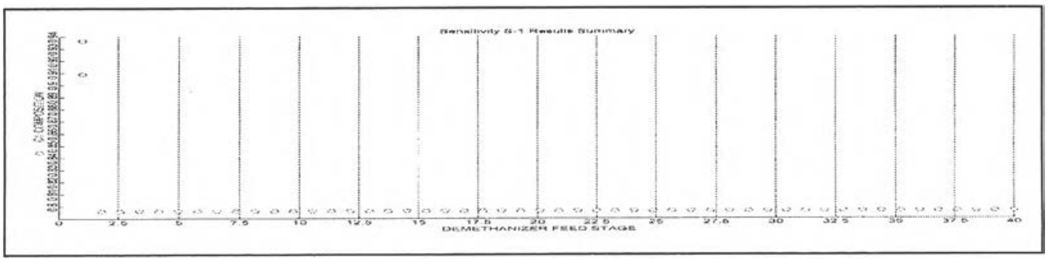

Figure 4.1 The relationships between methane purity and feed stage of demethanizer column.

Reflux ratio from 1 to 5 was changed to find the optimum reflux ratio which could give the highest purification of methane at the top product. The result showed that every reflux ratio between 1 and 5 will give the same purification as shown in Figure 4.2. The methane fraction in the top product is almost 0.93 in every reflux ratio value. However, this model was done under the first feed tray in order to get high purification. In actual process, it was not necessary to change reflux ratio of demethanizer column because every reflux ratio would give the same result. In summary, the actual reflux ratio had been already an optimum point.

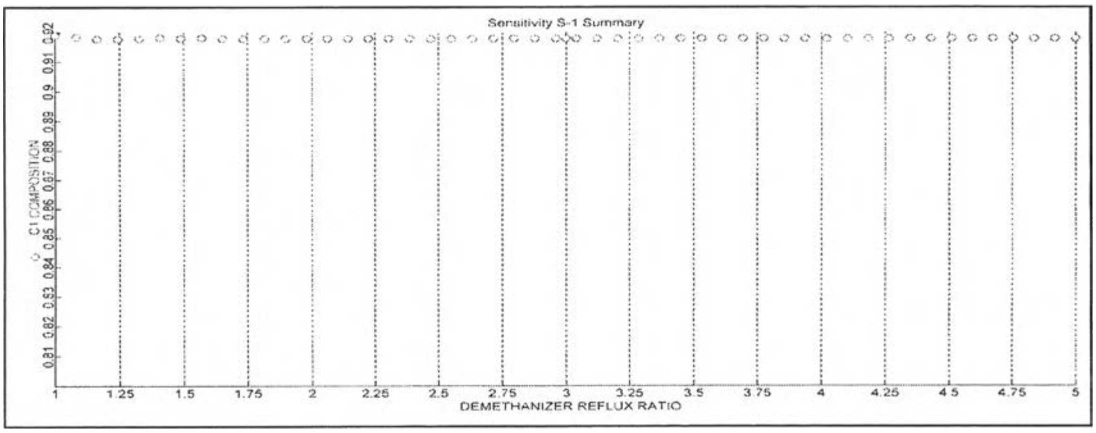

Figure 4.2 The relationship between methane purity and reflux ratio of demethanizer column.

Deethanizer

Feed tray from first tray (tray No.1) to the last tray (tray No.89) was varied to study the purification of ethane at the top of the column. The optimum range was between trays No.31 and 58. Fraction of ethane in this range was around 0.937 as shown in Figure 4.3. In the other ranges, the purification of ethane would be lower comparing to this optimum range. From tray No.1 to tray No.30 the purification would smoothly increase until reaching the tray No.31 and would dramatically decrease after tray No.58. The actual feed tray was tray No.56 so that it was not necessary to change the feed location. In summary, the actual feed tray had been already an optimum tray.

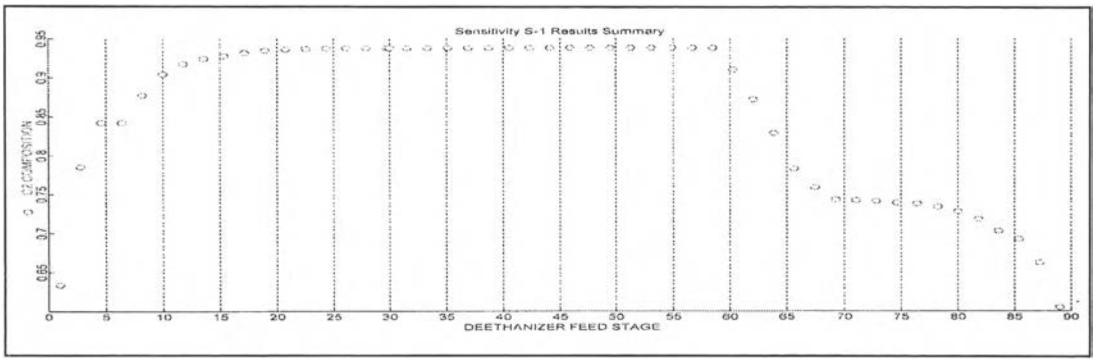

Figure 4.3 The relationship between ethane purity and feed stage of deethanizer column.

Reflux ratio between 1 and 5 were varied to find the minimum reflux ratio which gave the highest purification of ethane in the top product as shown in Figure 4.4. The highest value of ethane fraction which is 94% was obtaines at reflux ratio between 1.8 and 3.7. Between the reflux ratio of 1 and 1.8, fraction of ethane was low. However at reflux ratio greater or higher than 3.7 fraction of ethane was gradually decreased.

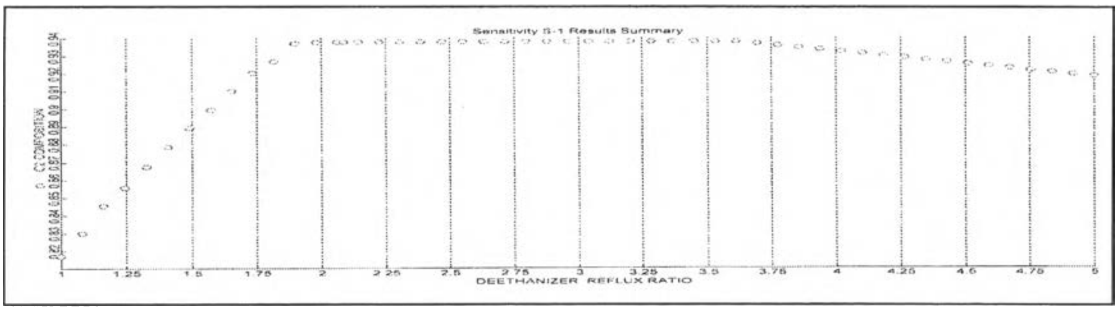

Figure 4.4 The relationship between ethane purity and reflux ratio of deethanizer column.

Depropanizer

Feed tray location between first tray (tray No.1) and the last tray (tray No.80) was varied to study the purification of propane at the top of the column. The optimum range was between tray No.40 and No.80. Figure 4.5 shows the relationship between location of feed stage and purification of top product of depropanizer.. The fraction of propane in this range was around 0.948. In actual operation, the feed stage is located at tray No. 56 and then it was already in appropriate state. Therefore, in this column there is no need to change feed stage location from actual operating location.

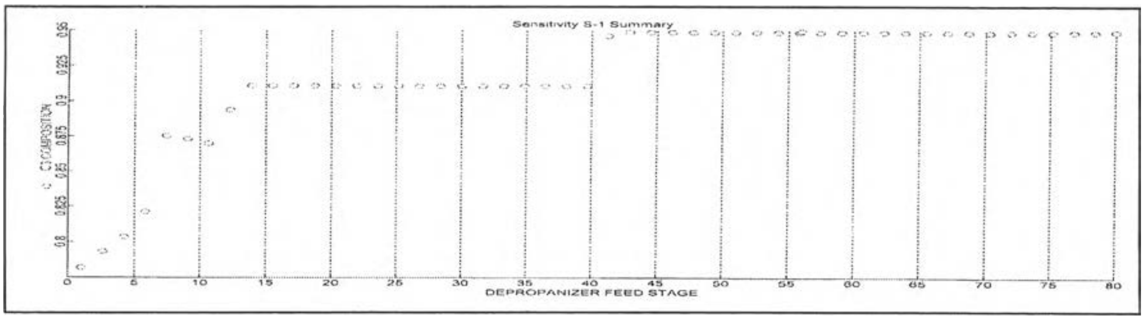

Figure 4.5 The relationship between propane purity and feed stage of depropanizer column.

In depropanizer column, reflux ratio would be varied similar to two previous columns. The most appropriate reflux ratio was at all ranges between one and five. Whether this column was operated at reflux ratio of one or five, the purification of propane at the top of the column is the same as shown in Figure 4.6. The purification of propane was 0.948.

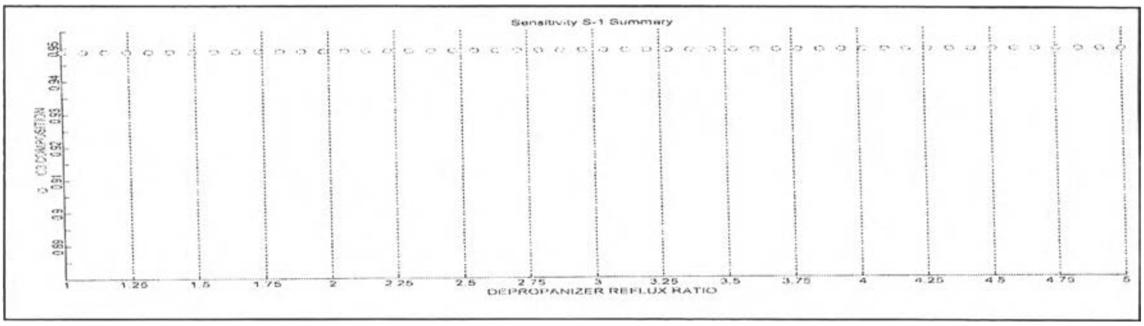

Figure 4.6 The relationship between propane purity and reflux ratio of depropanizer column.

4.1.2 Column Targeting

Column targeting is the target that minimize energy consumption of the column which is used by condenser and reboiler part. In Aspen plus there are functions that can easily generate Column Grand Composite Curve (CGCC) by calculating energy flow. After CGCC was obtained, there were some considerations about integrating all three columns to save energy . The way to integrate the columns was to try to find the overlap between each column.

Demethanizer

This column does not have any condenser because the dew point of methane is very low. It is used in gas phase in power plant. In this model, light key component is suitable to be used in generating CGCC.

There are four pinch points in CGCC, located near feed trays .The CGCC of this column was shown in Figure 4.7. This column has a huge part of pocket which is helpful for energy recovery because some hot streams can transfer heat to cold stream. It means that this process has been in good condition. The total utility of this column is only for reboiler duty not condenser.

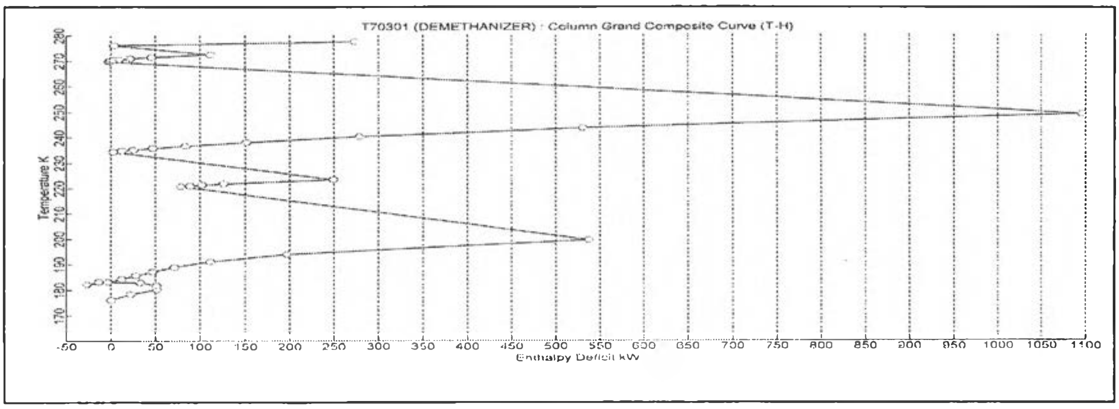

Figure 4.7 Demethanizer Column Grand Composite Curve (CGCC).

Deethanizer

Only one pinch point was found near the feed location of this column. The location of pinch point agrees well with the observation of many researchers (Dhole and Linnhoff, 1993; Bandyopadhyay *et al.*, 1998). This column has been using both condenser and reboiler. The pocket in this column is not much because it has only one feed point and does not have any pump around to conduct the heat on this column so the amount of heat at either condenser or reboiler is much consumed. From Figure 4.8 there are no any energy lost gap occurring because pinch point of the graph touches the vertical axis so this column is in optimum condition.

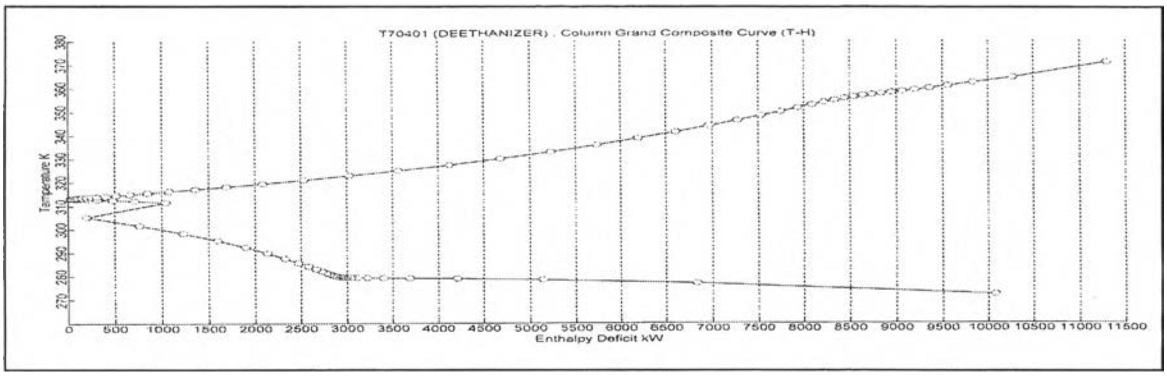

Figure 4.8 Deethanizer Column Grand Composite Curve (CGCC).

Depropanizer

The condenser of this column is omitted out when doing simulation because cold utility stream of condenser is modeled in background process of HENs. This column has only one pinch point near the feed location. The location of pinch point agrees well with the observation of many researchers (Dhole and Linnhoff, 1993; Bandyopadhyay *et al.*, 1998). CGCC as shown in Figure 4.9 does not have energy gap between the vertical axis and enthalpy deficit so this column does not have heat loss to surrounding then it is in optimum operating condition.

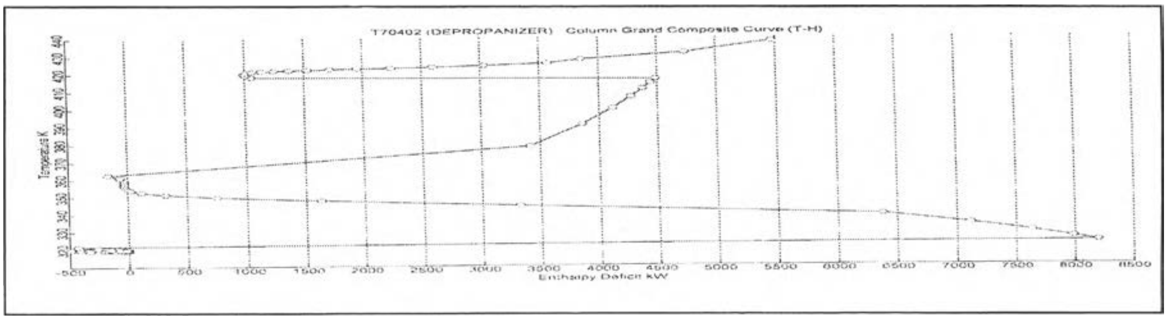

Figure 4.9 Depropanizer Column Grand Composite Curve (CGCC).

Three column grand composites curves were combined together in order to integrate heat between column to column as shown in Figure 4.10. From this figure, it was found that there would be possible integration if depropanizer curve shifts up or deethanizer curve shifts down. To shift the curve the pressure of each column needs to be changed i.e. depropanizer pressure needs to be increased or deethanizer pressure needs to be decreased. As shown in Figure 4.10 it was found that the overlap temperature of both columns was about 50 K but from the simulation result the pressure of 1 barg would change the temperature about 2.58 K so the pressure must be changed about 19.3 barg. This modification must also belong to the maximum tolerance of equipment. The current operating pressure of depropanizer is 15.56 barg and the maximum pressure which this column can endure is 19 barg. The depropanizer column can add pressure only 3.44 barg. But in order to meet the integration objective the pressure of this column must be up to 34.86 barg. Therefore integration between depropanizer and deethanizer column was impossible.

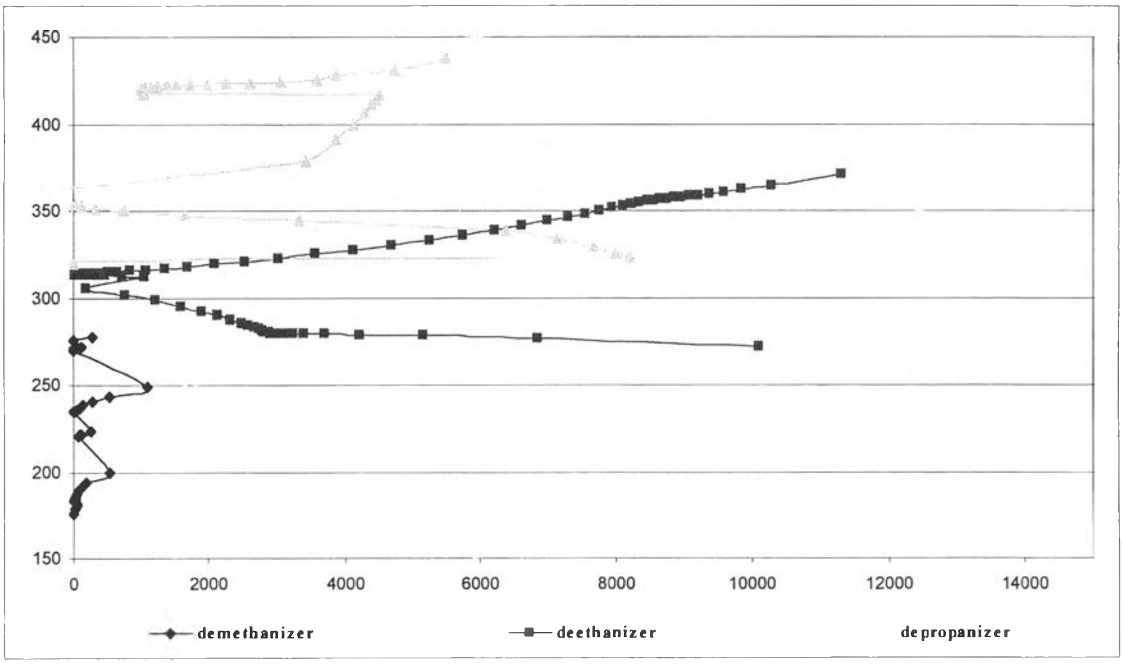

Figure 4.10 Integration of CGCCs of three distillation columns.

4.2 Overall Process

4.2.1 Process Heat Integration

The gas separation plant is a cold process i.e. this process uses only cold utility. It does not have pinch point occurring in this process. Although the experiment was done under varying ΔT min between 1 and 30 °C, pinch point did not appear. As shown in Figures 4.11 and 4.12, there is only cold end (cold utility) on the hot stream requirement.

Below threshold problem, it also belongs to this process because either ΔT min was varied but utility requirement did not change until ΔT min reaches 31 °C then pinch point appears.

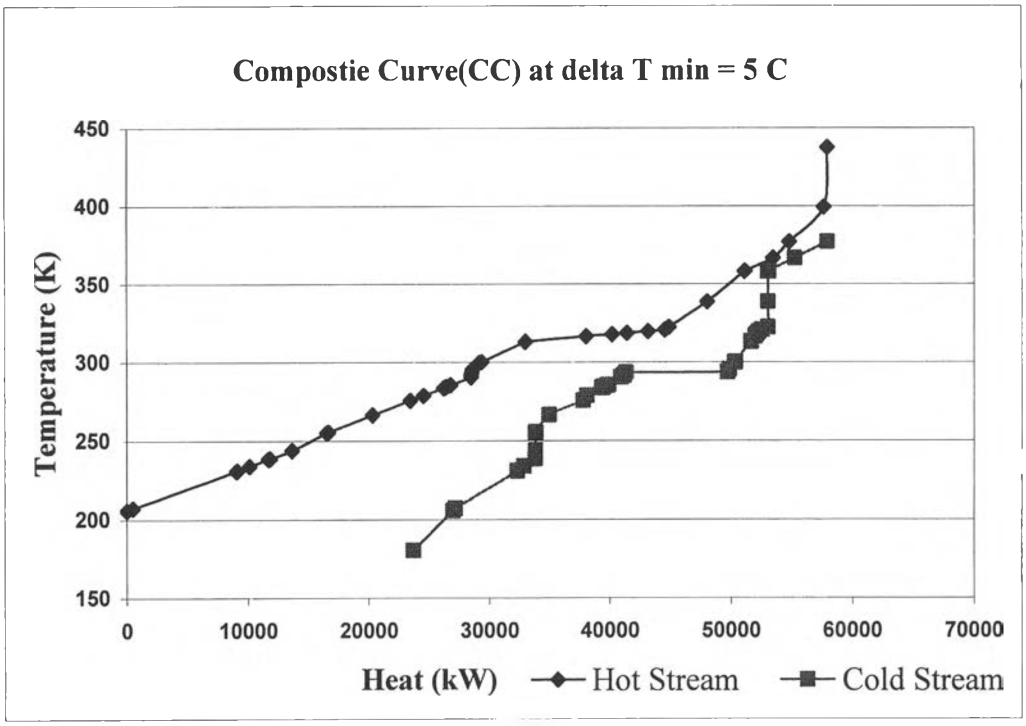

Figure 4.11 Process Composite Curve (CC).

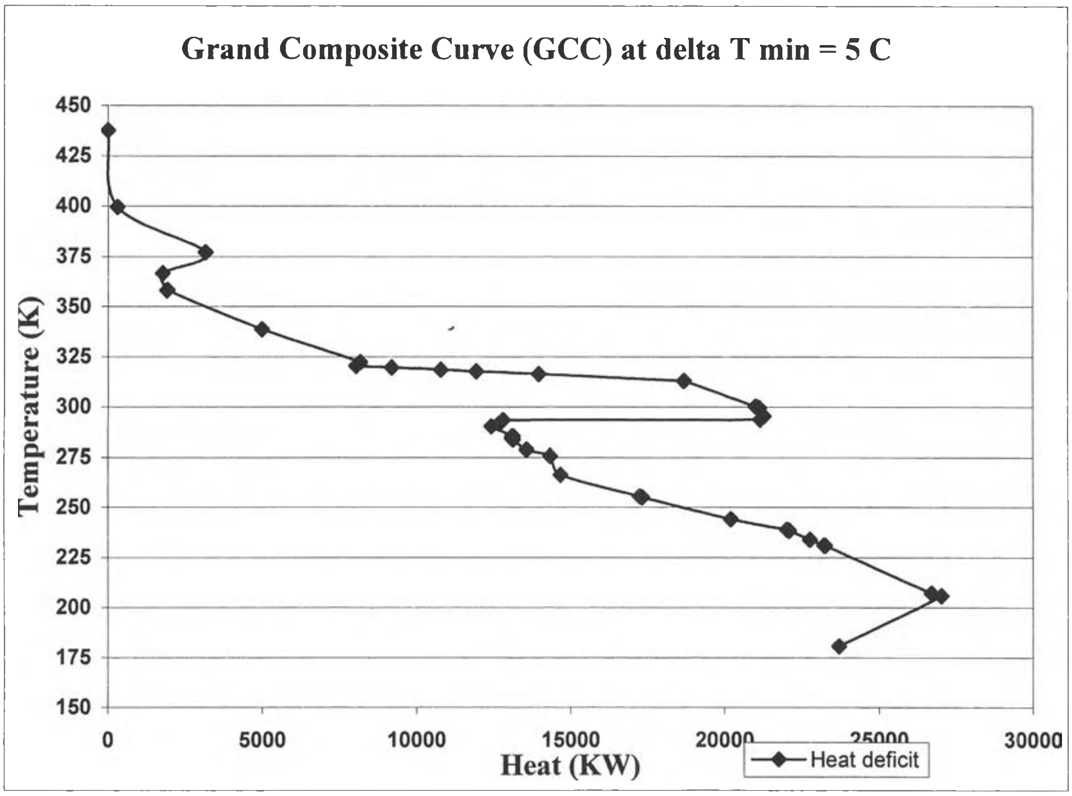

Figure 4.12 Process Grand Composite Curve (GCC).

The overall energy savings of the process could be investigated further by analyzing the heat integration between process streams and distillation columns. The analysis was done by plotting the process grand composite curve at ΔT_{min} = 5 °C and three column grand composite curves, i.e. demethanizer, deethanizer and depropanizer on the same temperature-enthalpy plot as shown in Figure 4.13. The heat integration between process streams and distillation column would be beneficial if the columns were placed on either side of the process pinch point without overlapping each other, i.e. the column should be entirely placed on either above or below pinch.

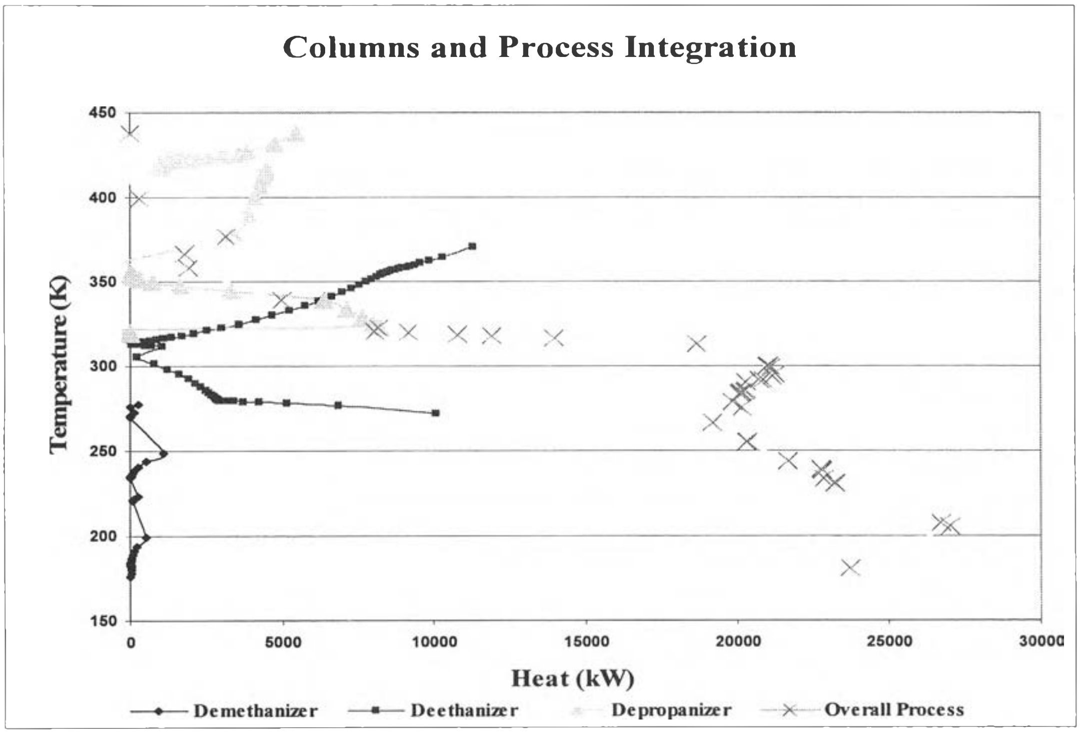

Figure 4.13 Process heat integration between process streams and distillation columns.

4.2.2 Process Heat Exchanger Network

Heat exchanger network is explained by using grid diagram . There are eight hot streams, nine cold streams and four cold utilities as shown in Figure 4.14. On this grid diagram, it was drawn based on ΔT min =5 °C because either changing delta ΔT min from 1 to 30 °C but utility was not changed. The energy was constant at 23kW.

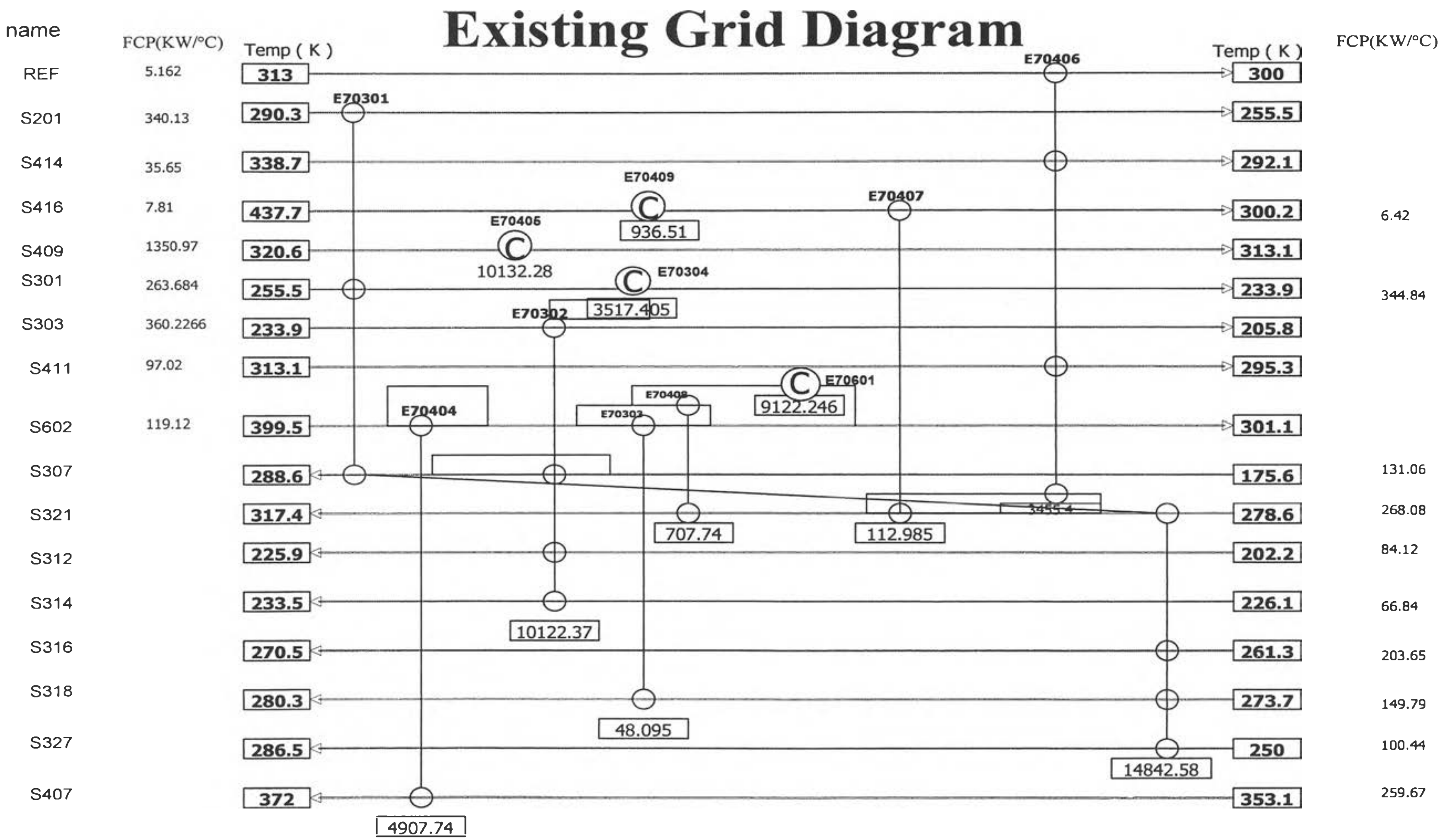

Figure 4.14 Grid diagram showing heat exchanger network.

This process is completely cryogenics process which has ΔT min around 3-5 °C therefore selecting higher ΔT min is more economical due to capital cost of heat exchanger so 5 °C was chosen. Since this process is below threshold problem which has no pinch point along ΔT min of 1-30 °C so modifications using inspection is recommended for this process because pinch analysis can not be applied for this case. Adding new heat exchangers is possibly the way to reduce amount of heat utility.

4.3 Retrofit

This study proposed four alternatives for the energy saving. Two of these came from inspection technique, one of these came from column and process integration technique.

4.3.1 Alternative 1

From inspection technique, if one heat exchanger is added between line s416 and s327 it will result in the reduction of the load of cooling utility number E70409 from 936.512 kw to 851.803 kw. Therefore this exchanger helps reduce load cooling utility about 84.7 kw or 9.04 % of E70409 cooling loads.

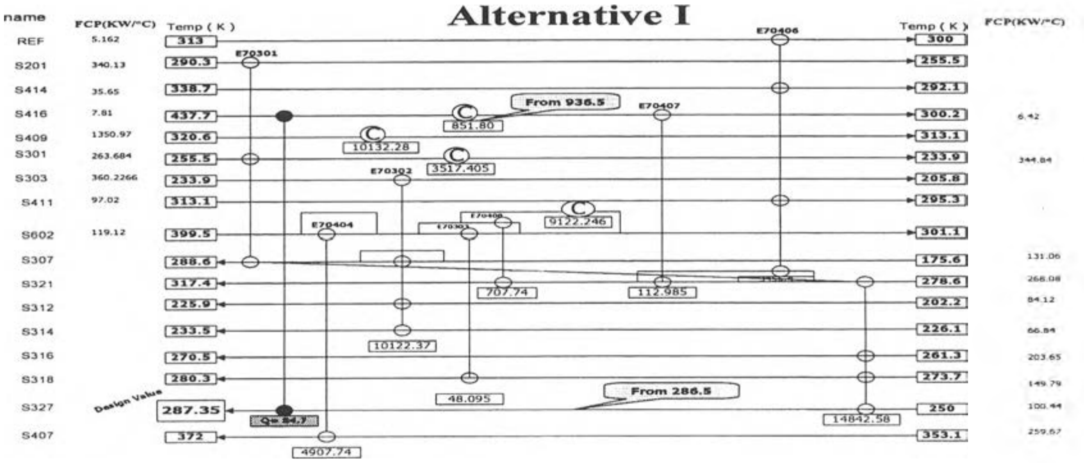

Figure 4.15 Retrofit on alternative 1.

About grand composite curve(GCC), existing energy consumption is 23,708 kw as shown in Figure 4.12 and following figure shows GCC of alternative 1.

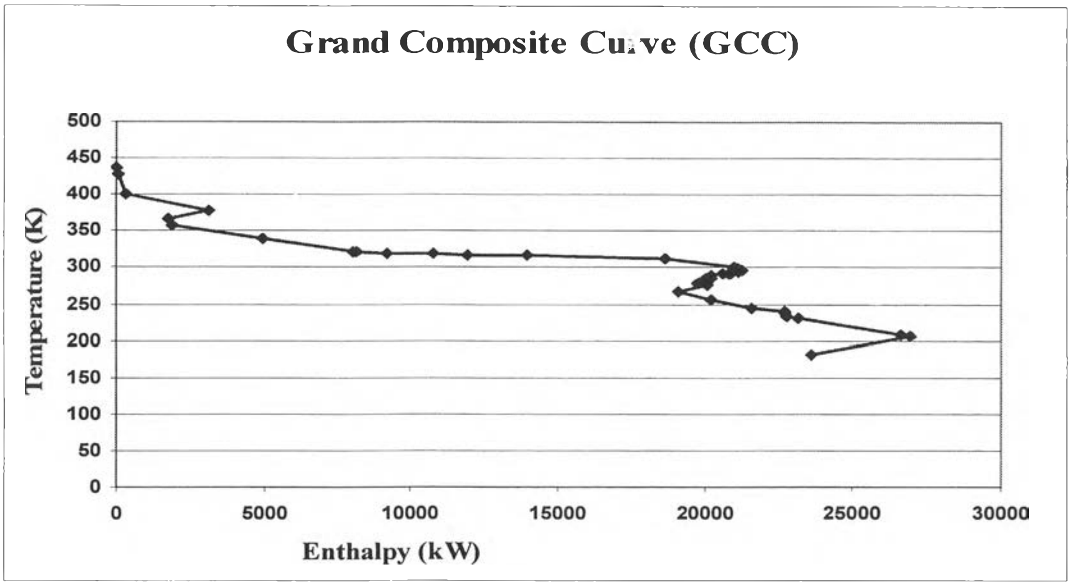

Figure 4.16 Alternative 1 Grand Composite Curve.

Overall energy is reduced from existing energy consumption of 23,708.4 kw to 23,623.7 kw of alternative 1 energy consumption. This alternative can lead to cost saving around 107,311.84 baths/year. However, payback period of this alternative is 0.683 year (the detail of calculation is shown in Appendix D).

The diagram of alternative 1 of gas separation plant would be presented in Appendix C.

4.3.2 Alternative 2

At depropanizer condenser, measured temperature is 313.1 K but actually this value should be the design value of 319.98 K . Therefore condenser duty of depropanizer should be 9,150.343 kw instead of 10,132.28 kw. The possible reason might be that the cooling water load of condenser E70405 was too much. This, the flow rate of cooling water should be reduce from 872,636.55 kg/hr to 788,067 kg (calculation step is shown in Appendix D)

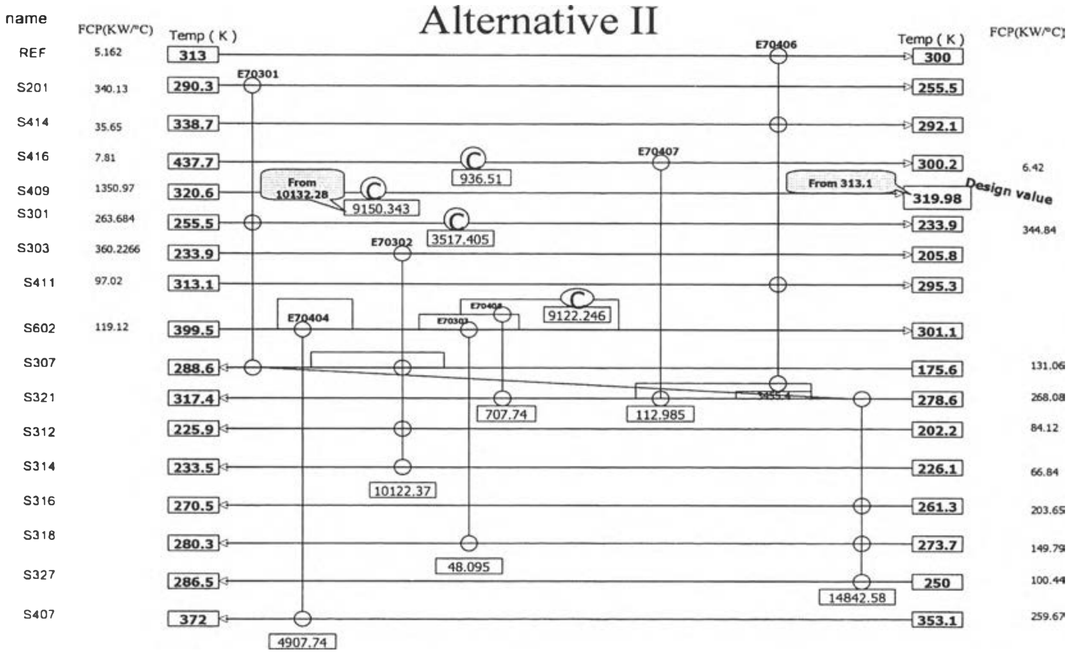

Figure 4.17 Retrofit on alternative 2.

But in case of reducing flow rate of cooling water heat exchanger would have fouling occurring. Therefore, weighing between the consequent problem and the energy saving is a necessity that should be considered.

4.3.3 Alternative 3

From column and process integration, there is a scope of integration between the process and column grand composite curve which was found at deethanizer reboiler as shown in Figure 4.18

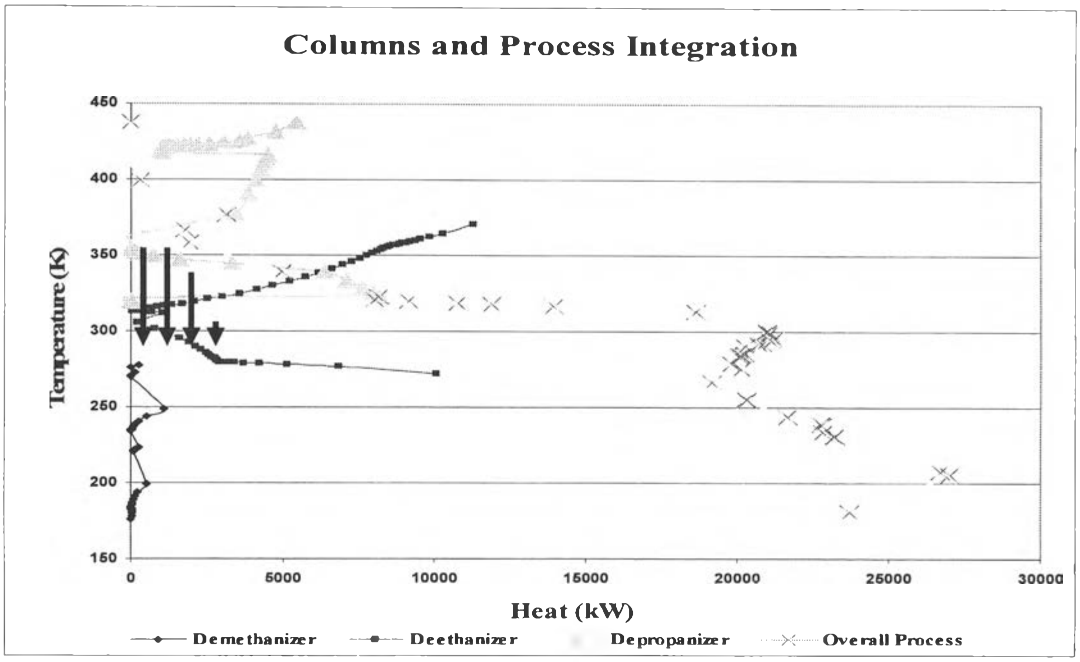

Figure 4.18 Scope of Integration between column and process.

It means that if side reboiler was added to the deethanizer, energy saving on both main reboiler and cooling water load of E70601 would be obtained. To calculate energy saving on this alternative, it needs to refer to bottom temperature of deethanizer and the sale gas in line S70603-2. The inlet temperature of sale gas into side reboiler was about 361 K and the outlet temperature of sale gas was 321 K. In the other hand, the inlet temperature of bottom product into side reboiler was 313.2 K and the outlet was 338.5 K. Energy savings was obtained at 6,197.782 kw on both reboiler and cooler or 36.96% of total steam consumption and 26.14% of total cooling water consumption in the process. However, payback period of this alternative is 0.783 year (the detail of calculation is shown in Appendix D).

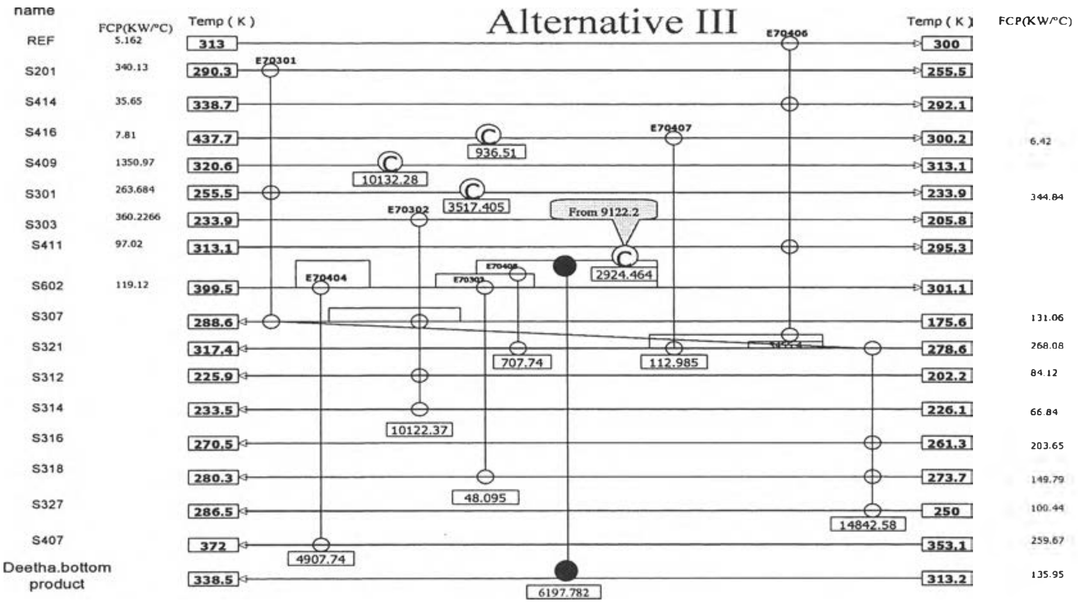

Figure 4.19 Retrofit on alternative 3.

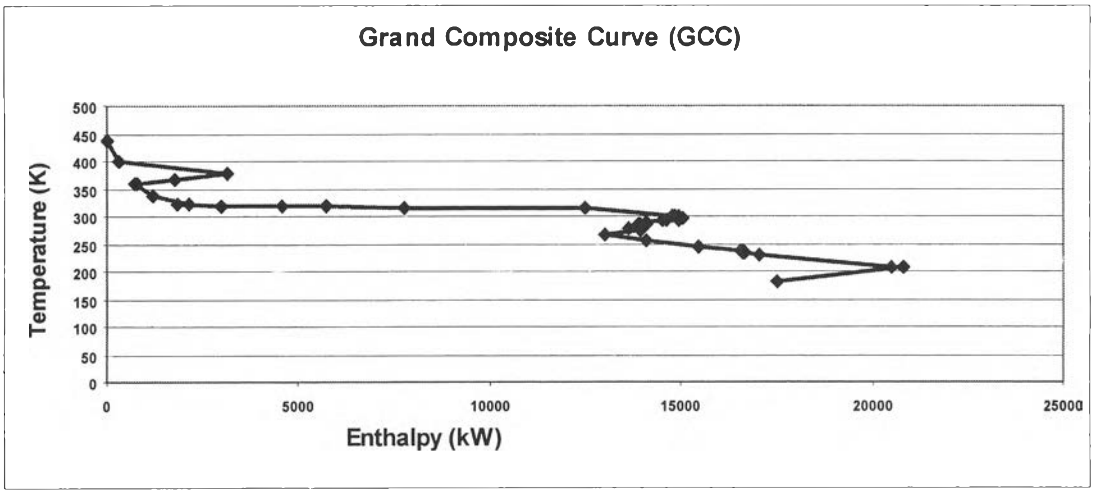

Figure 4.20 Alternative 3 Grand Composite Curve.

4.3.4 Alternative 4

Cooperating with company, there were some recommendations from company by changing the depropanizer product from 3 output (Propane, LPG, NGL) to 2 outputs (LPG, NGL) and Varying the operating pressure and varying the feed tray of depropanizer were done in order to study the different energy consumption .

The results showed that when the pressured of the column were increased the amount of condenser duty would be decreased. In the other hand, the amount of reboiler would be decreased as shown in Figure 4.21.

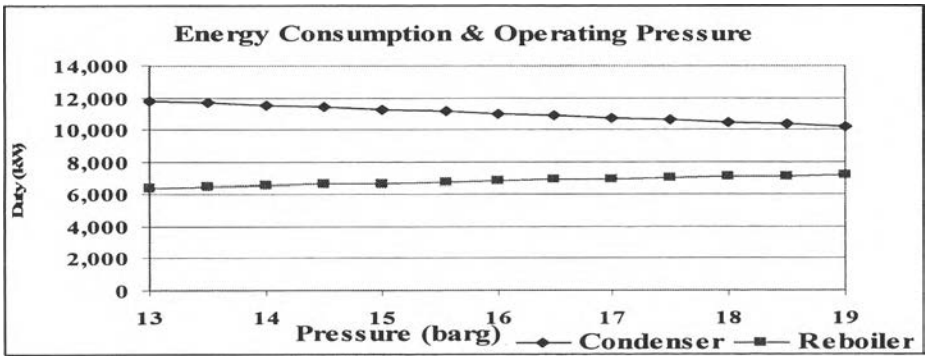

Figure 4.21 Energy consumption& Operating pressure on two products (LPG, NGL).

Utility of this column were calculated and they were found that higher pressure, higher cost so that the lowest pressure was recommended. The results were presented in Figure 4.22.

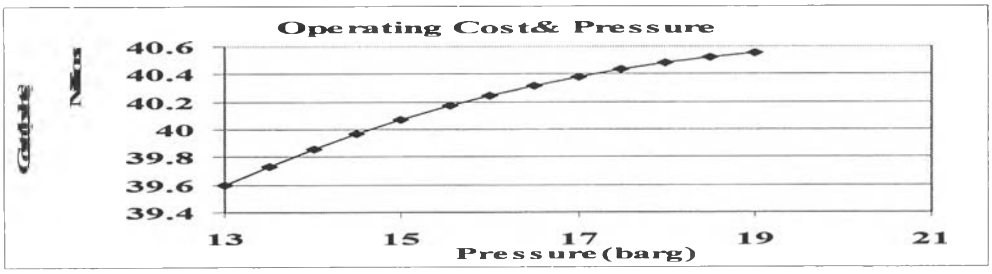

Figure 4.22 Operating cost vs Operating pressure on 2 products (LPG, NGL).

The constraint of this alternative was the specification of depropanizer. The modification could not be done over maximum tolerance of material so that it was necessary to set the boundary of modification.

- Maximum allowable operating pressure is 19 barg.
- Condenser UA cannot exceed 1,516 kw/K

** These values were based on the design specification sheet

Table 4.1 Condenser UA with different pressure of depropanizer column

P(barg)	13.0	13.5	14.0	14.5	15.0	15.6	16.0	16.5	17.0	17.5	18.0	18.5	19.0
Condenser Temp	322.9	324.5	326.1	327.6	329.1	330.8	332.0	333.4	334.8	336.1	337.5	338.8	340.0
T min	11.3	13.0	14.7	16.3	17.8	19.5	20.8	22.2	23.6	25.0	26.3	27.6	28.9
Q condenser	11805	1167	1154	11410	11278	11130	11015	10884	10752	10621	10489	10356	10223
UA	1045.2	897.3	787.5	702.2	633.8	571.3	530.5	490.3	455.7	425.4	398.7	374.9	353.6

From Table 4.1, the result showed that all operating pressure can be used since UA values was still under the constraint.

In addition to changing the pressure, trying to change feed tray was also interesting to consider. There are 4 feeding point in propanizer i..e. tray number 31,39,47 and 55. The result showed that not much changed in each feed tray so it was concluded that feed tray changing was not much affected to the energy consumption as shown in Figure 4. 23.

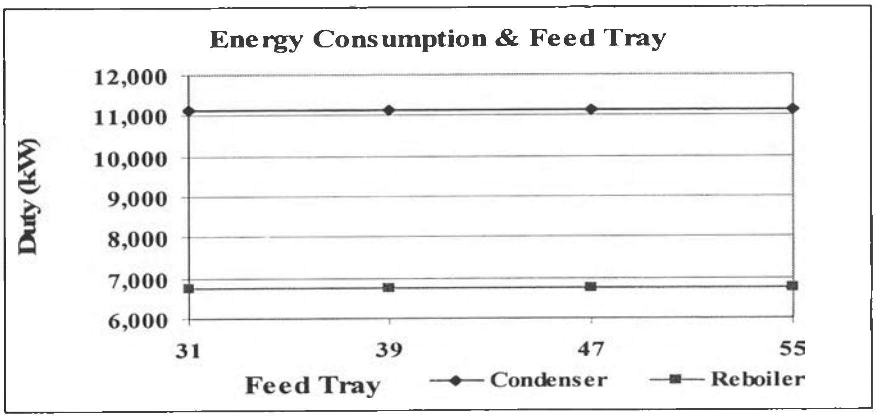

Figure 4.23 Energy consumption & Feed tray on two products (LPG,NGL).

4.4 Data Reconciliation

To get more reliability on this process simulation, this technique needed to be applied because if the plant had known measured variables as many as they could, it meaned that the simulation would be more correct compared to control actual condition. The number of measured and variables unknown of this process was 79 and 348 respectively. Using this technique to approximate unknown variables turned out that 31 variables can be given.

To do data reconciliation, diagram should be drawn in order that data could be easily analyzed. Figure 4.24 is a diagram that can specify the position of measured variables Figure 4.25 shows the point of reconciled variables. This technique will use DATA CON from the commercial software SIMSCI to generate reconciled value.

After flow rate is reconciled, energy balance would be the second task. The same technique will be done by using GAMS (optimization software) instead of DATACON.

This work was done by calculating both the material and energy balance, after running simulation by using DATACON, the results showed that there are 79 measured variables and 348 unmeasured variables including all flow rate, pressure, temperature and composition. This process contained 74 non- redundant variables and 322 unobservable variables. However, when the simulation was done the number of iteration was 10 plus 264 equations. The results of data reconciliation were shown in Appendix E.

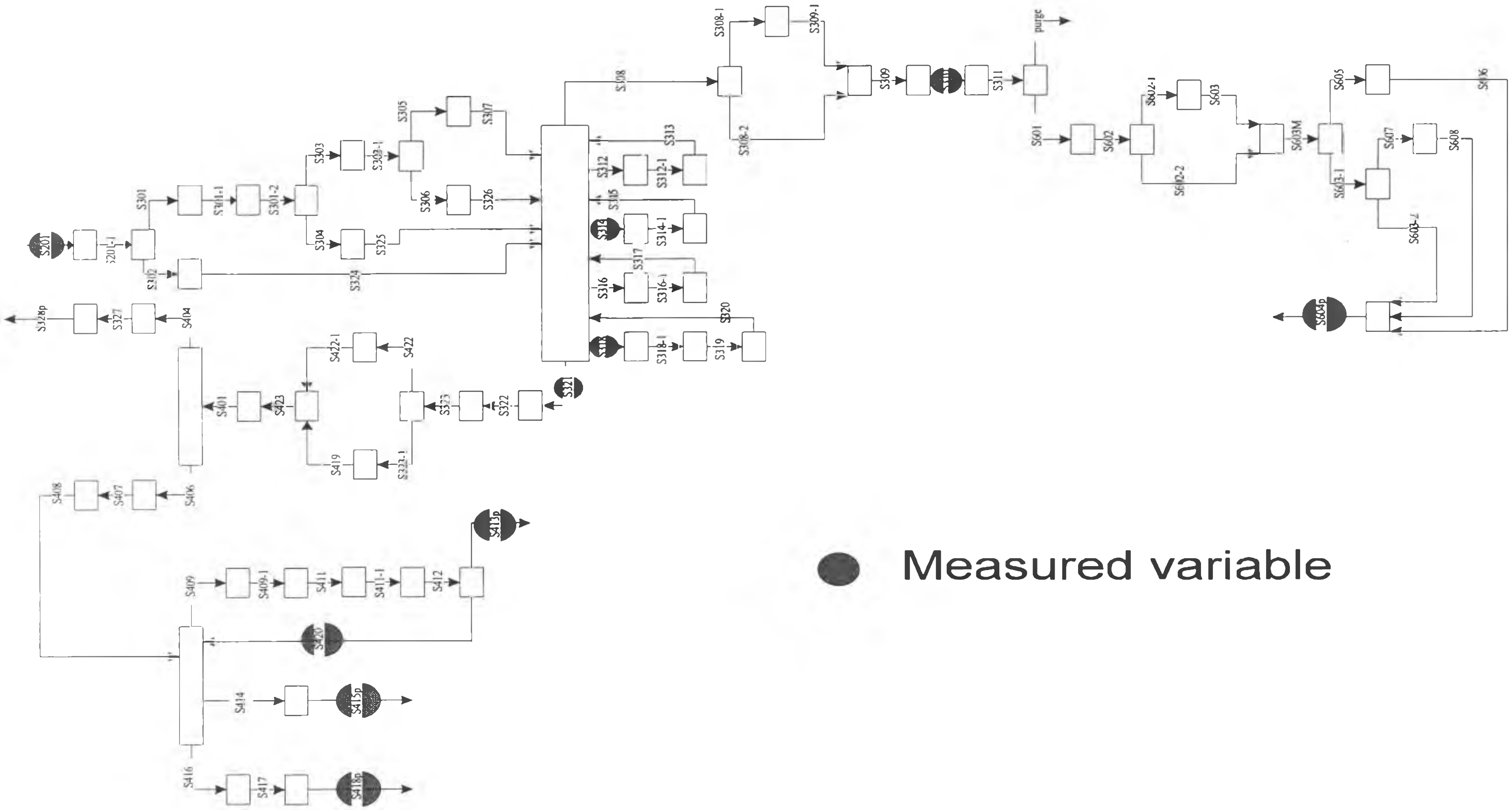

Figure 4.24 Diagram of gas separation plant on data reconciliation(measured variables).

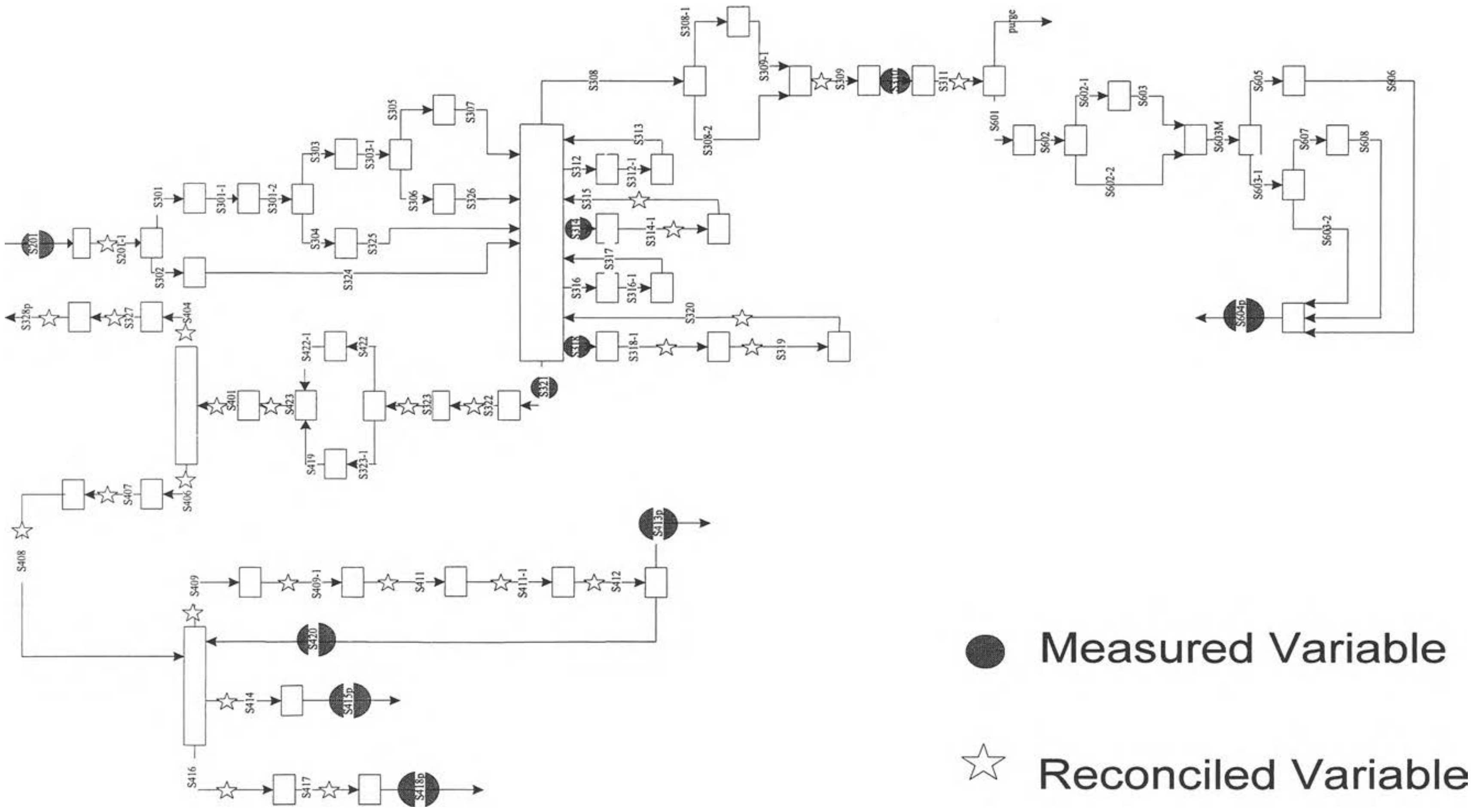

Figure 4.25 Diagram of gas separation plant on data reconciliation (measured and reconciled variables).