CHAPTER III
EXPERIMENTAL

Material and Equipment

Software: The commercial simulation software, PRO/II Provision (version 5.61, 1994-2002)

3.1 Data Collection from the GSP5

The design-data case including temperature, pressure, and flow rate were collected on Wednesday, June 14, 2006. Furthermore, the data and information of the actual-data case were collected on Tuesday, August 29, 2006.

3.2 Simulation of the Distillation Columns and the Heat Exchanger Networks

This research work is divided into two cases, the design-data case and the actual-data case. Starting from the design-data case, then doing the actual-data case. The simulator; PRO/II Provision, is used to simulate the distillation columns (the demethanizer, the deethanizer, and the depropanizer) and the heat exchanger networks.

3.3 Heat Exchanger Networks of the Background Process

The problem table algorithm (PTA) is used to ascertain the existing ΔT_{min} by matching the existing utility of the process.

3.3.1 Trial-and-error of the ΔT_{min}

3.3.2 Determination of temperature interval (T_{int})

$\Delta T_{min}/2$ is subtracted from the hot stream temperatures and $\Delta T_{min}/2$ is added to the cold stream temperatures. These temperatures are then sorted in descending order. This step ensures that there is an adequate driving force of ΔT_{min} between the hot and cold streams for possible heat transfer within each interval.

3.3.3 Calculation of net MC_p in each interval ($MC_{p,int}$)

The sum of the MC_p values of the hot streams is subtracted from the sum of the MC_p values of the cold streams present in each temperature interval.

3.3.4 Calculation of net enthalpy in each interval (Q_{int})

The $MC_{p.int}$ (calculated in Step 3.4.3) is multiplied by the temperature difference for that interval to obtain the heat requirement in the interval (Q_{int}). These are the net surplus ($Q_{int} < 0$) or deficit ($Q_{int} > 0$) in each interval.

3.3.5 Calculation of cascaded heat (Q_{cas})

The net enthalpy in an interval (obtained in Step 3.4.4) is subtracted from the cascaded heat in the previous interval to obtain the cascaded heat in that interval.

3.3.6 Revision of cascaded heat (R_{cas})

The highest negative Q_{cas} in column is brought to the first Q_{cas} column to obtain the revised cascaded heat (R_{cas}).

3.3.7 Generation of the grand composite curve (GCC)

The minimum hot utility requirement ($Q_{HU,min}$) and the minimum cold utility requirement ($Q_{CU.min}$) are the first and last values in column of R_{cas}. The temperature T_{int} that corresponds to zero revised cascaded heat is called the pinch temperature. A plot of T_{int} (obtained in step 3.3.2) and R_{cas} (obtained in step 3.3.6) yields the grand composite curve (GCC).

3.4 Retrofitting by Pinch Technology

This task is divided into two parts that are retrofit targets and retrofit designs, respectively.

3.4.1 Establishing the retrofit targets based on constant h-values

The target procedure is based on energy and area targets as well as on the concept of area efficiency. An area-energy and investment-saving plot is used to obtain a target for retrofit design.

3.4.1.1 Calculation of area efficiency of existing network (α)

The area efficiency is defined as

$$\alpha = A_{ideal} / A_{existing} \tag{3.1}$$

Where A_{ideal} is the ideal target area based on the composite curves corresponding to the current utility levels and $A_{existing}$ is the actual area of the existing network.

3.4.1.2 Calculation of area targets for various energy levels

The area and energy targets can be calculated at any ΔT_{min}.

3.4.1.3 Calculation of the retrofit curve

3.4.1.4 Calculation of the maximum area to be used in designing the new network ($A_{max,retr}$)

This is done by the following formula:

$$A_{max,retr} = A_{ideal}/\alpha_{existing} \quad \text{for } \alpha \geq 0.9 \tag{3.2a}$$

$$A_{max,retr} = (A_{ideal} - A_{ideal\,1})/\Delta\alpha + A_{existing} \quad \text{for } \alpha < 0.9 \tag{3.2b}$$

With $\Delta\alpha = 1$ for $\alpha < 0.9$ and $\Delta\alpha = \alpha_{existing}$ for $\alpha \geq 0.9$.

3.4.1.5 Plotting area-energy curves

Area-energy curves are obtained by plotting A_{ideal} against energy (based on hot utility).

3.4.1.6 Calculation of energy saving and extra area required

Energy savings = current utility usage - target utility required (based on hot utility) (3.3a)

Extra area = required new area - existing area (3.3b)

3.4.1.7 Economic analysis of investment vs. savings

This task is used to calculate an annual energy-saving cost and investment cost that are used to plot investment-saving curves.

3.4.1.8 Identification of target ΔT_{min}

The specified payback period is used to identify the target ΔT_{min} that is the best starting point in economic.

3.4.2 Retrofit designs for constant h-values

The design procedure is done by the following steps:

3.4.2.1 Identification of cross-pinch exchangers

Grid diagram is used to represent flow streams, heat recovery matches and external utility loads of existing process. Consequently, inserts the pinch location by using ΔT_{min} that obtained in section 3.4.1.8 to find heat exchangers crossing the pinch.

3.4.2.2 Elimination of cross-pinch exchangers

3.4.2.3 Revision of the network

This task is re-using existing exchangers or introducing the new exchanger or both of them.

3.5 Distillation Column Targeting

3.5.1 Using a converged simulation of each column and selecting the key components (light and heavy key group).

3.5.2 Calculation of minimum vapor and liquid flow rates

Before feed stage

$$G_{min}Y^*_L - L_{min}X^*_L = D_L$$
$$G_{min}Y^*_H - L_{min}X^*_H = D_H \qquad (3.4)$$

After feed stage

$$L_{min}X^*_L - G_{min}Y^*_L = B_L$$
$$L_{min}X^*_H - G_{min}Y^*_H = B_H \qquad (3.5)$$

Where G_{min}, L_{min} = Minimum vapor and liquid flow

Y^*_L, X^*_L = Light composition of vapor and liquid

Y^*_H, X^*_H = Heavy composition of vapor and liquid

D_L, D_H = Light and heavy component flow of distillate

B_L, B_H = Light and heavy component flow of bottm

Obtain the minimum vapor and liquid flow rates at each stage temperature by solving the two simultaneous equations.

3.5.3 Calculation of minimum vapor and liquid enthalpies

Assuming molar proportionality foe enthalpies, the minimum enthalpies corresponding to the minimum flows may be calculated from

$$H_{Gmin} = H^*_G(G_{min}/G^*) \tag{3.6a}$$

$$H_{Lmin} = H^*_L(L_{min}/L^*) \tag{3.6b}$$

Where H_{Gmin}, H_{Lmin} = Enthalpy of the minimum vapor and liquid flow

H^*_G, H^*_L = Enthalpy of equilibrium vapor and liquid flow

G^*, L^* = Molar flows of equilibrium vapor and liquid steam

3.5.4 Calculation of net heat deficit at each stage temperature (H_{def})

The enthalpy deficit on each stage is given by

Before feed stage

$$H_{def} = H_{Lmin} - H_{Gmin} + H_D \tag{3.7}$$

After feed stage

$$H_{def} = H_{Lmin} - H_{Gmin} + H_D - H_{feed} \tag{3.8}$$

3.5.5 Cascading heat deficits

This is done by adding the condenser load to the H_{def} (obtained in 3.5.4) on each tray.

3.5.6 Generation of the column grand composite curve (CGCC)

The resulting cascade can be plotted against the stage temperature to arrive at the CGCC.

3.6 Stand-Alone Column Modifications

Firstly, the sensitivity analyses of columns were done, and then do following modifications. The criteria of modifications are summarized below:

3.6.1 Reflux ratio modification
3.6.2 Feed conditioning (feed preheating/pre-cooling)
3.6.3 Side reboiling/condensing

3.7 Process Heat Integration

Generating the GCC (obtained in the heat exchanger network of background process section) and the CGCC (obtained in the distillation columns targeting section) in the same graph is used to investigate an inappropriately column placed and to find a way to obtain the benefit from the integration

3.8 UA Analysis (Revamp Studies)

By applying the well-known equation, UA = Q/LMTD to each unit, the effect of network changes on the total area of each heat exchanger unit is assessed. After modifying, if the total heat exchanger areas are larger than the existing then the modification of heat exchange unit is required.

3.9 Economical Evaluation

The economical evaluation comprises of a utility cost saving, an investment cost, and a payback period. In addition to heat exchanger cost, a module factor is implemented to estimate more accurate cost. A heat exchanger has module factor in a range from 3.09 to 3.29. This study uses a module factor, 3, for simplifying calculation (Sung-Geun Yoon, Jeongseok Lee, Sunwon Park, Heat integration analysis for an industrial ethylbenzene plant using pinch analysis. Applied Thermal Engineering, 2006).