CHAPTER III
PROCEDURE

3.1 Collecting the Data from Reformer Area of ATC Plant

The important step in HEN synthesis is data extraction. In this work, the design data of reformer area of aromatics plant is used for the analysis. For the first phase of study, the design data will be used first. The data of hot and cold streams for the existing plant are shown in Table 3.1. The data collected for design case are composed of material balance for the streams that involve the heat exchangers (i.e. temperatures, heat-capacity flow rates).

3.2 Modeling the Heat Exchanger and Stream Data by using Pro II.

For doing HEN synthesis, modeling all the plant can be neglected. Therefore, Pro II is used to simulate the heat exchangers.

Pro II Manual

1) Setup the unit of measurement.
2) Specify the components for the system.
3) Specify the thermodynamic property package for the system.
4) Insert stream into process flowsheet.
5) Insert unit operations into process flowsheet.
6) Make connectivity between unit operations and streams.
7) Input the feed stream information, unit operation operating parameters.
8) Click run button to simulate the program.
9) Check the results.

3.3 Data Extraction

The required data besides the streams and heat exchanger networks data are

1. Heat transfer coefficient for each stream
2. Utility and economic data

3.3.1 Stream Heat Transfer Coefficient

Heat transfer coefficient is another important data. The values are calculated based on the correlation and heat exchanger geometry (Seider, *et al.*, 1999). The correlation for the heat transfer coefficient calculation is shown below:

For shell side without phase change, heat transfer coefficient can be calculated by Donohue equation as shown in equation 3.1.

$$Nu = \left(\frac{hD_o}{k}\right) = 0.33\left(\frac{D_o u\rho}{\mu}\right)^{0.6}\left(\frac{C_p\mu}{k}\right)^{\frac{1}{3}} \tag{3.1}$$

For tube side, Colburn equation as shown in equation 3.2 is used to calculate this value.

$$Nu = \left(\frac{hD_o}{k}\right) = 0.023\left(\frac{D_o u\rho}{\mu}\right)^{0.6}\left(\frac{C_p\mu}{k}\right)^{\frac{1}{3}} \tag{3.2}$$

where, Nu	=	Nusselt number
h	=	heat transfer coefficient
D_o	=	outside diameter of tube
D_i	=	inside diameter of tube
k	=	thermal conductivity of tube
ρ	=	fluid density
μ	=	fluid viscosity
C_p	=	heat capacity of fluid

Table 3.1 Data for Hot and Cold Streams for the Existing Plant of Reformer Area

STREAM	HX	stream in name	stream out name	flowrate kg/hr	Tin C	Tout C	total duty MW
H1	100-E2/2A,100-EA3	346	351	71144.00	234.02	49.00	7.071
H2	100-E6,100-E9	540	544	19333.00	104.23	38.00	0.960
H3	100-E4,100-EA5,100-E12AB	511	565	35173.00	116.00	38.00	1.984
H4	110-E1A-D,110-EA1	006	008	242137.00	220.00	60.00	27.072
H5	150-E1AG	131	132	148267.00	343.00	131.00	31.847
H6	150-EA1	136	137	153252.00	121.37	49.00	7.912
H7	150-E2AB,150-EA3	341	399	146465.00	222.21	109.00	11.942
H8	200-E2	194	195	208.90	524.00	178.61	0.060
H9	200-EA1	167	181	176380.00	103.20	48.53	14.949
H10	200-EA3	1204	1212	22648.00	132.90	55.00	2.289
H11	200-E12,200-E13	1122	1123	4080.00	111.80	8.00	0.580
H12	200-E3	1164	1165	153530.00	46.86	37.91	1.076
H13	200-E4AB	1214	1215	137680.00	56.19	37.79	1.842
H14	200-E5	1254	1265	2519.00	59.54	37.78	0.090
H15	200-E6AB	1474	1469	126970.00	209.54	103.40	8.706
H16	200-E15	1411	-	985.80	37.77	8.00	0.073
H17	200-EA2	1154	1162	29600.00	131.00	56.11	2.560
C1	100-E2/2A	109	110	265176.00	118.00	142.00	4.014
C2	100-E6	517	513	19690.00	45.02	78.00	0.504
C3	100-E11	525	527	357.00	23.46	44.60	0.022
C4	100-E4	302	305	49679.00	52.28	77.00	0.864
C5	110-E2/2A			242137.08	184.50	220.00	8.238
C6	110-E1A-D		002	241836.00	36.80	188.70	24.174
C7	150-H1,150-E1A-H	112	115	148267.00	63.00	339.00	38.096
C8	150-E2AB	151	306	146965.00	49.00	157.00	9.932
C9	200-E2	190	193	263.60	111.00	314.00	0.060
C10	200-E6AB	1438	1420	131800.00	37.00	154.10	8.706

3.4 Energy Targets

Maximum energy recovery (MER) implies using the minimum amount of utilities. If Q_{Hu} is the heat supplied by hot utility and Q_{Cu} is the heat removed by cold utility, then computation of energy targets involves determining the minimum values of Q_{Hu} and Q_{Cu}. Calculation of energy target for any ΔT_{min} can be done by two ways; constructing the grand composite curve (Hohmann, 1971) and Problem Table Algorithm (PTA) (Linnhoff and Flower, 1978). But PTA can be done easily without plotting the graph. Steps for making problem table algorithm are

Step 1. 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, omitting temperatures common to both hot and cold streams. These form the limits of the various temperature intervals.

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.

Step 2. 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.

Step 3. Calculation of Net Enthalpy in Each Interval

The $MC_{p,int}$ (calculated in Step 2) 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.

Step 4. Calculation of Cascaded Heat (Q_{cas})

The net enthalpy in an interval (obtained in Step 3) is subtracted from the cascaded heat in the previous interval to obtain the cascaded heat in that interval.

Step 5. Revision of Cascaded Heat (R_{cas})

The most negative Q_{cas} in column is subtracted from each value in that column to obtain the revised cascaded heat (R_{cas}) in column. The cascaded heat needs to be revised since a negative heat transfer is thermodynamically infeasible. The negative heat transfer is a consequence of the heat from a higher interval being inadequate to satisfy the requirements of lower intervals. This may be rectified by supplying just enough heat at he highest temperature interval (through a hot utility) to temperature interval cannot be rejected to any cold stream and thus constitutes the minimum cold utility requirement.

Step 6. Determination of Energy Targets

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.

3.5 Plotting of Composite Curves

Step 1. Sorting of Hot Stream Temperatures (T_h)

The hot stream temperatures are sorted in ascending order, omitting repeated entries.

Step 2. Calculation of MC_p of Hot streams in Each Interval (Sum MC_p)

The sum of the MC_pvalues of the hot streams present in each temperature interval is calculated.

Step 3. Calculation of Enthalpy in Each Interval ($Q_{int,h}$)

The Sum $MC_{p,h}$ in each interval (calculated in step 2) is multiplied by the temperature difference for that interval.

Step 4. Calculation of Cumulative Enthalpy ($CumQ_h$)

This column is calculated using the formula

$$CumQ_{h,i} = CumQ_{h,i-1} + Q_{int,hi}$$

With $CumQ_{h,i} = 0$ for i = 0.

Step 5. Plotting of HCC

T_h are plotted against $CumQ_h$ to obtain the HCC

Step 6. Generation of CCC Data

The procedure to be followed for the CCC is virtually identical to that adopted for the HCC. The cold stream temperatures are sorted in ascending order, omitting repeated entries, to obtain T_c. The sum of the MC_p values of the cold streams present in each temperature interval is calculated and entered as $SumMC_{p,c}$ against the higher temperature limit of the interval. A zero is placed for the first entry. The $SumMC_{p,c}$ in each interval is multiplied by the temperature difference for that interval to obtain the enthalpy in each interval ($Q_{int,c}$). For the cumulative enthalpy $CumQ_c$ it is calculated by using the formula:

$$CumQ_{c,i} \quad = \quad CumQ_{c,i-1} \quad + \quad Q_{int,ci}$$

With $CumQ_{c,i} = Q_{cu,min}$ for i = 0. This is the only difference between the plotting procedureds for the HCC and the CCC. While the HCC starts from zero enthalpy, the CCC is displaced by the cold utility target. The CCC is obtain by plotting T_c vs. $CumQ_c$.

Step 7. Determination of Enthalpies for Intervals ($CumQ_i$)

The value of $CumQ_h$ and $CumQ_c$ are merged, omitting cumulative enthalpies common to both tables, and the entries are the sorted in ascending order.

This identifies all points where either composite curve has a vertex (change in slope) and thus determines the various enthalpy intervals over which the area is to be summed.

Step 8. Calculation of Interval Temperatures on HCC (T_{hi})

For each $CumQ_i$ from Step 7, a least value of $CumQ_h$ that satisfies $CumQ_h \geq CumQ_i$ is identified. Let this valued be in row r. Then,

$T_{hi} = T_{h,row\ r}$ if $CumQ_{h,row\ r} = CumQ_i$ or

$T_{hi} = T_{h,row\ r} - (CumQ_{h,row\ r} - CumQ_i)/SumMC_{p,h\ row\ r}$

in all other cases.

Step 9. Calculation of Interval Temperatures on CCC (T_{ci})

These temperatures are calculated in a manner similar to that in step 8. For each $CumQ_i$, the least value of $CumQ_c$ is identified such that $CumQ_c \geq CumQ_i$. Let this value in row r. Then,

$T_{ci} = T_{c,row\ r}$ if $CumQ_{c,row\ r} = CumQ_i$ or

$T_{ci} = T_{c,row\ r} - (CumQ_{c,row\ r} - CumQ_i)/SumMC_{p,c\ row\ r}$ in all other cases.

Step 10. Calculation of $\sum(MC_p/h)$ in Each Interval ($\sum(MC_p/h)_h$ and $\sum(MC_p/h)_c$)

These values are calculated in a manner similar to $SumMC_{p,h}$ and $SumMC_{p,c}$. Using the heat transfer coefficients, the sum of the (MC_p/h) values of all the hot process streams present in each temperature interval is calculated and enter against the higher temperature limit of the interval. Similarly, the sum of the (MC_p/h) values of all the cold process streams present in each temperature interval is calculated and entered against the higher temperature limit of the interval.

Step 11. Calculation of Sum(Q/h) in Each Interval (Sum(Q/h))

The $(\sum(MC_p/h)_h$ for the HCC is multiplied by the hot composite stream temperature difference and then added to the corresponding value for the cold composite curve. As per Equation 3.5 the value in interval i is given by

$$Sum(Q/h) = (T_{h,i} - T_{h,i-1})\,(\sum(MC_p/h)_{h,i} + (T_{c,i} - T_{c,i-1})\,(\sum(MC_p/h)_{c,i} \qquad \text{for } i \geq 1$$

$$Sum(Q/h) = 0 \qquad \text{for } i = 0.$$

Step 12. Calculation of Log Mean Temperature Difference in Each Interval ($LMTD_i$)

This is easily done by the following formula:

$$LMTD_i = \frac{(T_{h,i} - T_{c,i}) - (T_{h,i-1} - T_{c,i-1})}{\ln\left[\dfrac{T_{h,i} - T_{c,i}}{T_{h,i-1} - T_{c,i-1}}\right]} \qquad \text{for } i \geq 1$$

$$LMTD_i = 0 \qquad \text{for } i = 0.$$

Step 13. Calculation of Countercurrent Exchanger Area in Each Interval (A_i)

The overall Area can be calculated by summing over all the A_I values.

3.6 Plotting of Column Grand Composite Curve

Step 1. Simulation Distillation Column by using ProII Program

Use distillation column data of reformer area to simulate result.

Step 2. Calculation of Minimum Vapor and Liquid Flow Rates

Before feed stage

$$G_{min} Y^*_L - L_{min} X^*_L = D_L$$

$$G_{min} Y^*_H - L_{min} X^*_H = D_H$$

After feed stage

$$G_{min} Y^*_L - L_{min} X^*_L = D_L - F_L$$

$$G_{min} Y^*_H - L_{min} X^*_H = D_H - F_H$$

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

F_L, F_H = light and heavy component flow of feed

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

Step 3. Calculating of Minimum Vapor and Liquid Enthalpies

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

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

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

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

Step 4. Calculation of Net Heat Deficit at Each Stage Temperature

The enthalpy deficit on each stage is given by

Before feed stage

$$H_{def} = H_{Lmin} - H_{Gmin} + H_D$$

After feed stage

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

Step 5. Cascading the Heat Deficits

This is done by adding the condenser load to the H_{def} on each tray. The resulting cascade may be plotted against the stage temperature to arrive at the CGCC. The CGCC typically exhibits a pinch near the feed stage since its shape is distinctly affected by the feed enthalpy. Like the GCC, the CGCC provides a picture of the temperature levels at which heat is required to be supplied and rejected in the column.

3.7 Process Integration

GCC and CGCC in the same graph are plotted the possibility of heat transfer from column to process or process to column will be studied..

3.8 Collecting the Data from Aromatics Area of ATC Plant

The temperature and flow rate can be read by the TI or TIC and FI or FIC, respectively. The average value of these data was concluded in table 3.2. In total, the number of the hot and cold streams was 61 streams which are 37 hot streams and 24 cold streams. After that, the retrofit can be done by repeating the procedure 3.4, 3.5 and 3.9.

3.9 Retrofitting by Pinch Technology

The good retrofits should be conducted by aiming toward the optimum new design with the effective use of existing area. In other words, it should save energy as much as possible using the existing area. However, in practice, we usually have to invest some capital to make changes to an existing network, thus increasing area.

The basic methodology looks at the economics of plant operation and modification of provided targets. The next step involves network modification to achieve the set targets.

3.9.1 Targeting 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 investment vs. saving plot is used to obtain a target for retrofit design.

Step 1. Calculation of Area Efficiency of Existing Network

For retrofit design, the area efficiency, α, of an existing HEN is important. The area efficiency measures the performance of the existing design compared to the ideal target of the process data. The closer the existing HEN is to the ideal curve in an energy area plot the better the performance, as this indicates that the design is utilising the installed area efficiently. If there is poor correspondence between the two then there exists inefficient use of energy recovery, which implies that there is a large scope for improvement of the existing design. The area efficiency is defined as

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

where A_{ideal} is the ideal target area based on the composite curves corresponding to the current utility levels and $A_{existing}$ is the acual area of the existing network. This would involve use of the PTA to obtain ΔT_{min} and a trial and error procedure to ascertain the ΔT_{min} for the existing utility level.

Step 2. Calculation of Area Targets for Various Energy Levels

The area and energy targets can be calculated at any ΔT_{min} as in section 3.4 and 3.5.

Step 3. Calculation of the Retrofit Curve

One of the aims of retrofitting is to improve the use of area; hence, the efficiency should not decrease and may be chosen to be $\alpha_{existing}$ to provide the most conservative estimate for further calculations.

There are two area efficiency concepts, namely constant, α and incremental, $\Delta\alpha$. The constant α method states that the network would use the additional area as efficiently as the existing network over the full energy span.

This is a conservative approach, which gives good targets for networks with high α. However, when α is very low (i.e., $\alpha < 0.9$), the usage of an incremental value of $\Delta\alpha=1$ is recommended (Silangwa, 1986: Ahmad and Polley, 1990). Thus the maximum area to be used in designing the new network may be obtained as

$$\mathbf{A_{max,retr} = (A_{ideal} - A_{ideal\ 1}) / \Delta\alpha + A_{existing}}$$

$$A_{max,retr} = A_{ideal}/\alpha_{existing} \qquad \text{for } \Delta\alpha = \alpha_{existing}$$

$$A_{max,retr} = (A_{ideal} - A_{ideal\ 1}) + A_{existing} \qquad \text{for } \Delta\alpha = 1$$

where $A_{ideal\ 1}$ is the value of A_{ideal} of existing network.

Step 4. Calculation of Energy Saving and Extra Area Required

The formulae are

energy savings = current utility usage - target utility required

(based on hot or cold)

extra area = required new area - existing area

Before calculation of the energy saving, the utility usage for multiple utility levels is required and Problem Table Analysis will be used in this step.

Step 5. Economic Analysis of Investment vs. Savings

This step involves calculation of the energy saving into amount of saving in \$ and the extra area required into investment cost in US\$. Simplifying assumptions used for the calculation of energy and capital costs are:

The investment cost refers only to the cost of extra area required to achicve the energy recovery target. No piping or other costs are considered.

The average size of the heat exchanger shell is calculated from the existing HEN area and number of shells.

The existing average area per shell in the HEN is the same for the added area. For the existing network, the area is calculated for a counter-current single shell pass, single tube pass.

The investment cost is estimated using the following equation:

$$\text{Investment cost} = 21700*(\text{Area of exchanger}/9.3)^{0.59} *(1105/1000)$$

Step 6. Identification of Target ΔT_{min}

Based on the specified payback period (2 years), the required target is the point where the investment is twice the savings.

3.9.2 Design Procedure

The design procedure will be as follows

1) Identify cross-pinch exchangers. Draw the existing network on the grid (using ΔT_{min}identified in the targeting stage) to find the heat exchangers crossing the pinch.
2) Eliminate cross-pinch exchangers.
3) Complete the network--Position new exchangers and, where possible, reuse exchangers removed in Step2.
4) Evolve improvements--Improve compatibility with existing network via heat load loops and paths. Reuse area of existing exchangers as much as possible.

Table 3.2 Data for Hot Stream for the Existing Plant of Aromatics Area

STREAM	UNIT	flowrate	Tin	Tout
		kg/hr	C	C
H1	430-E3,430-EA9,430-E10	88576.50	96.801	36.784
H2	430-E1	67043.00	199.765	194.117
H3	430-EA3	175187.00	133.610	96.800
H4	540-E2	30431.10	85.566	32.328
H5	540-E1	394972.00	145.014	83.000
H6	540-EA1,540-E4	47718.60	118.890	32.761
H7	431-E2	88075.00	195.470	55.950
H8	431-EA2	133706.00	85.100	56.833
H9	431-EA1,431-E5	38000.00	83.495	33.480
H10	431-EA3	222353.00	116.000	95.348
H11	380-EA1,380-E1	127.74	89.983	29.649
H12	380-E4	189199.00	230.772	98.410
H13	380-EA3,380-E5	45101.00	145.674	32.776
H14	432-EA3,432-E4	15000.00	193.275	37.693
H15	432-E8	151090.00	254.284	197.242
H16	432-EA5	50835.30	147.456	137.187
H17	432-EA14	79967.00	174.479	154.959
H18	432-EA6,432-E7	8248.40	137.187	24.124
H19	432-EA10	8306.50	222.359	33.400
H20	432-E12	32548.00	297.465	201.916
H21	500-E6	218833.00	207.122	186.764
H22	500-EA8	239117.00	139.910	55.804
H23	500-E9	84049.20	204.511	186.261
H24	500-EA11	143262.00	144.554	120.945
H25	500-E12,500-EA13,500-E14	53310.00	150.060	33.576
H26	500-EA17	54977.96	111.501	66.034
H27	500-E15	59093.10	189.126	164.100
H28	500-E16	322480.00	185.932	152.164
H29	320-EA1	140050.00	128.351	41.492
H30	320-E1	140050.00	147.097	139.583
H31	320-E6	202300.00	229.398	177.842
H32	320-E7,320-E5	131180.00	235.806	140.436
H33	320-E8,320-EA2,320-E9	78917.60	160.723	37.533
H34	320-E17,320-E18	9343.40	212.518	41.216
H35	320-E16	30013.00	254.284	213.472
H36	390-E3	40133.20	227.228	135.862
H37	390-EA2	14245.20	125.633	44.786

Table 3.3 Data for Cold Stream for the Existing Plant of Aromatics Area

STREAM	UNIT	flowrate	Tin	Tout
		kg/hr	C	C
C1	430-E3	34000.00	30.000	82.131
C2	430-E1,430-E2	163117.00	124.268	136.791
C3	430-H1	340450.00	199.765	210.186
C4	540-E1	537759.00	64.435	111.630
C5	431-E2,431-E3	117351.00	40.605	197.850
C6	380-E4	190400.00	49.115	178.614
C7	432-H1	433598.00	254.284	276.615
C8	432-E8	210000.00	189.260	203.779
C9	432-E1	67043.00	191.143	240.849
C10	432-H3	1100239.30	289.735	312.000
C11	500-E6	343000.00	174.878	188.326
C12	500-E9	139500.00	177.228	188.637
C13	500-E12	55300.40	120.945	136.038
C14	500-E15	167740.00	150.060	151.393
C15	500-E16	105770.00	150.060	151.096
C16	320-E8,320-E1,320-E5,320-E6	138440.00	41.492	225.270
C17	320-E7	131180.00	178.165	223.657
C18	320-H2	340049.00	235.806	236.000
C19	320-E17	11273.00	39.493	132.683
C20	320-E16	55359.00	210.911	214.214
C21	390-E3	45368.00	40.754	136.422
C22	390-H2	106100.00	227.228	232.782
C23	431-E4	688602.00	132.021	133.000
C24	431-E6	769584.00	162.898	163.242