CHAPTER V

DESIGN OF WORKABLE COMPLEX HEAT-INTEGRATED HDA PROCESS AND STEADY STATE SIMULATION

For complex heat-integrated process, the heater and cooler are replaced by process to process heat exchanger. To control a high heat integration scheme, design modifications to process is needed to ensure controllability and operability. Luyben (1999) solves some of the control difficulties by adding auxiliary utility to the end of hot and cold streams that have no utility unit in order to assure target temperature each stream when disturbance come through the process. The many auxiliary units introduce the rising economic cost therefore the purpose in this chapter is to illustrate the strategy that can estimate the minimum auxiliary utility units, still achieve temperature each stream and apply this strategy to HDA process with complex energy integration alternative 6.

5.1 The strategy for estimating the minimum auxiliary utility units

Our strategy for design workable heat-integrated HDA process with minimum auxiliary utility units comprising of 4 steps, is described as follows:

1) Determined the expected disturbances and their magnitudes

The disturbance load requirement is determined in this step. Only temperature variation is considered here. The magnitude of the variation in this work is ± 10 Celsius as sensible heat load variation.

2) Design the worst case conditions

Wongsri (1990) defined four extreme conditions in order to design resilient heat exchanger network. Two of them are used to be worst case conditions as follows:

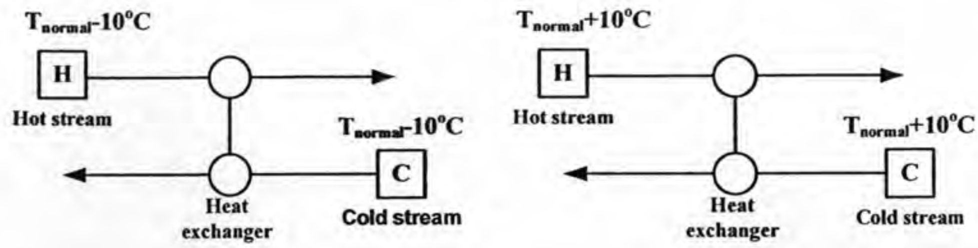
2.1. Minimum Heating Condition.

This is a condition where hot process streams are at their minimum heat loads (minimum cooling requirement) whereas cold process streams are at their maximum heat loads (maximum heating requirement). For example, inlet temperatures of hot and cold streams are the lowest. Therefore this worst case condition is employed to estimate minimum auxiliary heating units as minimum auxiliary reboiler units for heat-integrated distillation columns.

2.2. Maximum Cooling Condition.

This is a condition hot process streams are at their maximum heat loads (maximum cooling requirement) whereas cold process streams are at their minimum heat loads (minimum heating requirement). For example, inlet temperatures of hot and cold streams are the highest. Therefore this worst case condition is employed to estimate minimum auxiliary cooling units as minimum auxiliary condenser units for heat-integrated distillation columns.

In previous step, the magnitude disturbance is ± 10 °C. Hence minimum heating condition a condition where hot and cold process streams are the temperature at normal operating condition (T_n) minus 10°C (see fig.5.1.a). For maximum cooling condition, hot and cold process streams are the temperature at normal operating condition (T_{normal}) plus 10°C (see fig.5.1.b).



(a) (b)

Fig.5.1 Worst Case Condition (a) Minimum heating condition for estimate minimum auxiliary heating units (b) Maximum cooling condition for estimate minimum auxiliary cooling units

3) Design heat pathways for the worst case conditions

When disturbance load come to hot and cold process streams, the important thing is how to remove disturbance load. It has a few heat pathways to remove disturbance.

In the process heat integration, there are two kinds of disturbance loads (Wongsri, 1990). The first disturbance load is Positive disturbance load D+ i.e. a disturbance that will increase the heat load of stream. For example, when the inlet temperature of a disturbed hot stream increases or when the inlet temperature of a disturbed cold stream decreases. The second disturbance load is Negative disturbance load D- i.e. a disturbance that will decrease the heat load of stream. For example, when the inlet temperature of a disturbed hot stream decreases or when the inlet temperature of a disturbed cold stream increases. The shift approach is presented by Wongsri, 1990 that the disturbance load can be viewed as a heat packet that must be propagated as much as possible by transferring or shifting it to heat sinks (coolers) or heat sources (heater) of a network such as a simplified heat exchanger network as shown in Figure 5.2. Another concept that will be used together with shift approach is disturbance propagation design (Wongsri, 1990) as the disturbance load of a smaller heat load stream will be shifted to a larger heat load stream.

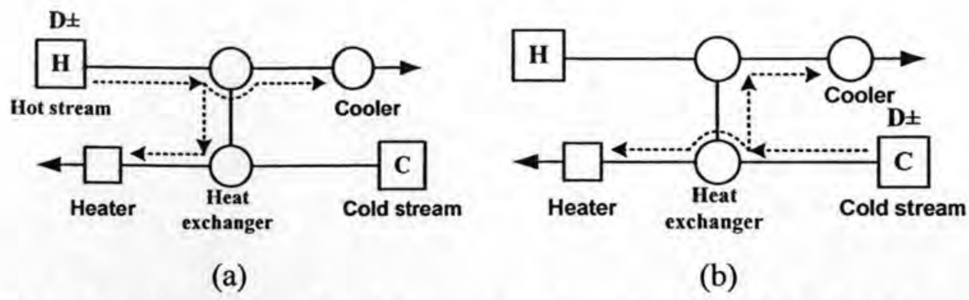


Fig.5.2 The Disturbance Load is propagated to Heater and Cooler (a) positive and negative disturbance load in hot stream cases (b) positive and negative disturbance load in cold stream cases

4) Estimated the minimum auxiliary utility units

The minimum auxiliary utility unit is estimated in this step consists of 2 parts as estimated the minimum auxiliary heating and cooling units

4.1. Estimated the minimum auxiliary heating units

In this part, the minimum heating condition (see fig 5.1.a) is employed to heat exchanger network and then the disturbance load is dissipated to cooler that is the appropriated heat path way. If the end stream can't achieve target temperature in worst case condition, the auxiliary cooler has to employ. Therefore the minimum number of auxiliary cooling unit is estimated.

4.2. Estimated the minimum auxiliary cooling units

For this part, the maximum cooling condition (see fig 5.1.b) is employed to heat exchanger network and then the disturbance load is dissipated to heater that is the appropriated heat pathway. If the end stream can't achieve target temperature in worst case condition, the auxiliary heater has to employ. Therefore the minimum number of auxiliary heating unit is estimated.

We found that only 1 auxiliary reboiler is needed instead of 3 for the 3 columns. A resilient heat exchanger network scheme is shown in Figure 5.3

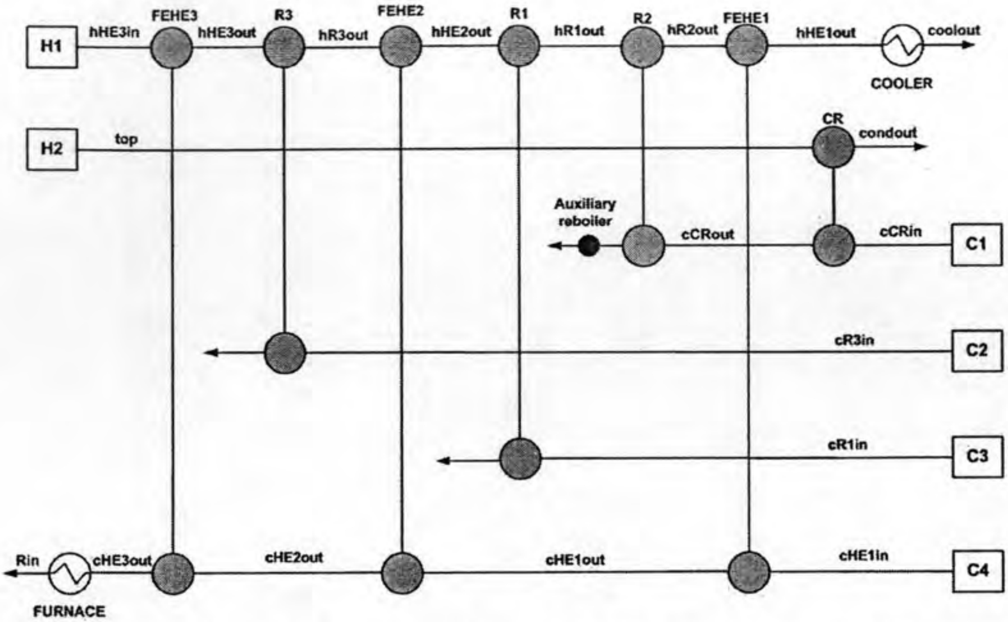


Figure 5.3 The Resilient Heat Exchanger Network (HEN) of HDA Process (Alternative 6)

5.2 The Information of HDA Process

the resilient heat exchanger network design method provided by Wongsri (1990) is used to design the resilient heat exchanger networks for Hydrodealkylation process (HDA Process). The design procedures and definitions from previous chapters will be an accessory to design in conceptual design. The Problem Table Method is applied to find pinch temperature and reach maximum energy recovery (MER).The information for used in design is shown in the following table.

Table 5.1 The Information of HDA Process

Stream Name	Tin (°C)	Tout (°C)	W (kW/°C)
H1: Reactor Product Stream (RPS)	621	45	33
H2: Recycle Column Condenser (RCC)	183	181	200
C1: Reactor Feed Stream (RFS)	65	621	32.24
C2: Product Column Rebolier (PCR)	145	193	91
C3: Stabilizer Column Reboiler (SCR)	190	215	59
C4: Recycle Column Reboiler (RCR)	349.5	350.7	456

5.3 HDA Process Alternative 6

From previous chapter the Alternative 6 can be writing a simply heat exchanger network as following: See Figure 5.4

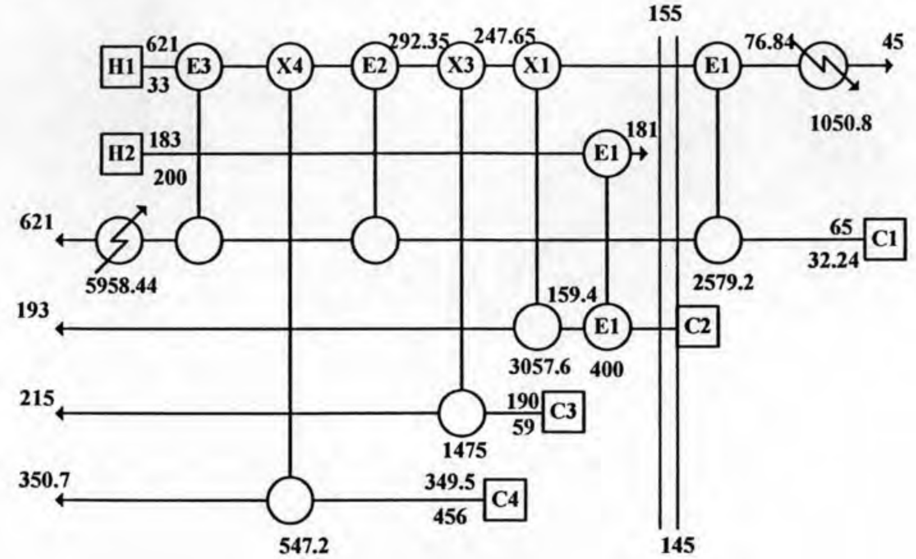


Figure 5.4 Resilient Heat Exchanger Network of Alternative 6

We can see that there are six streams in the network so we can find the Pinch temperature by using Problem Table Method as following: See Table 5.2

Table 5.2 Problem table for HDA process 1

W						T hot	T cold	ΣW	ΔT	Required Heat	Interval	Cascade Heat	Sum Interval
H1	H2	C1	C2	C3	C4								
0	0	0	0	0	0	631	621	0		Qh			
0	0	32.2	0	0	0	621	611	-32.24	10	5963.16	-322.40	0.00	-322.40
33	0	32.2	0	0	0	360.7	350.7	0.76	260.3	5640.76	197.83	5838.59	-124.57
33	0	32.2	0	0	456	359.5	349.5	-455.24	1.2	5838.59	-546.29	5292.30	-670.86
33	0	32.2	0	0	0	225	215	0.76	134.5	5292.30	102.22	5394.52	-568.64
33	0	32.2	0	59	0	203	193	-58.24	22	5394.52	-1281.28	4113.24	-1849.92
33	0	32.2	91	59	0	199.92	189.92	-149.24	3.08	4113.24	-459.66	3653.58	-2309.58
33	0	32.2	91	0	0	183	173	-90.24	16.92	3653.58	-1526.86	2126.72	-3836.44
33	200	32.2	91	0	0	181	171	109.76	2	2126.72	219.52	2346.24	-3616.92
33	0	32.2	91	0	0	155	145	-90.24	26	2346.24	-2346.24	0.00	-5963.16
33	0	32.2	0	0	0	69.63	59.63	0.76	85.37	0.00	64.88	64.88	-5898.28
33	0	0	0	0	0	45	35	33	24.63	64.88	812.79	877.67	-5085.49
												Qc	

By using Synthesis procedure in Chapter III, we can receive 3 resilient networks follow by Table 5.3 -5.6 and Figure5.5-5.7.

Table 5.3 Synthesis Table for cold end

Synthesis Table for cold end								
Stream	Load	W	T1	T2	Ds	Dw	Dt	Action
a) State1								
H1	3465	33	155	50	0	0	330	Selected B[C]
C1	2242.8	32.04	75	145	0	32	0	Selected
3								
H1	1190.2	33	86.067	45	32	0	330	To Cooler
C1								Matched to H1

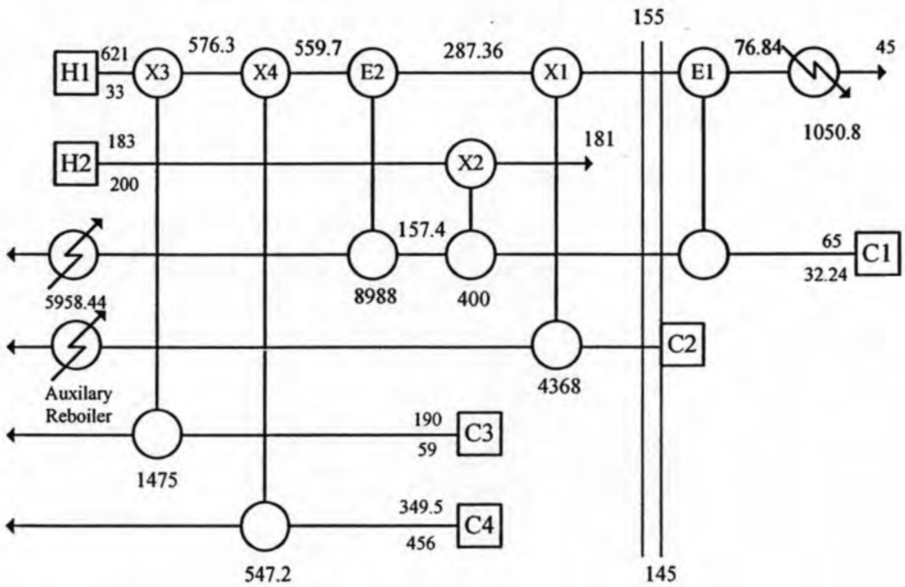


Figure 5.5 Resilient Heat Exchanger Network 1(RHEN1)

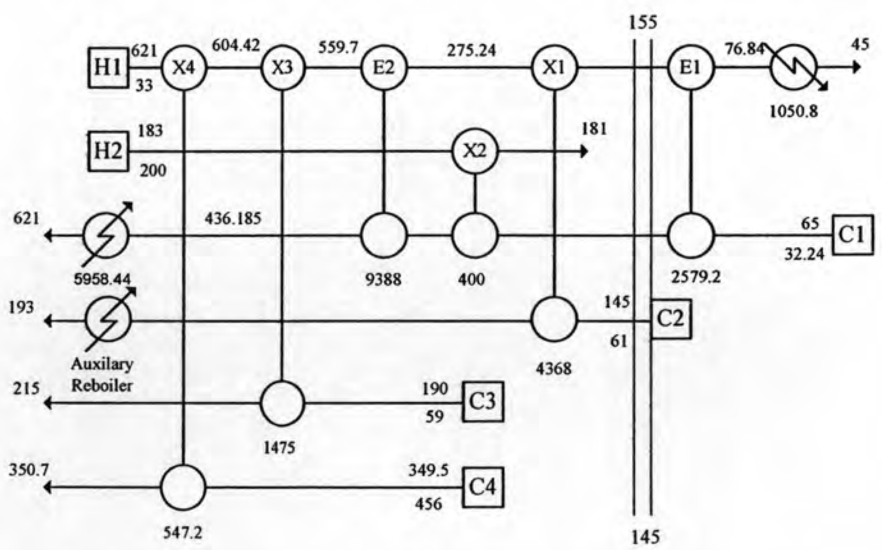


Figure 5.6 Resilient Heat Exchanger Network 2(RHEN2)

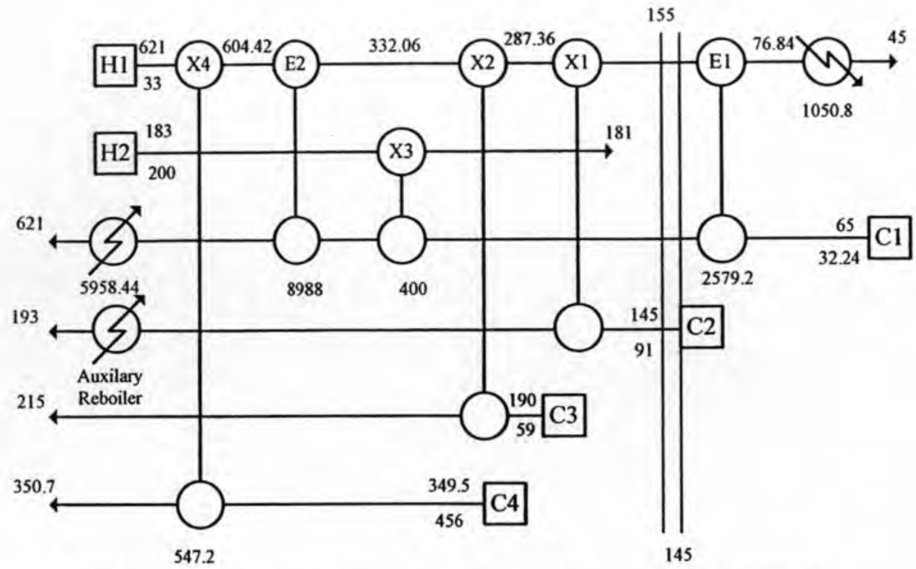


Figure 5.7 Resilient Heat Exchanger Network 3(RHEN3)

Table 5.4 Synthesis Table 1 for hot end

Synthesis Table 1 for hot end								
Stream	Load	W	T1	T2	Ds	Dw	Dt	Action
a) State1								
H1	15213	33	616	155	165	0	0	Selected C[H]
H2	410	200	183.05	181	0	0	0	
C1	15251	32.04	621	145	0	285.6	0	
C2	3969.4	91	188	144.38	0	0	910	Selected
C3	1184.7	59	210	189.92	0	0	590	
C4	620.16	456	350.7	349.34	0	0	0	
b) State2								
H1	11244	33	616	275.29	1075	0	0	
H2	410	200	183.05	181	0	0	0	Selected A[H]
C1	15251	32.04	621	145	0	285.6	0	Selected
C2						0		Matched to H1
C3	1184.7	59	210	189.92	0	0	590	
C4	620.16	456	350.7	349.34	0	0	0	
c) State3								
H1	11244	33	616	275.29	1075	0	0	Selected B[C]
H2								Matched to C1
C1	14841	32.04	621	157.8	285.6	0	0	
C3	590	59	200	210	0	0	590	Selected
C4	547.2	456	349.5	350.7	0	0	0	
d) State4								
H1	10064	33	598.12	275.29	1665	0	0	Selected B[C]

C1	14424	32.04	621	157.8	285.6	0	0	
C3								Matched to H1
C4	547.2	456	349.5	350.7	0	0	0	Selected
e) State5								
H1	9516.4	33	581.54	275.29	1665		0	Selected A[H]
C1	14841	32.04	621	157.8	285.6		0	Selected
C4								Match to H1
e) State5								
H1								Matched to C1
C1	3659.7	32.04	621	454.81	1950.6		0	To heater

Table 5.5 Synthesis Table 2 for hot end

Synthesis Table 2 for hot end								
Stream	Load	W	T1	T2	Ds	Dw	Dt	Action
a) State1								
H1	15213	33	616	155	165	0	0	Selected C[H]
H2	410	200	183.05	181	0	0	0	
C1	15251	32.04	621	145	0	285.6	0	
C2	3969.4	91	188	144.38	0	0	910	Selected
C3	1184.7	59	210	189.92	0	0	590	
C4	620.16	456	350.7	349.34	0	0	0	
b) State2								
H1	11244	33	616	275.29	1075	0	0	
H2	410	200	183.05	181	0	0	0	Selected A[H]
C1	15251	32.04	621	145	0	285.6	0	Selected
C2								Matched to C1
C3	1184.7	59	210	189.92	0	0	590	
C4	620.16	456	350.7	349.34	0	0	0	
c) State3								
H1	11244	33	616	275.29	1075	0	0	Selected B[C]
H2								Matched to C1
C1	14841	32.04	621	157.8	0	285.6	0	
C3	594.72	59	200	189.92	0	0	590	
C4	547.2	456	349.5	350.7	0	0	0	Selected
d) State4								
H1	10696	33	599.42	275.29	1075	0	0	Selected B[C]
C1	14841	32.04	621	157.8	0	285.6	0	
C3	594.72	59	200	189.92	0	0	590	Selected
C4								Matched to H1
e) State5								
H1	9511.7	33	581.4	275.29	1665		0	Selected A[H]

C1	14841	32.04	621	157.8	0	285.6	0	Selected
C3								Matched to H1
f) State6								
H1								Matched to C1
C1	3664.4	32.04	621	454.66	1950.6		0	To Heater

Table 5.6 Synthesis Table 3 for hot end

Synthesis Table 3 for hot end								
Stream	Load	W	T1	T2	Ds	Dw	Dt	Action
a) State1								
H1	15213	33	616	155	165	0	0	Selected C[H]
H2	410	200	183.05	181	0	0	0	
C1	15251	32.04	621	145	0	285.6	0	
C2	3969.4	91	188	144.38	0	0	910	Selected
C3	1184.7	59	210	189.92	0	0	590	
C4	620.16	456	350.7	349.34	0	0	0	
b) State2								
H1	11244	33	616	275.29	1075	0	0	
H2	410	200	183.05	181	0	0	0	Selected A[H]
C1	15251	32.04	621	145	0	285.6	0	Selected
C2								Match to H1
C3	1184.7	59	210	189.92	0	0	590	
C4	620.16	456	350.7	349.34	0	0	0	
c) State3								
H1	11244	33	616	275.29	1075	0	0	Selected C[H]
H2								Matched to C1
C1	14841	32.04	621	157.8	0	285.6	0	
C3	590	59	200	210	0	0	590	Selected
C4	547.2	456	349.5	350.7	0	0	0	
d) State4								
H1	10064	33	616	285.29	1665	0	0	Selected B[C]
C1	14936	32.04	621	157.72	0	285.6	0	
C3								Match to H1
C4	547.2	456	349.5	350.7	0	0	0	Selected
e) State5								
H1	9516.4	33	599.42	285.29	1665	0	0	Selected A[H]
C1	14936	32.04	621	157.72	0	285.6	0	Selected
C4								Matched to H1
f) State6								
H1								Matched to C1
C1	3754.9	32.04	621	454.73	1950.6	0	0	To Heater

5.4 Steady State Simulation in HYSYS

In order to guarantee a workable process, the worst case condition is made. We can evaluate the performance of our design of the Alternative 6 of HDA process with minimum auxiliary reboilers by using HYSYS simulator. Figure 5.8, 5.9, 5.10 and Figure 5.11 show HYSYS flowsheet of the steady state modeling of HDA process with three auxiliary reboilers scheme (introduced by Luyben, 1999) and with minimum auxiliary reboilers scheme respectively. From the simulation results at worst case condition, our design guarantee that it is workable despite only an auxiliary reboiler.

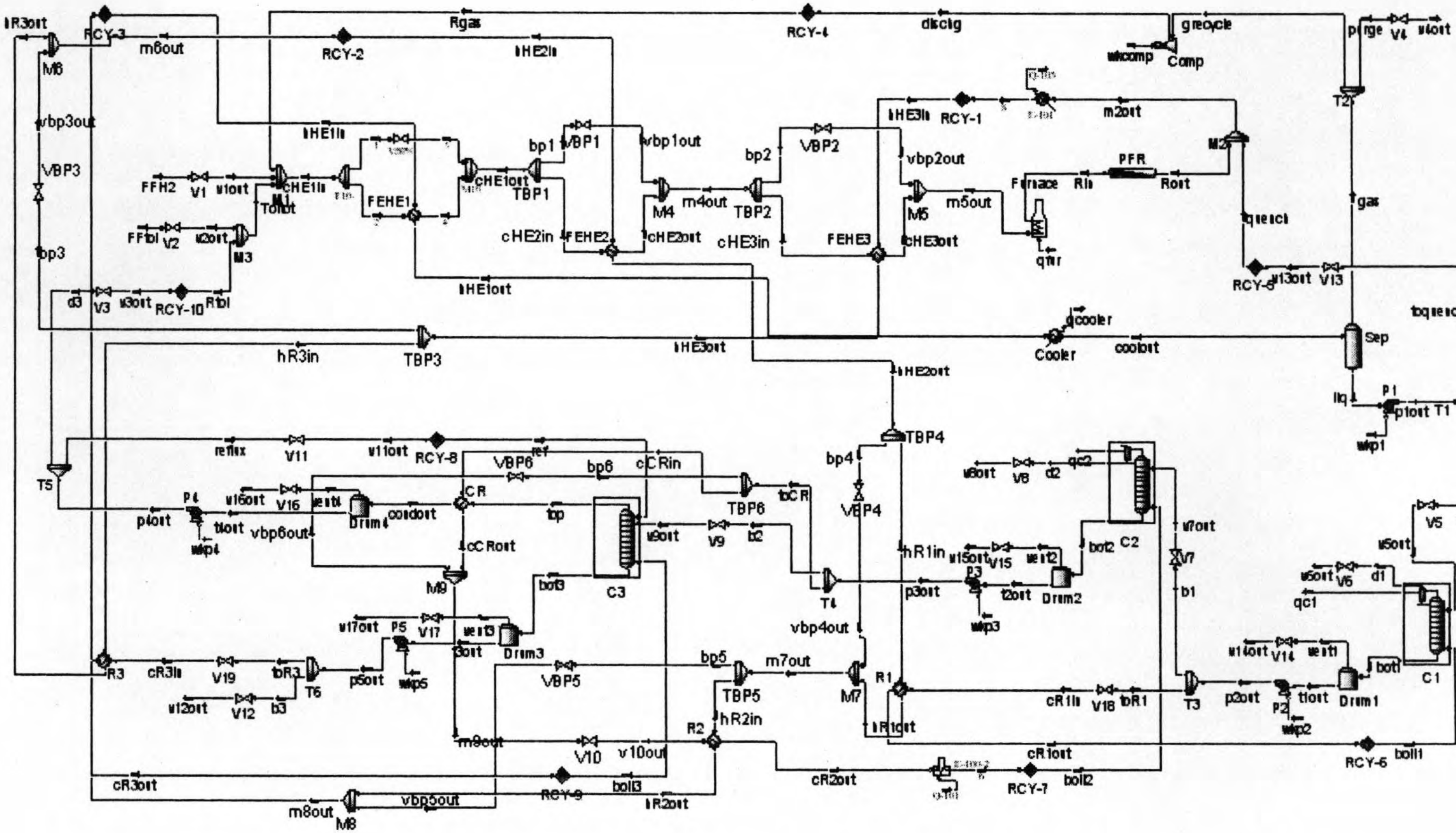


Figure 5.8 HYSYS Flowsheet of HDA Process (Alternative 6) Basecase with minimum auxiliary reboiler

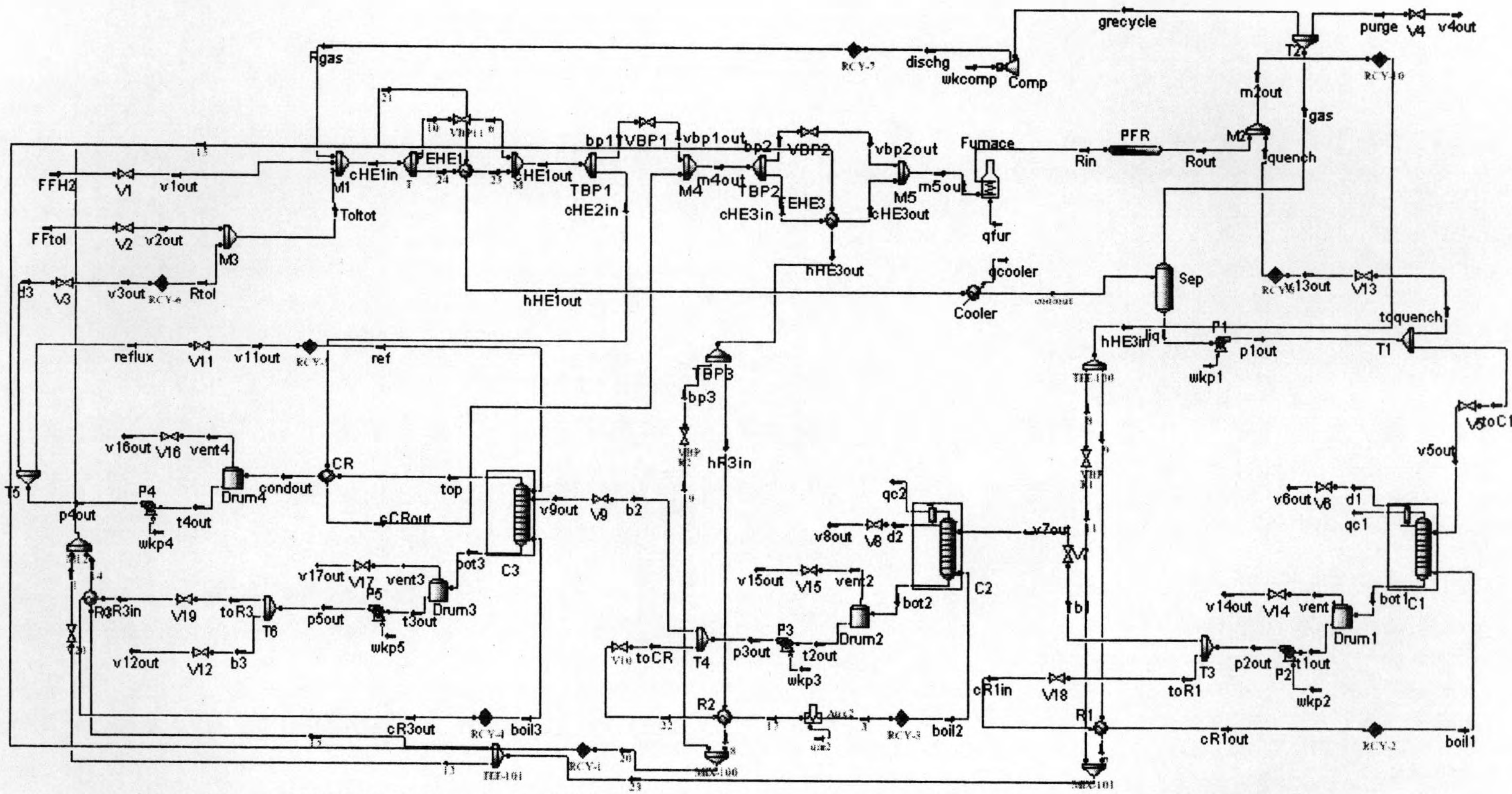


Figure 5.9 HYSYS Flowsheet of HDA Process (Alternative 6) RHEN1 with minimum auxiliary reboiler

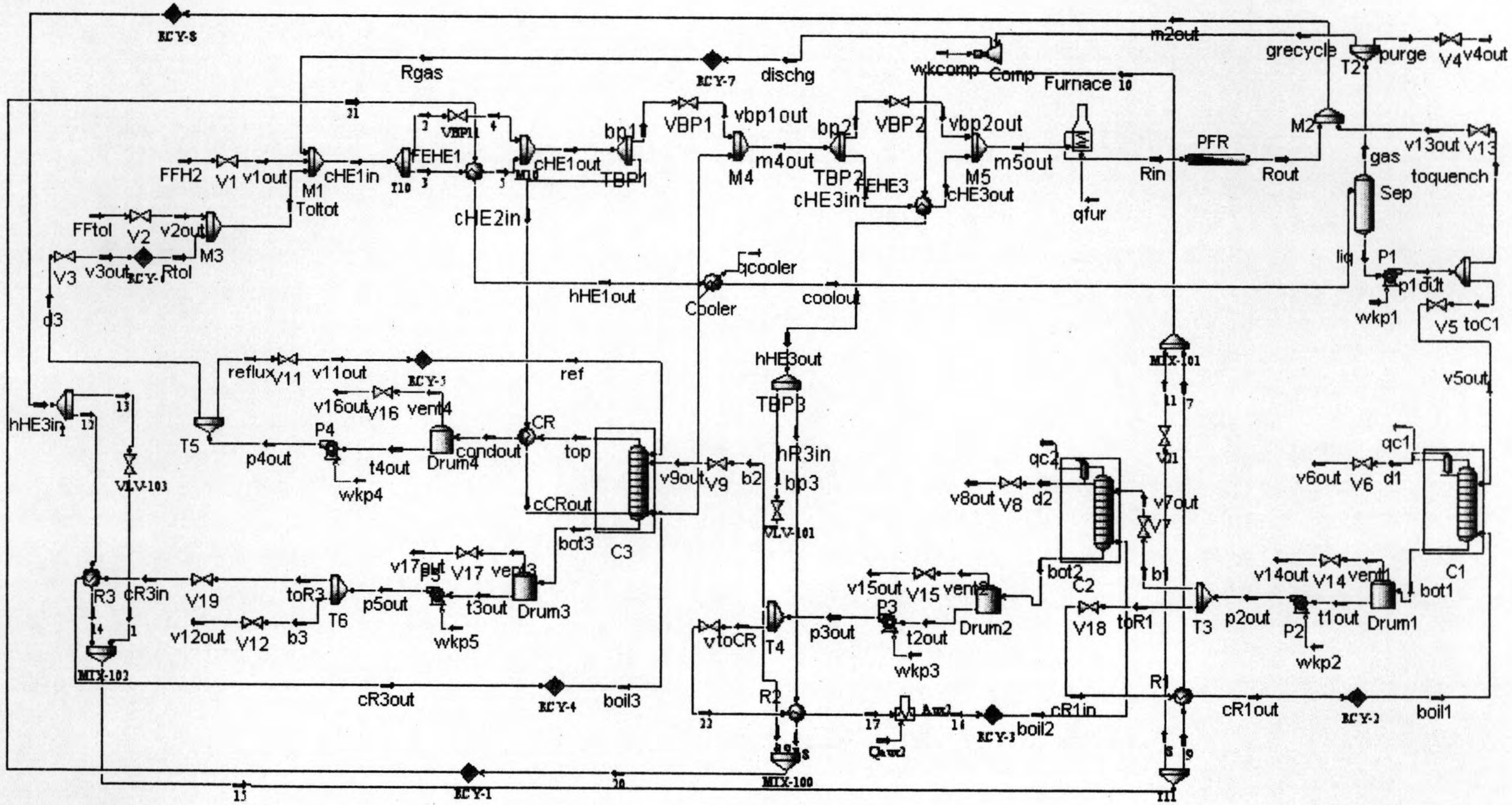


Figure 5.10 HYSYS Flowsheet of HDA Process (Alternative 6) RHEN2 with minimum auxiliary reboiler

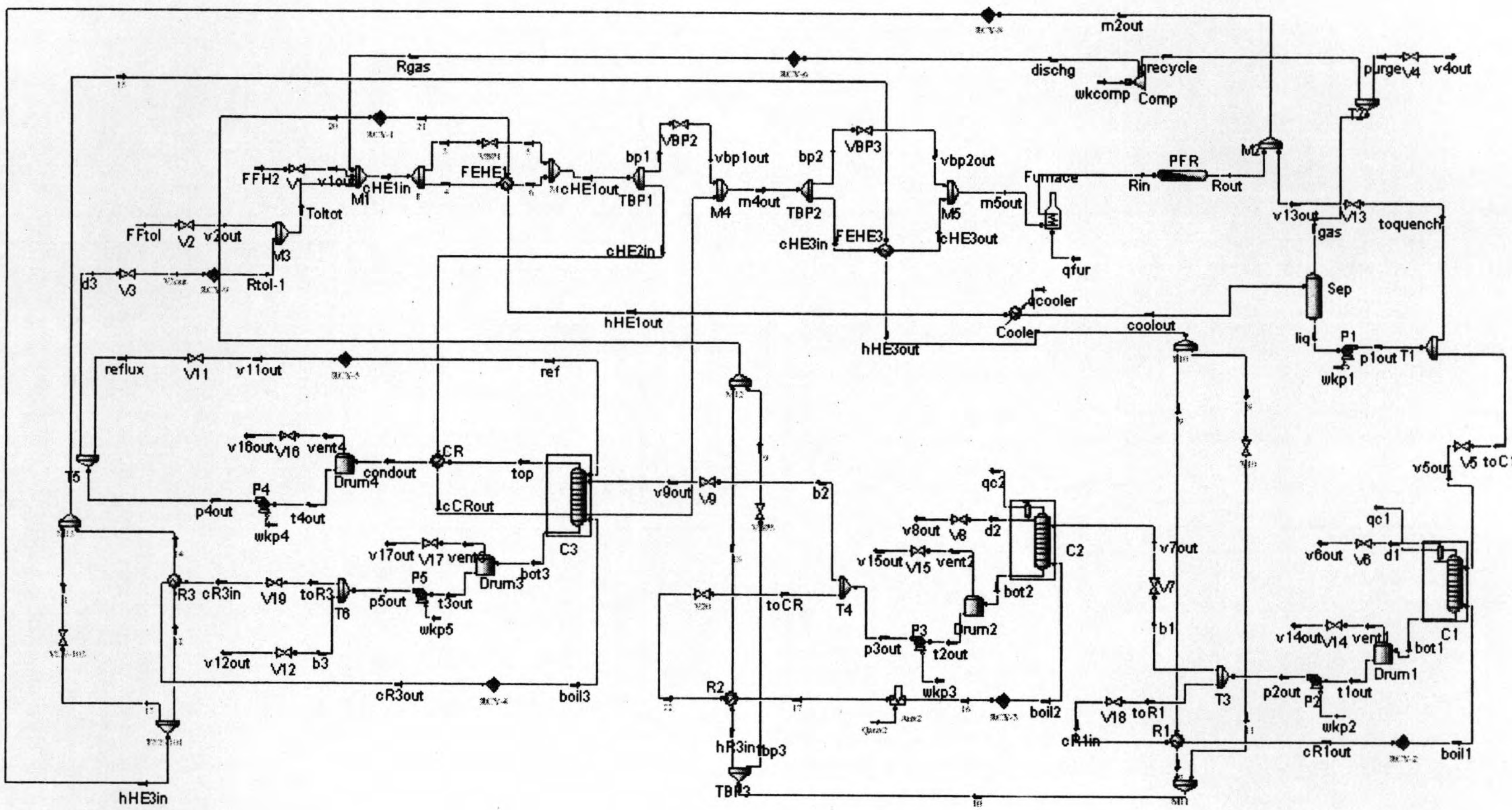


Figure 5.10 HYSYS Flowsheet of HDA Process (Alternative 6) RHEN3 with minimum auxiliary reboiler