ChemTech

International Journal of ChemTech Research
CODEN (USA): IJCRGG, ISSN: 0974-4290, ISSN(Online):2455-9555
Vol.9, No.06 pp 432-439, 2016

Pinch analysis of Acrylic Acid Process Plant

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Abstract : This study deals with design and heat integration of acrylic acid process plant. This work is divided in to two parts. In the first part acrylic acid process was designed using ASPEN PLUS V8.8. In the second part, pinch analysis was applied using ASPEN ENERGY ANALYZER and a base case HEN was developed. The base case performance was improved with Retrofit analysis. The retrofit design saves the energy of the process by minimizing the operating costs. In retrofit mode two new heat exchangers were added to the base case HEN which reduced the operating cost with the payback period of 0.3254 years.
Key words: Pinch analysis, Aspen Plus, Heat exchanger networks (HEN), Aspen energy analyzer, Retrofit analysis.

1. Introduction

Incorporating process simulators in process design is the new trend in chemical engineering. By the introduction of process simulators in process design facilitated in designing automated process plants with good control and safe to environment[1-5, 22-25]. To improve the process efficiencies process engineers and technical service engineers are continuously searching for design alternatives. Process performance can be enhanced by developing rigorous models which mimic the large-scale real plants. Introducing recycle streams, energy integration techniques and use them for evaluating plant-wide control schemes enhanced the performance of the process plants [1-5, 26-30].

The concept of pinch technology was introduced by Linnhoff et al. and Umeda based on Hohmann's work[6].Energy efficient systems can be designed by pinch technology[7].Designing HEN using pinch analysis of processes is the new trend in pinch technology[8-13]. It is proved in the case of new plant designs that industrial energy cost can be saved up to 30% in combination with capital cost and payback times in retrofit applications were reported to be less than one year[11]. Pinch analysis was derived from combined first and second law analysis, as a technique ensuring a better thermal integration, aiming the minimization of entropy production or equivalently exergy destruction by heat exchangers networks[15]. Heat integration schemes are proposed to improve companies economic performance and to reduce its environmental impacts[21]. To reduce the drawbacks in pinch analysis different techniques are proposed for example total entropy generation minimization techniquesetc[16-18]. To improve process efficiencies heat integrated distillation columns and process equipment alternatives are designed[19-21].

Pinch analysis concept can be understood in terms of composite curves, grand composite curves, grid diagram, grid diagram for retrofit analysis etc.The above all pinch principles involved in energy analysis are simplified by introducing the commercial software like Aspen energy analyzer. By using aspen energy analyser here energy analysis is performed for the acrylic acid production process.

2. Methodology

The proposed design for the production of acrylic acid consists ofone compressor, two heat exchangers, one rector and distillation columns.Process flow diagram was shown in figure 1. Pinch analysis for the entire process plant was done by using Aspen energy analyzer.

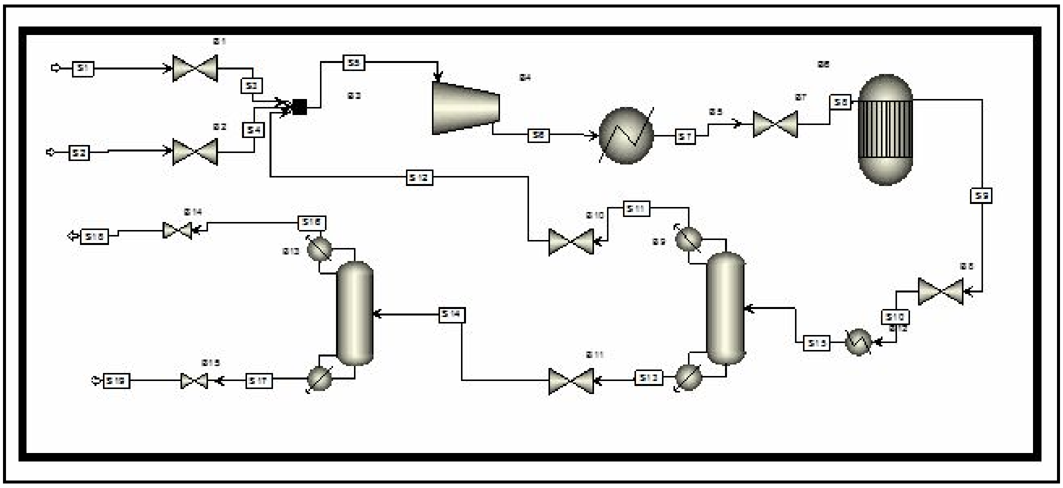

Figure 1. Process flow diagram for Acrylic acid process plant

3. Results and discussion

Steady state process conditions of acrylic acid plant are extracted for heat integration studies by using Aspen Energy Analyzer.From the extracted data HEN is designed it is named as base case design. In the next step an alternative design for the base case design is developed by applying retrofit analysis for the base case HEN.Retrofit analysis results are justified with the help of range target plot, composite curve, Grand composite curve and grid diagram of improved HEN.

3.1. Data extraction from the process

The process was designed using Aspen Plus. Process stream data is extracted from the steady state process using Aspen energy analyzer.The data extracted contains temperatures, heat duty, heat capacity of each stream, utility data and the cost data which is helpful in determining the energy cost and capital investment. Calculation of heat duty for each stream is done by Aspen Energy analyzer. The extracted data of process is shown in tables1 to 6.The process containsfivehot streams and two cold streams. Utilities present in the process are one hot utilityand four cooling utilities. Hot utility is HP (High pressure) steam. Cooling utilities are HP steam, LP (Low pressure) steam, Air and Refrigerant 1.

After process data extraction pinch analysis is applied to get HEN for the process. In the next step retrofit analysis is performed. Retrofit is a trade-off problem between energysaving and capital investment.

Table 1.Process data of Acrylic Acid process

Name	S1	S2	S3	S4	S5	S6	S7
MoleFlowkmol/hr							
PROPYLEN	100	0	100	0	111	111.11	111.1
OXYGEN	0	150	0	150	166	166.67	166.6
ACRYL-01	0	0	0	0	3.09	3.0966	3.096
WATER	0	0	0	0	59.1	59.119	59.11
Total Flow kmol/hr	100	150	100	150	339	339.99	339.9
Temperature K	298	298.15	298.15	298.15	330	622.21	573.1
Pressure atm	1	1	0.49346	0.49346	0.49	10	10
Enthalpy cal/mol	4831	-8.8E-13	4831.8	-8.8E-13	-8861	-5252	-5933
Entropy cal/mol-K	-33	0	-32.57	1.402622	-8.7	-7.004	-8.143
Density mol/cc	4.0E-05	4.08747E-05	2E-05	2E-05	1E-5	0.00019	0.0002
Average MW	42.08	31.9988	42.08064	31.9988	33.2	33.2269	33.226

From the process flow diagram as shown in figure 1, heat is exchanged in heaters and coolers respectively. All the heating and cooling requirements of the process were combined together, the result is the Grid diagram and it is shown in figure 6. Simply the Grid diagram is an overview of all the heating/cooling requirements of the process. The local heat transfer coefficient associated with the individual stream (HTC) is the default values calculated by Aspen energy analyzer. Flow rate, effective C_P and ΔT the minimum approach temperature are the parameters used in Aspen energy analyzer. Grid diagram contains process streams, utility streams, heat exchangers, and split mixers. In the grid diagram blue colour represents cooler, red represents heater, and green shows that the heat exchanger has been added or modified by a retrofit action.

Table 2.Process data

Name	S8	S9	S10	S11	S12	S13	S14	S15
Mole Flow kmol/hr								
PROPYLEN	111.1	111.1	11.1	11.1	11.11	11.11	0.00024	0.0002
OXYGEN	166.6	166.6	16.6	16.6	16.67	16.67	7E-12	7E-12
ACRYL-01	3.096	3.096	103	103.09	3.096	3.096	99.9996	99.99
WATER	59.11	59.11	159	159.11	59.11	59.11	99.9994	99.99
Total Flow kmol/hr	339.9	339.9	289	289.99	90	89.99	199.999	199.9
Temperature, K	573.1	573.1	573	573.15	430.1	430.1	462.572	462.5
Pressure, atm	10	9.506	9.506	9.013	8	7.506	10	9.506
Enthalpy cal/mol	-5933.2	-56193	-56193	-38846	-38845	-74240	-74240	-60125
Entropy cal/mol-K	-8.04	-14.72	-14.61	-11.247	-11.12	-38.00	-38.00	-23
Density mol/cc	0.0002	0.0002	0.0001	0.00022	0.0002	0.0182	0.0182	0.0003
Average MW	33.2	38.955	38.95	25.4364	25.436	45.039	45.039	38.955

Table 3. Process data

Name	S16	S17	S18	S19
Mole Flow kmol/hr				
PROPYLEN	111.1	111.1108	11.11108	11.11108
OXYGEN	166.6	166.6721	16.67243	16.67243
ACRYL-01	3.096	3.096641	103.0964	103.0964
WATER	59.11	59.11968	159.1194	159.1194
Total Flow kmol/hr	339.9	339.9992	289.9993	289.9993
Temperature K	394.0	520.7844	394.0568	520.7844
Pressure atm	2	15	1.5	14.5
Enthalpy cal/mol	-57909.13	-80726.15	-57909.13	-80726.15
Entropy cal/mol-K	-10.4885	-43.37114	-9.917213	-43.37114
Density mol/cc	6.1853E-05	0.0106407	4.63897E-05	0.0106407
Average MW	20.34458	69.73446	20.34458	69.73446

Table 4. Process Hot stream data

Hot stream Name	Hot T_{in} ^{0}C	Hot T_{out} ^{0}C
HP Steam	250.00	249.05
S9_To_S15	187.22	25.000
S6_To_S8	349.03	348.12
To Condenser@B13_TO_S16	134.48	120.93
HP Steam	249.05	249.00
To Condenser@B9_TO_S11	168.96	156.96
B6_heat	300.00	299.50
S6_To_S8	348.12	299.99
S9_To_S15	300.00	187.22

Table 5. Process Cold stream data

Cold stream Name	Cold T_{in} ^{0}C	Cold T_{out} ^{0}C
To Reboiler@B13_TO_S17	203.43	212.05
Refrigerant 1	-25.00	-24.0
To Reboiler@B9_TO_S13	186.16	186.1
Air	30.00	35.00
To Reboiler@B9_TO_S13	189.14	189.42
LP Steam Generation	124.00	125.00
HP Steam Generation	249.00	249.98
HP Steam Generation	249.98	250.00
To Reboiler@B9_TO_S13	186.18	189.14

Table 6. Process Heat exchanger load and area data

Heat exchanger Name	Load (MW)	Area(m^2)	ΔT_{min} Hot	ΔT_{min} Cold	Overall heat transfer coefficient (kJ/hr-m^2-C)
Reboiler@B13	3827928.02	10.39	37.94	45.61	8793.78
B12	2085336.9	8.28	211.2	50.00	2032.49
E-100	18000.00	0.35	162.8	161.9	314.410
Condenser@B13	2378480.0	65.0	99.48	90.93	384.215
Reboiler@B9	205779.38	0.35	59.62	59.85	9784.23
Condenser@B9	6713198.6	111.71	43.96	32.96	1504.22
B6_heat_Exchanger	59782348.96	1707.24	50.0156	50.50	696.774
B5	950115.01	42.38	98.122	50.01	314.011
E-101	2688451.3	41.90	110.85	1.036	2776.03

Table 7. Process Utility stream data

Utility Name	Load (MW)
Refrigerant 1	5.531
Air	6.765
LP steam	9.238
HP Steam	4.69e-3

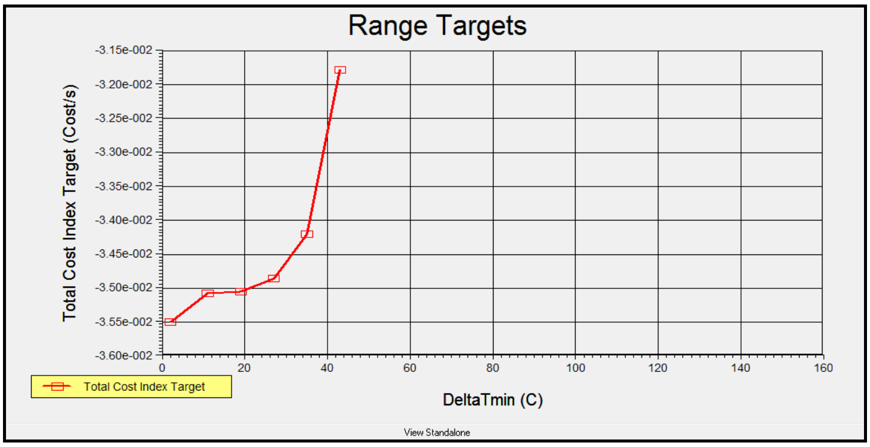

Figure 2. Range targets plot

Figure 2 shows the range targets plot. Range target gives the information corresponding to the optimization of the minimum approach temperature. It is calculated by minimizing the total annual cost. It means finding the best compromise between utility requirements, heat exchange area and unit shell number. As the minimum approach temperature is varied the total annual cost of the network is calculated. There will be a ΔT_{min} which will yield a minimum total cost. Here the ΔTmin calculated is 2^0C.

Figure 3 shows the temperature versus enthalpy plot or composite curve. Composite curves set the energy targets prior to design. Figure 4 shows the Grand composite curve (GCC). GCC is a plot of shifted temperatures versus the cascaded heat between each temperature interval.

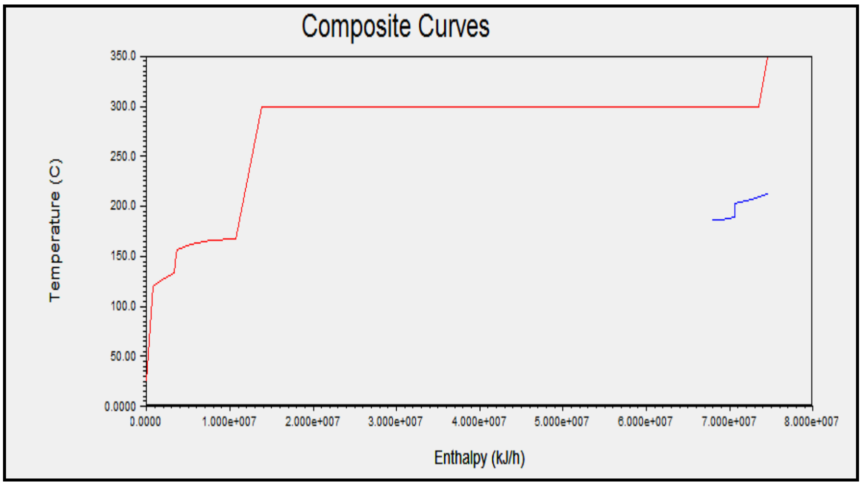

Figure 3. Composite curve

GCC shows the heat available in various temperature intervals and the net heatflow in the process (which is zero at the pinch).ΔT_{min} is noted as 2^0C. It explains the minimum number of heat exchangers required, minimum number of exchangers required (MER) to achieve maximum energy recovery, and the sum of the minimum number of shells from all the exchangers.

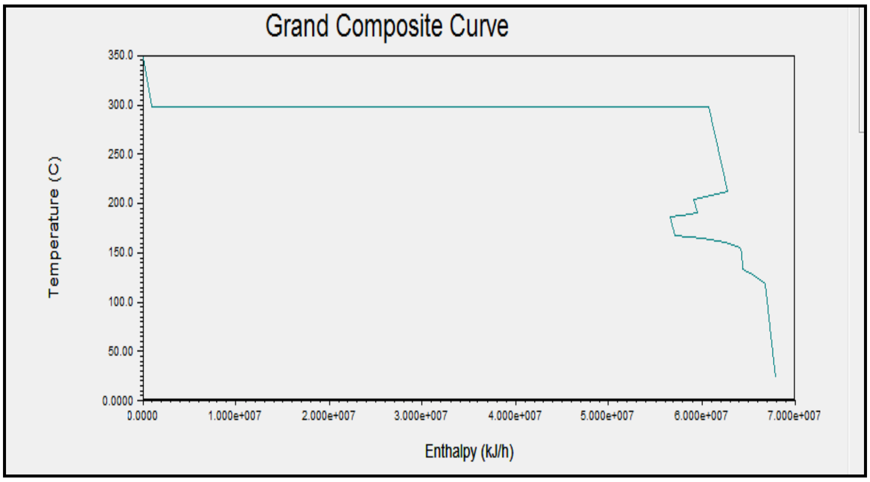

Figure 4. Grand Composite curve

3.2 Performance Evaluation

Retrofitted HEN is compared with the base case HEN to know the improvement in energy savings and capital cost investment. The parameters include the heating, cooling, operating, capital, and total cost values relative to the target values, amountof energy being transferred for heating and cooling purpose inthe design, number of exchangers, number of shells, and the total heat transferarea values relative to the target values, the individual utility cost and load for all the utilities in the design, the percentage values of the utility load relative to the target values.

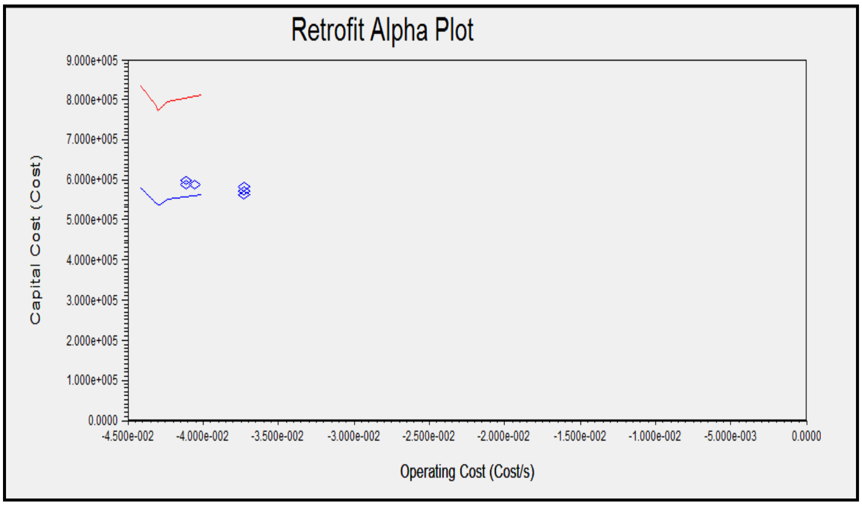

Figure5.Retrofit alpha plot

Figure 5 explains the variation of capital cost index with operating cost index for possible retrofitsfor the base case. The best retrofit is the design which reduces the operating cost. From the plot best retrofit can be selected. The best retrofit noted is the case for which the payback period is 0.3254 years.

3.3Process heat exchanger network analysis for retrofit

Acrylic acid process plant HEN obtained is shown by a grid diagram and is shown in figure 6. The process has five hot streams and two cold streams. The current HEN has seven heat exchangers between processstreamsfourheat exchangers for heating by LP steam and HP steam. Utility use is represented by thin lines and Air, Refrigerant 1are cooling utilities and LP steam, HP steam are the heating utilities. The present grid diagram efficiency can be improved by adding two new heat exchangers to recover much heat energy from hotstreams.

By using Aspen energy analyzer retrofit analysis is performed for the base case design. Capital and payback period data are recorded. In retrofit analysis two new heat exchangers are added. For each addition of the exchanger payback period and capital cost were noted. Figure 7shows the alternative design obtained from retrofit analysis with payback period0.3254years.

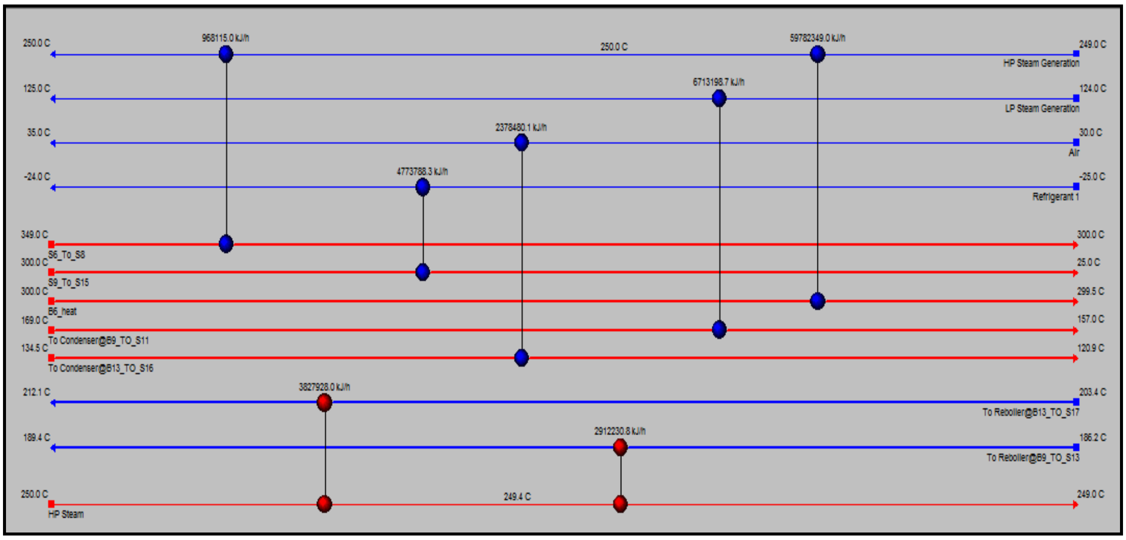

Figure 6.Base case HEN design of the Acrylic acid process plant

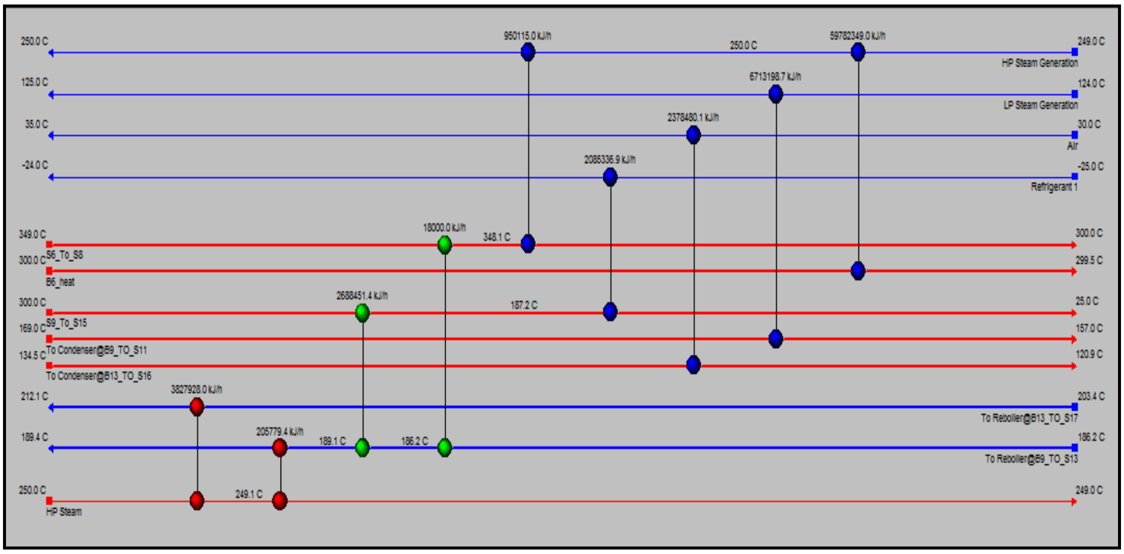

Figure 7. Retrofitted HEN for the base case design

4. Conclusion

Process for production of Acrylic acid is designed and the product purity obtained is 99.9%. The plant designed is safe to operate and environmentally friendly with less emissions. By using Aspen Energy Analyzer the entire plant energy data is extracted. From the extracted data HEN is designed for the base case. Retrofit analysis was done for the base case using Aspen Energy Analyzer. Payback period of 0.3254 years was obtained, which is a favourable retrofit design for the process.

5. Acknowledgement

The author is grateful to VIT University for creating research facilities.

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