RESEARCH ARTICLE OPEN ACCESS

Design of Heat Exchanger Network for VCM Distillation Unit Using Pinch Technology

VISHAL G. BOKAN [1], M.U.POPLE[2]

[1] Student of M.E. chemical, Department of Chemical Engineering, MGM'S jawaharlal Nehru College of Engineering, Aurangabad, India.

[2] Associate Professor, Department of Chemical Engineering, MGM'S Jawaharlal Nehru College of Engineering, Aurangabad, India.

Abstract

In process industries, heat exchanger networks represent an important part of the plant structure. The purpose of the networks is to maximize heat recovery, thereby lowering the overall plant costs. In process industries, during operation of any heat exchanger network (HEN), the major aim is to focus on the best performance of the network As in present condition of fuel crises is one of the major problem faced by many country & industrial utility is majorly depend on this. There is technique called process integration which is used for integrate heat within loop so optimize the given process and minimize the heating load and cooling load .In the present study of heat integration on VCM (vinyl chloride monomer) distillation unit, Heat exchanger network (HEN) is designed by using Aspen energy analyzer V8.0 software. This software implements a methodology for HEN synthesis with the use of pinch technology. Several heat integration networks are designed with different ΔT min and total annualized cost compared to obtain the optimal design. The network with a ΔT min of 9^0C is the most optimal where the largest energy savings are obtained with the appropriate use of utilities (Save 15.3764% for hot utilities and 47.52% for cold utilities compared with the current plant configuration). Percentage reduction in total operating cost is 18.333%. From calculation Payback Period for new design is 3.15 year. This save could be done through a plant revamp, with the addition of two heat exchangers. This improvement are done in the process associated with this technique are not due to the use of advance unit operation, but to the generation of heat integration scheme. The Pinch Design Method can be employed to give good designs in rapid time and with minimum data.

Key Words: VCM Process, Process Integration, Synthesis of HEN, Aspen Energy Analyzer V 8.0

I. INTRODUCTION OF INTEGRATION

Today in the industry, the design and optimization procedures have the trend to identify the configurations where, less energy consumption can be achieved. The possibilities for energy savings resulting in environmental and economic saving for various industrial applications can be diverse and very useful nowadays, when the search of new energy resources because the scarcity of traditional fuels and instability in the global markets, demands to maximize their efforts in energy consumption optimization. The use of Pinch Technology allows to finding balance between energy and costs as well as correct location of utilities and heat exchangers. The procedure first predicts the minimum requirements of external energy network area and number of units for given process at the pinch point. Next heat exchanger network design that satisfies these targets synthesized. Finally the network is optimized by comparing energy cost and the capital cost of the network, so that the total cost is minimized. Thus the prime objective of pinch analysis is to achieve financial savings by better process heat integration. [3, 4].

II. MATERIALS AND METHODS

2.1 Concept of Pinch Analysis

Pinch Analysis is also known as process integration, heat integration, energy integration, or pinch technology. This method for minimizing the energy costs of a chemical process by reusing the heat energy in the process streams rather than outside utilities. The process requires three pieces of data from each process stream: the heat load (enthalpy) in kW or Btu, the source temperature in °C or °F, and the target temperature in °C or °F. The data from all streams are combined in order to create plots of enthalpy against temperature, called composite curves. Composite curves are needed for the hot and cold process streams, a combined plot of both the hot and cold composite curves, and the grand composite curve. From the combined curve plot we can see the region where the distance between the hot and cold curves is minimum this region is called the pinch point. Pinch point provides an important constraint for the design of our heat exchanger network, it is only after the constraint is determined that we can design a heat exchanger network that can meet our ideal minimum energy requirements. [5, 8, 11]

By adjusting the minimum approach distance, known as ΔTmin, then find a balance between ideal minimum utility requirements and total surface area of our heat exchanger network. As the value of ΔTmin is made smaller our utility needs go down, but at the same time the required total surface area of our heat exchanger network is increased in order to achieve the necessary amount of heat transfer between our process streams. Therefore, ΔTmin indicates a bottleneck in the heat integration system. From the combined composite curve and grand composite curve plots we can easily see the temperature that the pinch point falls on, as well as the ideal minimum heating and cooling utility requirements. It is very important to know the pinch temperature in order to maximize the process-to process heat recovery and minimize the utility requirements, as process-to-process heat exchange should not be occurring across the pinch. This constraint is applied automatically in this program, allowing the user to only place heat exchangers between process streams on only one side of the pinch or the other, but not on both sides at the same time. The important questions is, are these targets achievable in real industrial practice, or are they confined to paper theoretical studies?

Within a short time, the team had calculated targets showing that the process could use much less energy even with expansion; Targets were lower than the current energy use moreover, they quickly produced practical designs for a heat exchanger network, which would achieve this. As a result, saving of over a million pounds per year was achieved on energy, and the capital cost of the new furnace with its associated problems was avoided. Although new heat exchangers were required, the capital expenditure was actually lower than for the original design, so that both capital and operating costs had been slashed. [6]

III. PROCEDURE

In this work data required for the design of heat exchanger network was taken from "Cosmo films limited,waluj,Aurangabad" in VCM Plant datasheet. The specific heat capacity for the stream component is known to be significantly dependent on temperature. The components that are present in comparatively large amount haves the significant effect on specific heat capacity of mixture. Hence components like hydrogen chloride (HCl), low boils, high boils and other non condensable are neglected in the specific heat capacity calculations.

3.1 Process description

The product from the cracking unit consists of VCM, HCl, unconverted ethylene dichloride (EDC) and By-products of various chemical structures. Hydrogen chloride is recovered in the HCl column and fed to the oxychlorination unit. Vinyl chloride is obtained at the top of the VCM column. Any traces of HCl are removed from the VCM in the HCl column. The bottom product of the VCM column, i.e. unconverted EDC, was returned to the EDC distillation process after the low-boiling compounds have been converted by chlorination to high-boiling compounds. Thus the difficult and energy-consuming separation of recycle EDC from other low-boiling components is avoided.

3.2 Data Extracted from VCM Process Unit:

With consistent heat and mass balance available, stream data are extracted. Here only those flows, which require heating or cooling, are extracted from given process. This leaves four actual streams whose characteristics are listed in table 1.From below table it has been found that total heat load for the cold streams is 2173152.186 KJ/hr. and for the hot streams is 1881156.938 KJ/hr. This implies that current hot utility and cold utility demands, reducing the hot utility and cold utility targeting procedure is applied. There are two targeting procedure applied for utility reduction. One is to draw "composite curve" and other is to form "problem table algorithm". For drawing the composite curve, understanding of pinch concept is very essential and here we are targeting on composite curve. [10]

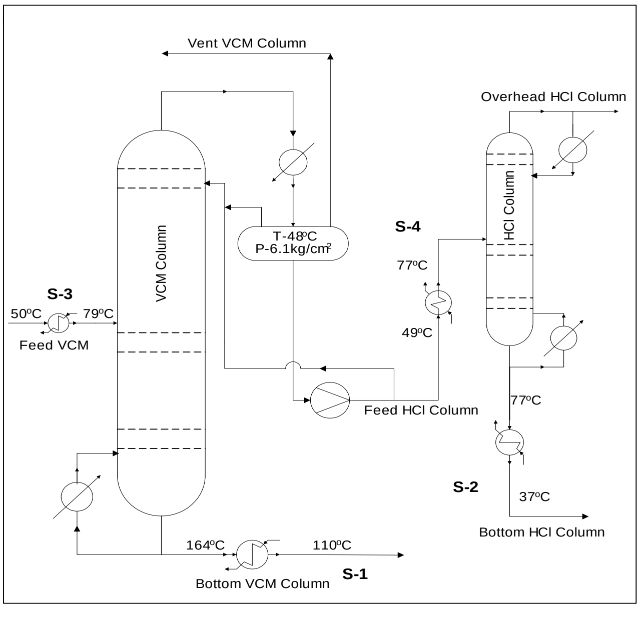


Fig. 1. Data extraction from VCM Process Flow diagram

Stream no.	**Name**	**Type**	**T_{in}(^{0}C)**	**T_{out}(^{0}C)**	**MCp (KJ/hr)**	**C_p KJ/(Kg. K)**
1	Bottom of column 1	HOT	164	110	17734.457	0.9427
2	Bottom of column 2	HOT	77	37	23087.4065	1.5393
3	Feed of column 1	Cold	50	79	43286.3278	1.2004
4	Feed of column 2	Cold	49	77	32780.31	1.2009

Table no.1 Extracted data from VCM PFD for Pinch analysis

IV. PINCH ANALYSIS USING ASPEN ENERGY ANALYZER V8.0

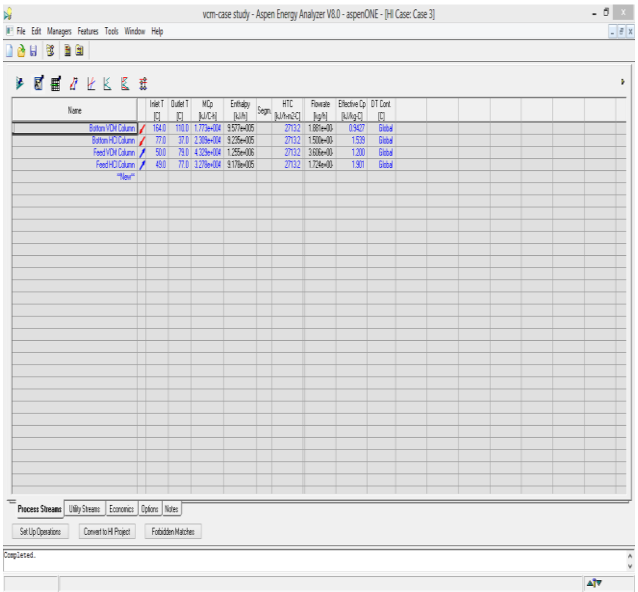
Heat integration in Aspen Energy Analyzer (formerly called HX-Net) is designed for analyzing and improving the performance of HEN. Aspen Energy Analyzer focuses on analyzing the networks from operations' as well as design's point of view. HEN operations features are designed to provide you with an understanding of current plant operation and related issues such as fouling. Furthermore fouling mitigation strategies can be studied and simulated in Aspen Energy Analyzer. HEN design features assist the designer in understanding the gap between current operation and the thermodynamic optimum operation. Furthermore, the designer can use Aspen Energy Analyzer to identify and compare options to improve the performance and reduce the gap between current and thermodynamic optimum operations. To perform any heat integration study from a design or operations perspective, Aspen Energy Analyzer needs the process requirements and the HEN that achieves the process requirements. The terminology that is used in Aspen Energy Analyzer is "scenario" for process requirements and "design" for the HEN.

4.1 Data Entry to Aspen Energy Analyzer

The Process Streams tab allows us to specify information about the process streams in the HEN. Here we were provided stream data extracted from above flow diagram. Considering ethylene dichloride and vinyl chloride as Low Molecular Weight Hydrocarbon we were selected heat transfer coefficient from aspen energy analyzer database as 2713.2 kJ/(h.m^2.^{0}C). [2] The Utility Streams tab allows us to specify the utilities used in the HEN to cool or heat the process streams. Here we were provided cooling utility as cooling water available at 20^{0}C and hot utility as a low-pressure (LP) steam available at 125^{0}C. The cost index of LP steam and cooling water are and respectively[2] The Economics tab allows us to modify the cost calculations. We were considered heat exchanger capital cost index parameters for calculation of heat exchanger capital cost index values were as follows: a=100000, b=800, c=0.8. Here we were assumed rate of return was 10%, plant life was 5 years, and hours of operation were 8765.76 hours/years. [2]

4.2 Process streams tab

The Process Streams tab allows us to specify information about the process streams in the HEN. Here we are providing stream data extracted from above flow diagram. Considering ethylene dichloride and vinyl chloride as Low Molecular Weight Hydrocarbon we are selecting heat transfer coefficient from aspen energy analyzer database as 2713.2 kJ/(h.m^2.^{0}C).

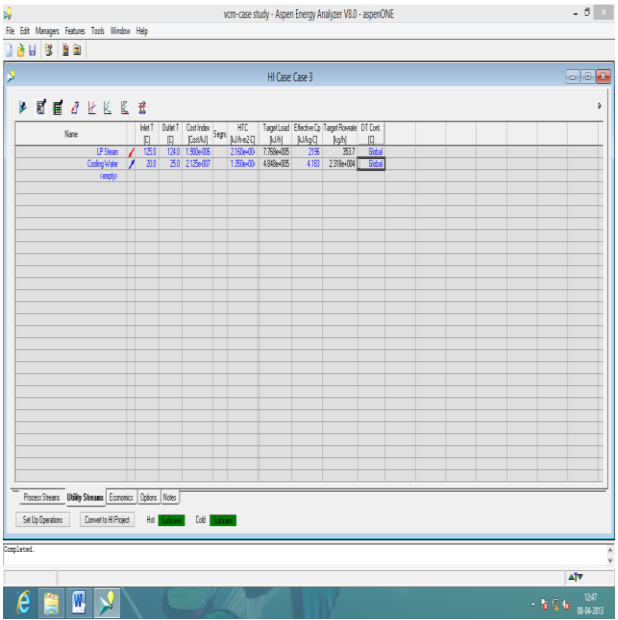


Name	Inlet T [C]	Outlet T [C]	MCp [kJ/C-h]	Enthalpy [kJ/h]	Segm.	HTC [kJ/h-m2-C]	Flowrate [kg/h]	Effective Cp [kJ/kg-C]	DT Cont. [C]
Bottom VCM Column	164.0	110.0	1.773e+004	9.577e+005		2713.2	1.881e+00	0.9427	Global
Bottom HCl Column	77.0	37.0	2.309e+004	9.235e+005		2713.2	1.500e+00	1.539	Global
Feed VCM Column	50.0	79.0	4.329e+004	1.255e+006		2713.2	3.606e+00	1.200	Global
Feed HCl Column	49.0	77.0	3.278e+004	9.178e+005		2713.2	1.724e+00	1.901	Global
New									

Figure 2 Process streams tab [2]

4.3 UTILITY STREAMS TAB

The Utility Streams tab allows us to specify the utilities used in the HEN to cool or heat the process streams. Here we are providing cooling utility as cooling water available at 20^{0}C and hot utility as a low-pressure steam available at 125^{0}C. The cost index of LP steam and cooling water are 1.9×10^{-6} and 2.125×10^{-7} respectively.


vcm-case study - Aspen Energy Analyzer V8.0 - aspenONE

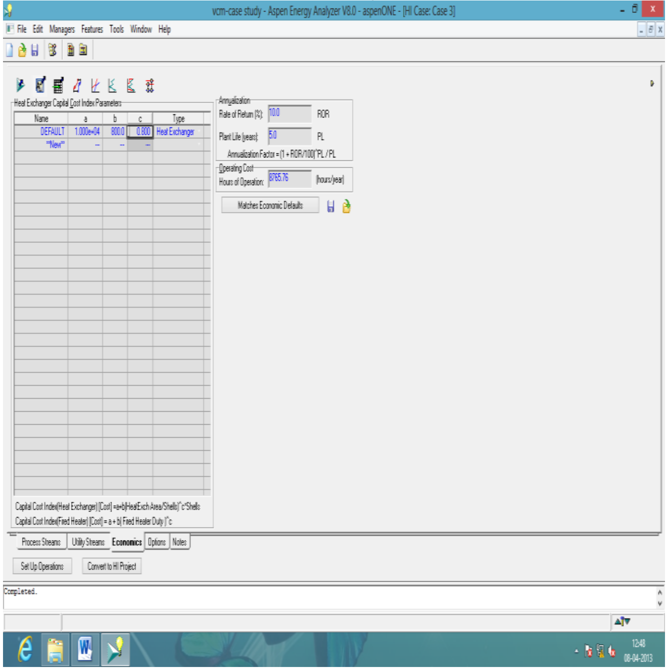
HI Case: Case 3

Name		Inlet T [C]	Outlet T [C]	Cost Index [Cost/kJ]	Segm.	HTC [kJ/h-m2-C]	Target Load [kJ/h]	Effective Cp [kJ/kg-C]	Target Flowrate [kg/h]	DT Cont. [C]
LP Steam		125.0	124.0	1.900e-006		2.160e+00	7.768e+005	2196	353.7	Global
Cooling Water		20.0	25.0	2.125e-007		1.350e+00	4.848e+005	4.183	2.318e+004	Global
<empty>										

Figure 3 Utility stream tab[2]

4.4 ECONOMICS TAB

The Economics tab allows us to modify the cost calculations. We are considering heat exchanger capital cost index parameters for calculation of heat exchanger capital cost index value are as follows a=100000, b=800, c=0.8. Here we are assuming rate of return is 10%, plant life is 5 years, hours of operation are 8765.76 hours/years.


vcm-case study - Aspen Energy Analyzer V8.0 - aspenONE - [HI Case: Case 3]

Heat Exchanger Capital Cost Index Parameters

Name	a	b	c	Type
DEFAULT	1.000e+04	800.0	0.800	Heat Exchanger
New	---	---	---	

Annualization
Rate of Return (%): 10.0 ROR
Plant Life (years): 5.0 PL
Annualization Factor = (1 + ROR/100)^PL / PL

Operating Cost
Hours of Operation: 8765.76 (hours/year)

Capital Cost Index(Heat Exchanger) [Cost] = a+b(HeatExch Area/Shells)^c*Shells
Capital Cost Index(Fired Heater) [Cost] = a + b Fired Heater Duty ^c

Figure 4 Economics tab[2]

4.5 TARGETS VIEW

The Targets view allows us to observe all the target values for the values specified on the HI Case view. From the targets view tab we get following information,

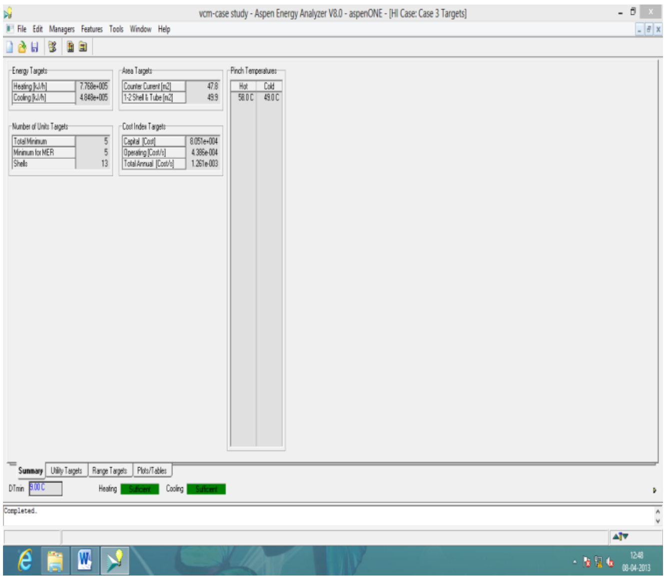
Minimum heating load = 7.768×10^5(kJ/hr)

Minimum cooling load = 4.848×10^5(kJ/hr)

Pinch temperature = (58-49) ^{0}C

Total minimum no of units = 5

Total annual cost = 1.261×10^{-3}(cost/sec)


vcm-case study - Aspen Energy Analyzer V8.0 - aspenONE - [HI Case: Case 3 Targets]

Energy Targets

Heating [kJ/h]	7.768e+005
Cooling [kJ/h]	4.848e+005

Area Targets

Counter Current [m2]	47.8
1-2 Shell & Tube [m2]	49.9

Pinch Temperatures

Hot	Cold
58.0 C	49.0 C

Number of Units Targets

Total Minimum	5
Minimum for MER	5
Shells	13

Cost Index Targets

Capital [Cost]	8.051e+004
Operating [Cost/s]	4.386e-004
Total Annual [Cost/s]	1.261e-003

DTmin: 10.00 C

Figure 5 Targets view tab[2]

4.6 HEAT EXCHANGER NETWORK VIEW

The HEN view allows us to build the network based on all of the parameters entered in the main view. The network can be manipulated through the Grid Diagram or the Worksheet.

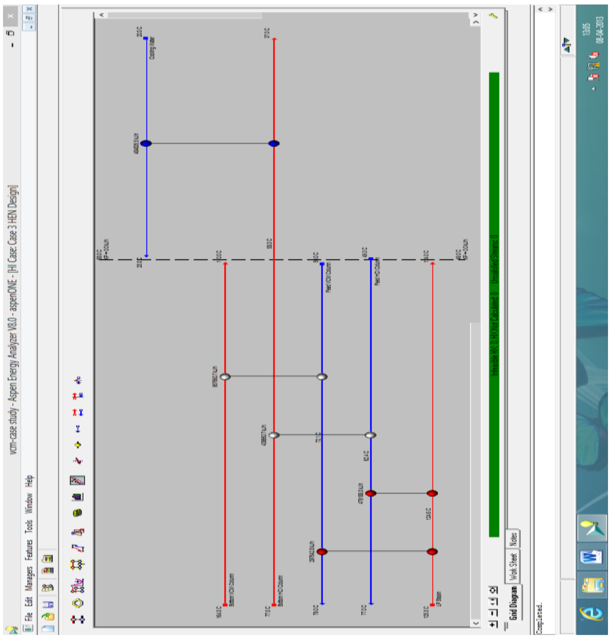


Figure 6 Heat Exchanger Network View[2]

4.7 Optimum ΔTmin in comparison with operating cost index and capital cost index

Based on the capital cost index and operating cost index with respect ΔTmin value we got optimum value equals to 9^0C.[2]

4.8 Composite curve

Following composite curve, displays both the hot composite curve and cold composite curve on the same plot. The closest temperature difference between the hot and cold composite curves is known as the minimum approach temperature, i.e. ΔTmin. The composite curves was moved horizontally such way that minimum approach temperature on the plot equals to minimum approach temperature we specified.

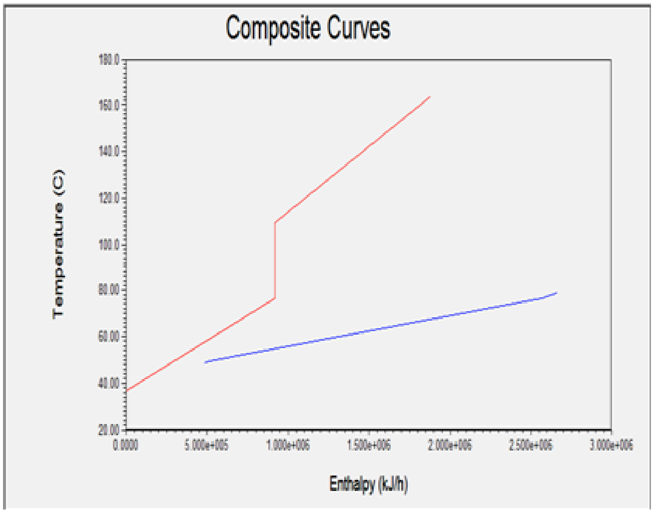


Fig. 7 Composite Curve at OPTIMUM Tmin [2]

4.9 COSTING OF HEAT EXCHANGERS AFTER NETWORK DESIGN

Heat Exchanger Capital Cost Index Parameters are as follows,

$$a = 10000$$
$$b = 800$$
$$c = 0.8$$
$$CC = a + b \times \left(\frac{Area}{N_{Shell}}\right)^c \times N_{Shell}$$

$$\text{Annualization Factor (A)} = \frac{\left(1+\frac{ROR}{100}\right)^{PL}}{PL}$$

$$\text{Total annualized cost (TAC)} = (A \times \sum \text{installed capital cost}) + \text{operating cost}$$

Where; CC = Installed capital cost of a heat exchanger ($)
a = installation cost of heat exchanger ($)
b,c = duty/area –related cost set coefficient of the heat exchanger
Area = heat transfer area of heat exchanger
N_{Shell} = number of heat exchanger shells in the heat exchanger
ROR = rate of return (percent of capital)
PL = plant life (yr)

Using above equation, capital cost of each heat exchanger is as follows,

Sr No.	Heat exchanger	Capital cost ($\times 10^4$) ,$
1	E-102	1.4820
2	E-103	1.1670
3	E-104	1.4598
4	E-105	2.5740
5	E-106	1.2260
	Total capital cost	8.0510

Table 2 Capital cost of each heat exchanger

Assuming, 1$ = 54 Rs.

Operating cost of minimum heating & cooling utilities are as follows;

For heating utility,

Cost = $Q_{Hmin} \times$ cost index
=776800 $\times 1.9 \times 10^{-6}$
=1.47592 $/hr
= 80 Rs/hr

Cost for 1 year considering hours of operations = 8765.76 (hrs/year)

Cost = 80$\times$ 8765.76
= 7,01,260.8 Rs/year

- For cooling utility,

Cost = 484800$\times 2.125 \times 10^{-7}$
= 0.10302 $/hr
= 5.563 Rs/hr

cost for 1 year considering hours of operations = 8765.76 (hrs/year)

cost = 5.563$\times$8765.76
= 48763.923 Rs/year

- Total operating cost = operating cost of heating + cooling utilities
=7,01,260.8 + 48,763.923
= 7,50,024.723 Rs/year

Now we calculate Annualization Factor as follows,

$$\text{Annulization Factor} = \frac{\left(1+\frac{10}{100}\right)^5}{5}$$
$$= 0.3221$$

- Capital cost per year = total capital cost of all HE × annualization factor

$= 8.0510 \times 10^4 \times 0.3221$

= 25932.271 \$/year

= 14,00,342.634 Rs/year

- Total annualized cost = total capital cost + total operating cost

= 14,00,342.634 + 7,50,024.723

= 21,50,367.337 Rs/year

- Calculation of Payback Period,

$$\text{PBP} = \frac{0.85}{m_{ar} + {}^{0.85}/_{PL}}$$

The 0.85 value it obtained by assuming that the working capital is 15% of Total capital investment.[15]

$$= \frac{0.85}{0.1 + {}^{0.85}/_{5}}$$

= 3.15 yr.

4.10 COSTING OF EXISTING HEAT EXCHANGERS

Table 3 Capital Cost Index of Existing Heat Exchanger

Total Capital Cost $= 6.8611 \times 10^4$ (cost)

Operating cost for existing heating & cooling load are as follows,

- For heating utility,

Cost = Q_{Hmin} × cost index

$= 917948 \times 1.9 \times 10^{-6}$

= 1.7439 \$/hr = 8,25,476.9 Rs/year

- For cooling utility,

Cost = Q_{Cmin} × cost index

$= 923496 \times 2.125 \times 10^{-7}$

= 0.19624 \$/hr = 92,917 Rs/year

- Total operating cost = operating cost of heating + cooling utilities

= 8,25,476.9 + 92,917

= 9,18,393.9 Rs/year

Annualization factor = 0.3221

- Capital cost per year = total capital cost of all HE × annualization factor

$= 6.8611 \times 10^4 \times 0.3221$

= 22099.6031 \$/year = 11,93,378.6 Rs/year

- Total annualized cost = total capital cost + total operating cost

= 9,18,393.9 + 11,93,378.6

= 21,11,772.5 Rs/year

- Percentage reduction in heating load,

$$\% \text{ Reduction} = \frac{917948 - 776800}{917948} \times 100 = 15.3764$$

- Percentage reduction heating utility cost,

$$\% \text{ Reduction} = \frac{8{,}25{,}476.9 - 7{,}01{,}260.8}{8{,}25{,}476.9} \times 100 = 15.048$$

- Percentage reduction in cooling load,

$$\% \text{ Reduction} = \frac{923496 - 484800}{923496} \times 100 = 47.5038$$

- Percentage reduction cooling utility cost,

$$\% \text{ Reduction} = \frac{92{,}917 - 48{,}763.923}{92{,}917} \times 100 = 47.52$$

Sr No.	**Heat exchanger**	**Area(m^2)**	**Capital cost(\$)**
1	E-1512	20.04	1.8808×10^4
2	E-1506	23.94	2.0148×10^4
3	E-1513	54.72	2.9661×10^4

- Percentage reduction in total operating cost,

$$\% \text{ Reduction} = \frac{9{,}18{,}393.9 - 7{,}50{,}024.723}{9{,}18{,}393.9} \times 100 = 18.333$$

V. RESULTS AND DISCUSSION:

1. Minimum heating load = 7.768 × 10^5 (kJ/hr)
2. Minimum cooling load = 4.848 × 10^5 (kJ/hr)
3. Pinch temperature = 58-49^{0}C
4. Total minimum no of units = 5

5.1 Final design of flow sheet based on grid

Based on the above design of HEN by using methodology of aspen energy analyzer software and use of pinch technology actual arrangement of heat exchanger in VCM distillation process flow diagram as shown in fig. 3. Here we added some extra heat exchangers (HE) to recover the process to process heat and to save addition heating or cooling load of utilities.

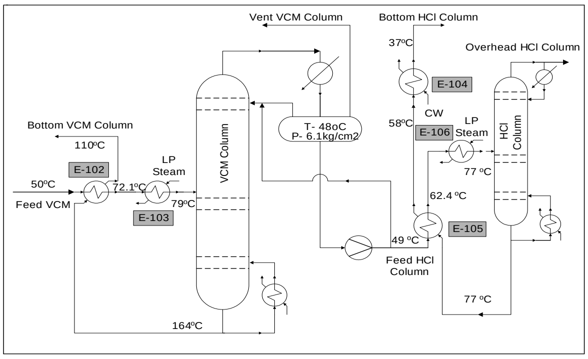


Fig.8 Specification of heat exchangers in final design

5.2 Specification of heat exchangers in final design

Specification of heat exchangers appeared in the final VCM PFD is tabulated as follow Table 2. Specification of Heat Exchangers in Final Design

HE	Heat Load (kJ/hr)	Area(m^2)	HTC KJ/(m^2 K)	LMTD(^{0}C)
E-102	957660.7	9.4	1356.6	74.81
E-103	297642.8	2.5	2410.4	49.18
E-104	484835.5	8.9	2259.2	24.12
E-105	438660.7	34.8	1356.6	11.58
E-106	479188.0	3.7	2410.4	49.18

Table 4 Specification of heat exchangers in final design

VI. CONCLUSION:

In present case study of VCM distillation unit of heat exchanger network was designed by use of methodology of aspen energy analyzer software V8.0 and pinch technology. Several HEN are designed at different ΔTmin values and by comparing the total annualized costs to obtain the optimum design was selected and among the various values ΔTmin at 9^0C gives the most optimal results. Whereas the largest energy savings were obtained with the appropriate use of utilities (Saves 15.3764% of hot utilities and 47.52% of cold utilities compared with the current plant configuration). Percentage reduction in total operating cost is 18.333%. From calculation Payback Period for new design is 3.15 year. This save could be done through a plant revamp, with the addition of two heat exchangers. Additionally it is possible to realize a detailed study with a rigorous design methodology of Heat Exchanger Network. This improvement are done in the process associated with this technique are not due to the use of advance unit operation, but to the generation of heat integration scheme. The Pinch Design Method can be employed to give good designs in rapid time and with minimum data.

ACKNOWLEDGEMENTS:

I am especially grateful to my guide Prof.M.U. Pople Sir for their time and much needed valuable guidance and without their moral support and cheerful encouragement my synopsis would not have been successful.

REFERENCES:

[1] Andres Felip Suarez,Rio de Janeiro “Heat Exchanger Network Optimization Using Integrated Specialized Software from ASPENTECH And GAMS Technology”, Brazil, July 2012.

[2] Scuola Tech “Aspen Energy Analyzer V8.0.”

[3] Robin Smith,”Chemical Process Design and Integration”, pp 357-410, June 2010.

[4] Eric S. Fraga, “A rewriting grammar for heat exchanger network structure evolution with stream splitting, Engineering Optimization”, Vol. 15:7, 1–21.May 6, 2009.

[5] Linnhoff March`s “Introduction To Pinch Technology”, 1998.

[6] Kamel Singh, Raymond Crosbieb, Use of Pinch Analysis in Sizing and Integrating a Heat Exchanger into an Existing Exchanger Network at a Gas Processing Plant, The Journal of the Association of Professional Engineers of Trinidad and Tobago, Vol.40, No.2,pp.43-48,October/November 2011.

[7] Kedar Telang, F.Carl Knopf, Ralph W.Pike, the Heat Exchanger Network, March 2001.

[8] NPTEL, Chemical Engineering, “Process Integration, lecture”no: 1, 2,4,5,6.

[9] Padole Manjusha, Sapkal Pradyumna, Dawande S.D., Nitin Kanse, Heat Integration of Crude Organic Distillation Unit, Research Journal of Engineering Sciences, Vol. 2(2), 47-55, Feb 2013,

[10] Don W Green, Robert H Perry “Perry chemical engineers Handbook” 8th edition, Table no 2-153, page no 2-170.

[11] Ian C. Kemp”Pinch analysis and Process Integration” Elsevier second ed., 2007.

[12] SHA Nejad, AF Shahraki, MRS Birjandi, A. KovacKralj, F Fazlollahia, Modification Of Heat Exchanger Network Design By Considering Physical Properties Variation, Chem. Biochem Eng, Q. 26 (2) 79–87, 2012.

[13] Shuncheng Ji, Miguel Bagajewicz, Design Of Crude Distillation Plants With Vacuum Units Ii Heat Exchanger Network Design, Ind. Eng. Chem. Res, 2002, Vol 41, pp. 6100-6106.

[14] W.A.S. Coetzee, Steam System Network Synthesis Using Process Integration, Sep 2007.

[15] Timmerhaus Klaus D., Plant Design and Economics for Chemical Engineers, Fifth Edition 2004,pp. 324.

[16] Visio Technical 4.0 for Chemical Engineering Drawing.