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Energy Recovery of Ethylene Dichloride (EDC) Production by Pinch Analysis (Abu-Kamash EDC plant)

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Abstract

The pinch analysis has emerged as a powerful tool for the integrated design of process heat networks which include heat exchangers, distillation columns, furnaces, etc.., in order to reduce energy consumption of such units .The key strategy of this methodology is to set energy targets prior to design based on basic thermodynamic principles.

The subject of this research in to apply this analysis to one of the chemical plants in Libya, namely, the ethylene di chloride plant (EDC) at Abu Kamash chemical complex. The objectives are to assess energy utilization of such big energy – consuming plants and to explore the potential of energy saving based on the results of applying this analysis.

Actual data is collected from the plant and application of the procedure of the pinch analysis to this case study, where a minimum temperature difference approach in the EDC plant heat exchangers design of 10 ℃ (ΔT min =10 ℃) is used, gave the following results. Since high pressure saturated steam are the source of energy consumed in the plant as hot utility, the result of pinch analysis showed that a minimum energy requirement to operate the plant is 96.82 Mcal/hr. The actual energy consumption of the plant is 279.6 Mcal/hr, and then amounts to 65% energy saving.

Keywords: Pinch , Analysis, Energy , Recovery, Consumption , Ethylene Dichloride (EDC).

الملخص

يعتبر تحليل (Pinch Analysis) تطبيق قوي في التصميم المتكامل لشبكات الحرارة العملية التي تشمل المبادلات الحرارية وأعمدة التقطير والأفران ، إلخ .. و ذلك من أجل تقليل استهلاك الطاقة لهذه الوحدات. حيث تتمثل الاستراتيجية الرئيسية لهذه المنهجية في وضع أهداف الطاقة قبل التصميم بناءً على مبادئ الديناميكا الحرارية الأساسية.

يهدف هذا البحث الى تطبيق هذا التحليل على أحد المصانع الكيماوية في ليبيا وهو مصنع ثنائي كلوريد الإيثلين (EDC) في مجمع أبو كماش الكيميائي. تتمثل هذه الأهداف في تقييم استخدام الطاقة لمثل هذه المصانع الكبيرة المستهلكة للطاقة واستكشاف إمكانات توفير الطاقة بناءً على نتائج هذا التطبيق.
يتم في هذا البحث جمع البيانات الفعلية من المصنع وتطبيق إجراء هذا التحليل على هذه الدراسة، حيث يتم استخدام نهج الحد الأدنى من فرق درجة الحرارة في تصميم المبادلات الحرارية لمحطة (EDC) بمقدار 10℃ ($\Delta T_{min.} = 10^oC$) . نظرًا لأن البخار المشبع ذو ضغط عالي و هو مصدر الطاقة المستهلكة في المحطة كمرفق ساخن ، فقد أظهرت نتيجة تحليل هذا الضغط أن الحد الأدنى من متطلبات الطاقة لتشغيل المحطة هو 96.82 Mcal/hr, حيث استهلاك الطاقة الفعلي للمحطة هو 279.6 Mcal/hr, وهذا يعني توفير في الطاقة بنسبة 65%.

1. Introduction

The Abu Kamash petrochemical complex was established in the 1970s and comprises three units producing 104,000 tons per year of ethylene dioxide, 60,000 tons per year of vinyl chloride (VCM), 60,000 tons per year of polyvinyl chloride (PVC) and 50,000 tons per year of caustic soda, 45,000 tons per year of chlorine. A large portion of Abu Kamash's products are exported. Ethylene dichloride plants are among the major energy consuming industrial plants. In this research, we will conduct a study on the production line of ethylene dichloride by using pinch analysis. Ethylene dichloride plants are among the major energy consuming industrial plants.[1]

The objective of this research is to assess the designed energy requirement for the Abu Kamash EDC plant by applying the pinch analysis using actual plant data. As a result, a scope of energy saving during the operation of the plant is explored and a maximum energy recovery design of heat exchangers suggested. The steps of this analysis will be demonstrated through the following tasks:

1- Calculating the minimum heat requirement possible for the process.
2- Comparison between actual energy consumption with that of minimum energy requirement (MER) design as predicted by the pinch analysis.

Ethylene Dichloride (EDC) Production is made by the chlorination of ethylene via one of two processes:

Direct chlorination: Direct chlorination is performed in the liquid phase where liquid chlorine and pure ethylene are reacted in the presence of ferric chloride, although other catalysts have been suggested. The reaction can be carried out at either low (20-70 C°) or high (100-150 C°) temperatures. The low temperature process has the advantage of low by-product formation but requires more energy to recover the EDC.

Oxy-chlorination: In the oxy-chlorination process, pure ethylene and hydrogen chloride, mixed with oxygen, are reacted at 200-300 C° and 4-6 bar in the presence of a catalyst, usually cupric chloride. The reaction takes place in either a fixed bed or fluid bed reactor, the latter being preferred, as it is easier to control the temperature. The oxy-chlorination unit can use air or pure oxygen but the oxygen-based route is favoured on environmental and efficiency grounds . This process showed in Figure 1.

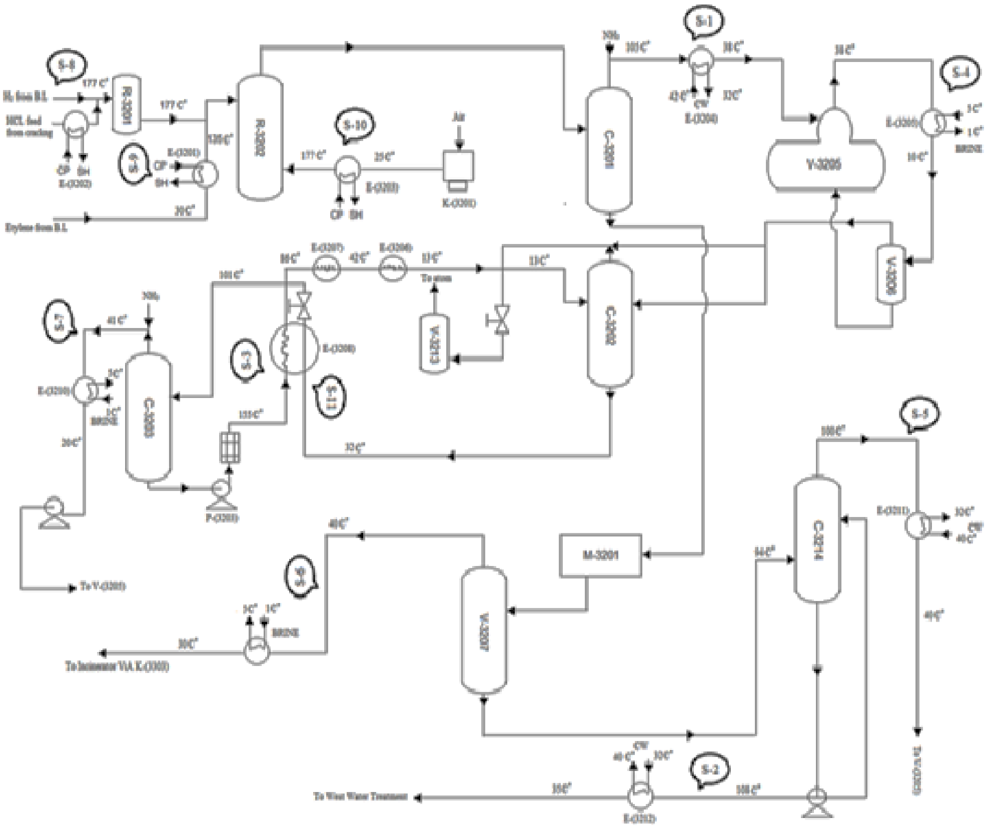


Figure 1: Ethylene Dichloride (EDC) Abu Kamash plant by Oxy-chlorination.[1]

The term "Pinch Technology" was introduced by Linnhoff and Vredeveld in 1978 to represent a new set of thermodynamically based methods that guarantee minimum energy levels in design of heat exchanger networks. Over the last few decades it has emerged as an unconventional development in process design and energy conservation. [2] The term ‘Pinch Analysis’ is often used to represent the application of the tools and algorithms of Pinch Technology for studying industrial processes.

Pinch analysis is a thermodynamic concept where a proper analysis of process heat exchange leads to identification of preferred options in terms of many other design objectives, for example, minimization of capital cost and operational cost. Pinch analysis is a methodology for minimizing energy consumption of chemical processes by calculating thermodynamically feasible energy targets (or minimum energy consumption) and achieving them by optimizing heat recovery systems, energy supply methods and process operating conditions. It is also known as process integration, heat integration, energy integration or pinch technology.[3]

In pinch analysis the system design problems are considered for identification of energy saving opportunities and modification of existing plant or for designing of a new energy efficient plant. The approach rests on concepts that are convenient and simple and make it possible to deal with problems hitherto considered complex. The technique emphasizes on simple sums rather than complex mathematics. A pinch analysis starts with the heat and material balance for the process. Using pinch technology, it is possible to identify appropriate changes in the core process conditions that can have an impact on energy savings (onion layers). After the heat and material balance are established, targets for energy saving can be set prior to the design of the heat exchanger network. The pinch design method ensures that these targets are achieved during the network design. Targets can also be set for the utility loads at various levels (e.g. steam and refrigeration levels). The utility levels supplied to the process may be a part of a centralized site-wide utility system (e.g. site steam system). Pinch technology extends to the site level, wherein appropriate loads on the various steam mains can be identified in order to minimize the site wide energy consumption. Pinch technology therefore provides a consistent methodology for energy saving, from the basic heat and material balance to the total site utility system. [4]

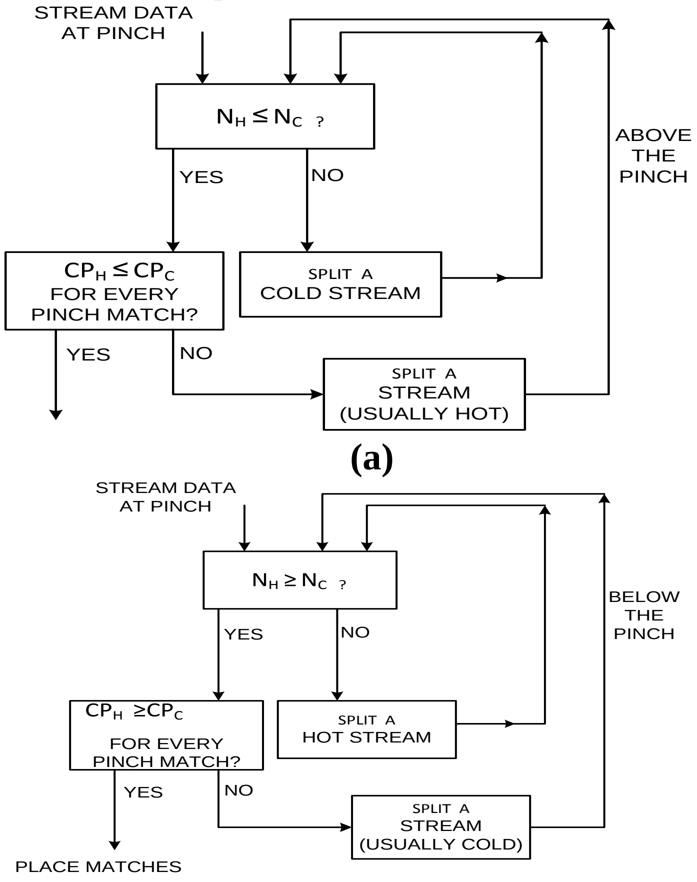
The process data are represented as a set of energy flows, or streams, as a function of heat load versus temperature. These data are combined for all the streams in the plant to give composite curves, one for all hot streams (releasing heat) and one for all cold streams (requiring heat). The point of closest approach between the hot and cold composite curves is the pinch temperature (pinch point or just pinch), and is where design is most constrained. Hence, by finding this point and starting design there, the energy targets can be achieved using heat exchangers to recover heat between hot and cold streams. In practice, during the pinch analysis, often cross-pinch exchanges of heat are found between a stream with its temperature above the pinch and one below the pinch. Removal of those exchanges by alternative matching makes the process reach its energy target.

2. Pinch Methodology

This section presents an insight into the key concepts which are the building blocks of pinch analysis. [7]
These concepts are:

1- Data extraction from a process flow sheet.
2- Identification of hot, cold, and utility streams in the process.
3- Thermal Data Extraction for Process and Utility Streams.
4- Selection of Initial ΔT $_{min}$ Value.
5- Construction of Composite Curves and Grand Composite Curve.
6- Estimation of Minimum Energy Cost Targets.
7- Design of Heat Exchanger Network (HEN).

These Algorithms for design at the pinch showed in Figure 2, where (a) above the pinch, and (b) below the pinch.



(a)

(b)

Figure 2: Algorithms for design at the pinch (a) above (b) below

2.1 Process Data

The PFD of the EDC plant abu kamash is used to identify the hot and cold streams names and thermal data, which are listed in tables 1 and 2 respectively.

Table 1: Process Stream Names

Stream No.	Names of streams
1	Quench overhead C - (3201)
2	E - (3212) feed
3	Feed of C - (3202)
4	E - (3205) feed
5	Top of C - (3204)
6	E - (3213) feed
7	Top of C - (3203)
8	Hydrogen chloride feed
9	Ethylene feed
10	Purge air
11	Bottom of C - (3202)

Table 2: Process Stream Thermal Data.[1]

Stream No.	Condition	CP (Mcal/hr. °C)	T(s) (°C)	T(t) (°C)	ΔH (Mcal/hr)
1	HOT	25.9	105	38	1735
2	HOT	2.1	108	35	152
3	HOT	0.67	155	13	94
4	HOT	5.4	38	10	151
5	HOT	3.7	100	40	221
6	HOT	0.15	40	30	1.5
7	HOT	2.1	41	20	43
8	COLD	0.92	25	177	139.6
9	COLD	0.75	5	135	97.5
10	COLD	0.28	25	177	42.5
11	COLD	1.37	32	101	94

2.2 Problem Table Algorithm

The first step in problem table algorithm is to construct temperature intervals for each stream (Temperature scales are shifted by ½ ΔT_{min}, as illustrated in Figure 3)

The enthalpy balance intervals set up based on stream supply and target temperatures. This is done in the way shown in Figure 3 for the problem data from Table 2. Streams are shown in a schematic representation with a vertical temperature scale. Temperature interval boundaries are superimposed on the interval boundary Temperatures are set at ½ ΔT_{min} (5°C in in this example) below hot stream temperatures and ½ ΔT_{min} above cold stream temperature, So for example in interval number 1 in Figure 3 stream 1 (the hot stream) run from 105°C to 100°C , and streams 8 (the cold stream) 30°C to 182°C.

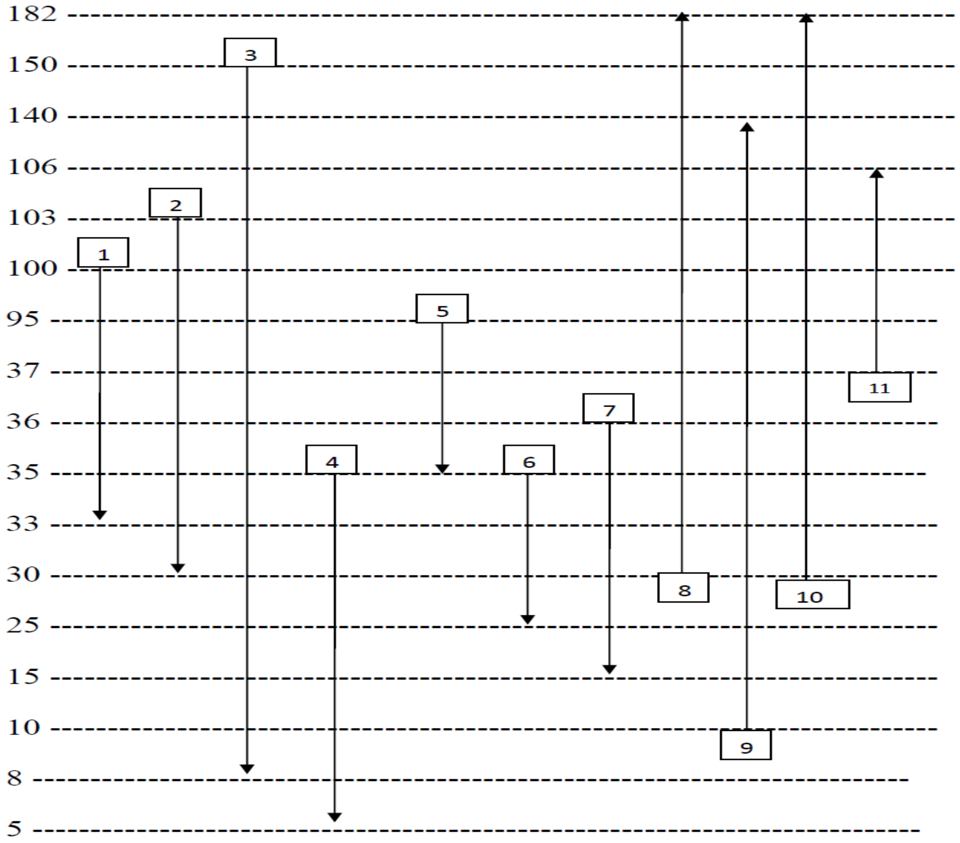


Figure 3: Process Temperature Interval

In each interval, heat from any hot streams in the high-temperature interval can be transferred to any of the cold stream at lower- temperature interval. As a result of Figure 3 sixteen intervals along with heat surplus or deficit are demonstrated in table 3. Thus, for the first interval a deficit value of

38.4 Mcal/hr is obtained .The values for other intervals are shown in table 3. And calculated by using the following equations

$$\Delta CP = \Sigma CP_{cold} - \Sigma CP_{Hot} \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Table 3: Net Energy Required at Each Interval

Interval *NO.*	ΔT_i $T_i - T_{i+1}$ (°C)	ΔCP $\Sigma CP_{cold} - \Sigma CP_{Hot}$	Hi (Mcal)	Surplus or Deficit
182/150 "1"	32	1.2	38.4	DEFICIT
150/140 "2"	10	0.53	5.3	DEFICIT
140/106 "3"	34	1.28	43.52	DEFICIT
106/103 "4"	3	2.65	7.95	DEFICIT
103/100"5"	3	0.55	1.65	DEFICIT
100/95 "6"	5	-25.35	-126.75	SURPLUS
95/37"7"	58	-29.05	-1684.9	SURPLUS
37/36"8"	1	-30.42	-30.42	SURPLUS
36/35 "9"	1	-32.52	-32.52	SURPLUS
35/33 "10"	2	-28.97	-57.94	SURPLUS
33/30 "11"	3	-8.47	-25.41	SURPLUS
30/25"12"	5	-7.57	-37.85	SURPLUS
25/15 "13"	10	-7.42	-74.2	SURPLUS
15/10 "14"	5	-5.32	-26.6	SURPLUS
10/8"15"	2	-6.07	-12.14	SURPLUS
8/5 "16"	3	-5.4	-16.2	SURPLUS

For example to calculate the **Δ CP** of the interval (182) we need to sum the **CP** of the hot streams and then subtracted from the sum of the cold stream's **CP** as it shown down below. The interval 182 have 2 cold streams (8, 10) and none of the hot streams. And this is the same for the whole intervals shown in table 3. And for the calculation of **Hi** we just need to use this equation

$$Hi = \Delta T_i * \Delta CP \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Figures (4.A), and (4.B) are cascade diagrams where heat cascades through the temperature intervals are shown. At this stage we arrange the intervals as its located in the table 3 and then we put the energy of each interval in boxes in order to the end of the table as its shown in figure (4.A) . Then we put a zero power of the plant to obtain the largest negative energy in the factory so that it is considered the deficit expected to reach the pinch point.

By adding in the top of the energy cascade the most negative propagated flow of enthalpy, the minimum energy cascade is obtained. This propagated enthalpy will be zero in at least one displaced temperature interval of the energy cascade. These points correspond with the points of maximum approach between composite curves, and are called "Pinch Points". The value of propagated enthalpy in the hottest temperature interval represents energy (that is, the minimum heating requirements), and the value of propagated enthalpy in the coldest temperature interval represents energy that must be removed by an external energy sink (that is, the minimum cooling requirements).

The hot result of this operation is that the minimum utilities requirements have been predicted, i.e. 96.82 Mcal/hr hot and 2124.93 Mcal/hr cold. Furthermore, it is observed from Figure (4.B) that there is no transfer of energy between the Fiveth and Sixth temperature intervals. This is called the pinch point at 105 C° for the hot streams and 95 C° for the cold streams. The temperature at the pinch point provides a breakdown of the design problem where heat is supplied above the pinch point temperature and heat is rejected below it.

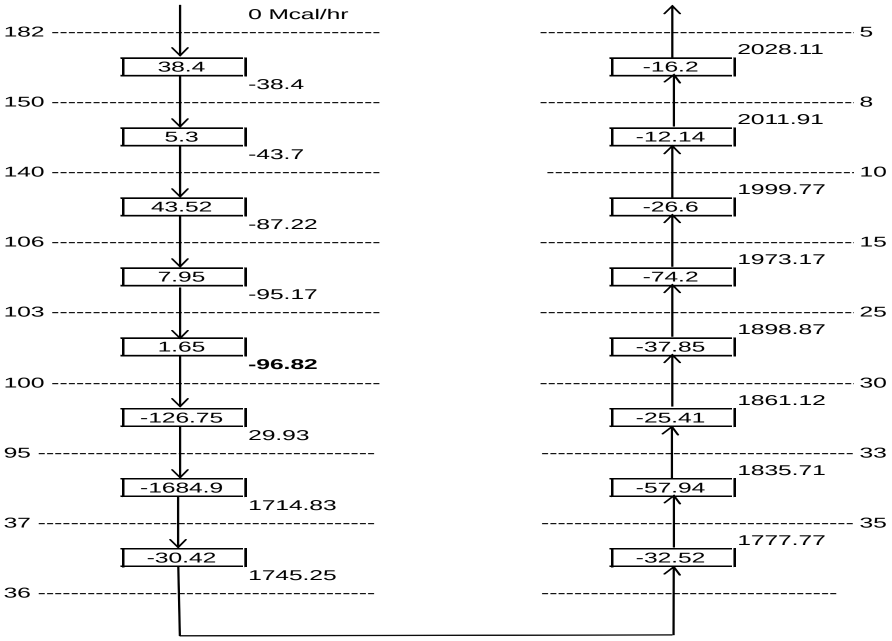


Figure (4.A) Cascade diagram

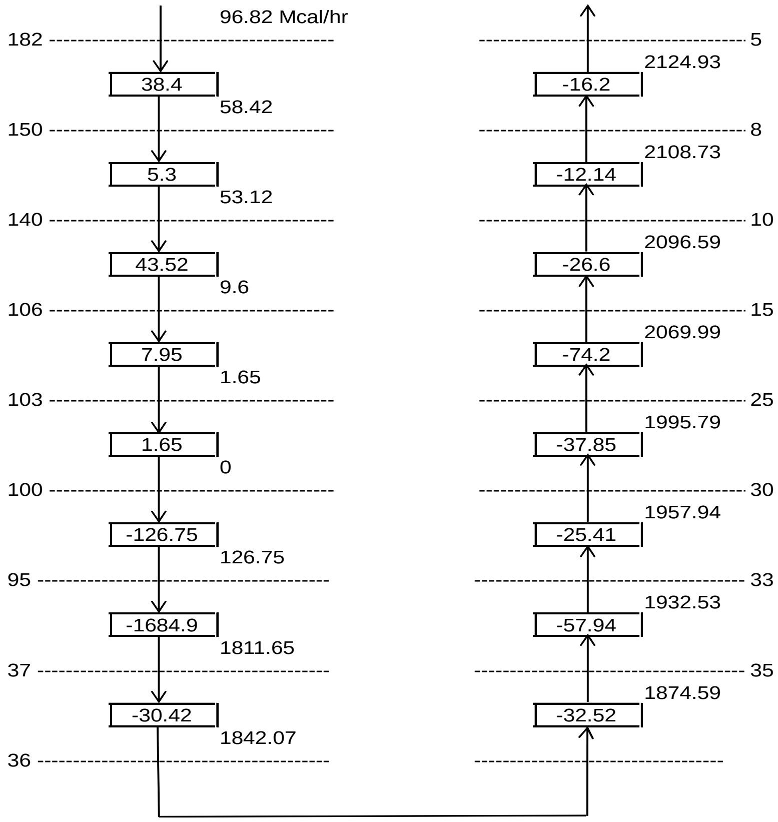


Figure (4.B) Cascade diagram

2.3 The Pinch Design

The actual heat exchangers network at EDC plant where the heating utility used (Q_H) is 279.6 Mcal/hr, and the cold utility (Q_C) is 2303.5 Mcal/hr as shown in Figure 5.

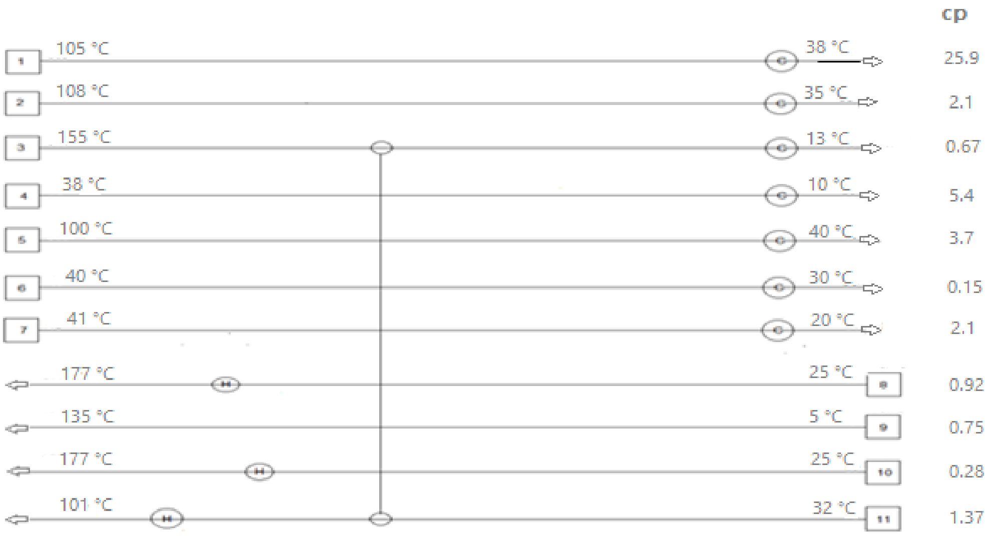


Figure 5: The Base Case Design

There are three rules of the pinch principle (section) are central to the procedure for designing the network. According to the pinch rules there must be no external cooling above the pinch (on the left side of the grid diagram so hot streams on this side must be brought to pinch temperature by heat transfer with cold streams on the same side i.e. on the lift .Similarity cold streams on right side of the grid diagram must be brought up to pinch temperature by using hot streams on the right rather than utility heating. The ΔT_{min} puts another constraint on the design because it has been defined as the minimum temperature difference for heat transfer anywhere in the system. The results of the problem table procedure as summarized in table 4.

($\Delta T_{min} = 10$ C°)

Table 4: Utility data at the pinch and base case (actual)

Utility	Pinch case	Base case (actual)
Q_H (Mcal/hr)	96.82	279.6
Qc (Mcal/hr)	2124.93	2303.5

The pinch design of maximum energy recovery (MER design)is illustrated in figure 6 to figure 9.

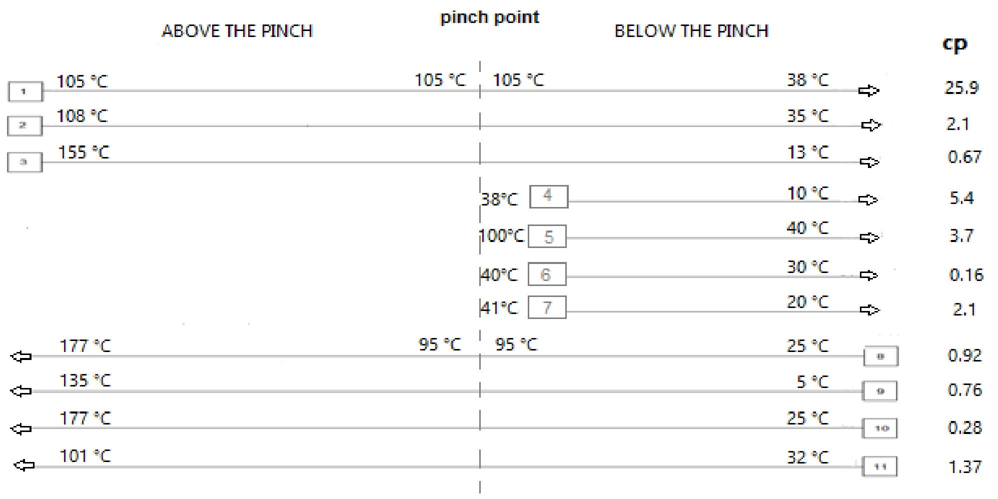


Figure 6: Stream Set Above and Below the Pinch

2.3.1 Design above the Pinch

Some ground rules for setting up the heat exchanger matches between the hot and the cold streams on the design of above the pinch

$$\mathbf{CP_{cold} \geq CP_{hot}}$$

Take the example stream shown in Figure 8 a proposed match can be drawn between streams 3 and 9 , Because the CP of the stream 3 is less than stream 9 (CP of hot stream less than CP of cold stream). And for the match between stream 3 and stream 10, It is important to realize that the “CP rule” for temperature feasibility is only rigid for units directly adjacent to the pinch.

The remaining heating load on the cold streams must now be provided by the utilities.

And for the match between stream 2 and stream 8 and also streams (2 , 11) .

There is a problem if there are matches at the pinch that do not comply with the $\mathbf{CP}_{\mathbf{Cold}} \geq \mathbf{CP}_{\mathbf{Hot}}$ rule. In this case, an incoming stream could be split to reduce its CP.

in addition to the CP feasibility criterion introduced earlier we have a “number count” feasibility criterion, where above the pinch,

$\mathbf{N}_{\mathbf{HOT}} \leq \mathbf{N}_{\mathbf{COLD}}$

$\mathbf{N}_{\mathbf{HOT}}$ = number of hot stream branches at the pinch (including full as well as split streams).

$\mathbf{N}_{\mathbf{COLD}}$ = number of cold stream branches at the pinch (including full as well as split streams).

In the Figure 7 the number count criterion is satisfied (two hot streams against four cold streams) but the CP criterion [CP cold ≤ CP hot] is not met for either of the possible matches. In this case the solution is to split a hot stream with CP of 0.73 for the stream 2 and stream 8 match now the CP criterion is satisfied , And for the match between stream 2 branch and stream 11 we subtract 0.73 of 2.1 the total stream CP to find that CP criterion for this match is also satisfied with the CP of 1.37 as shown in Figure 7 .

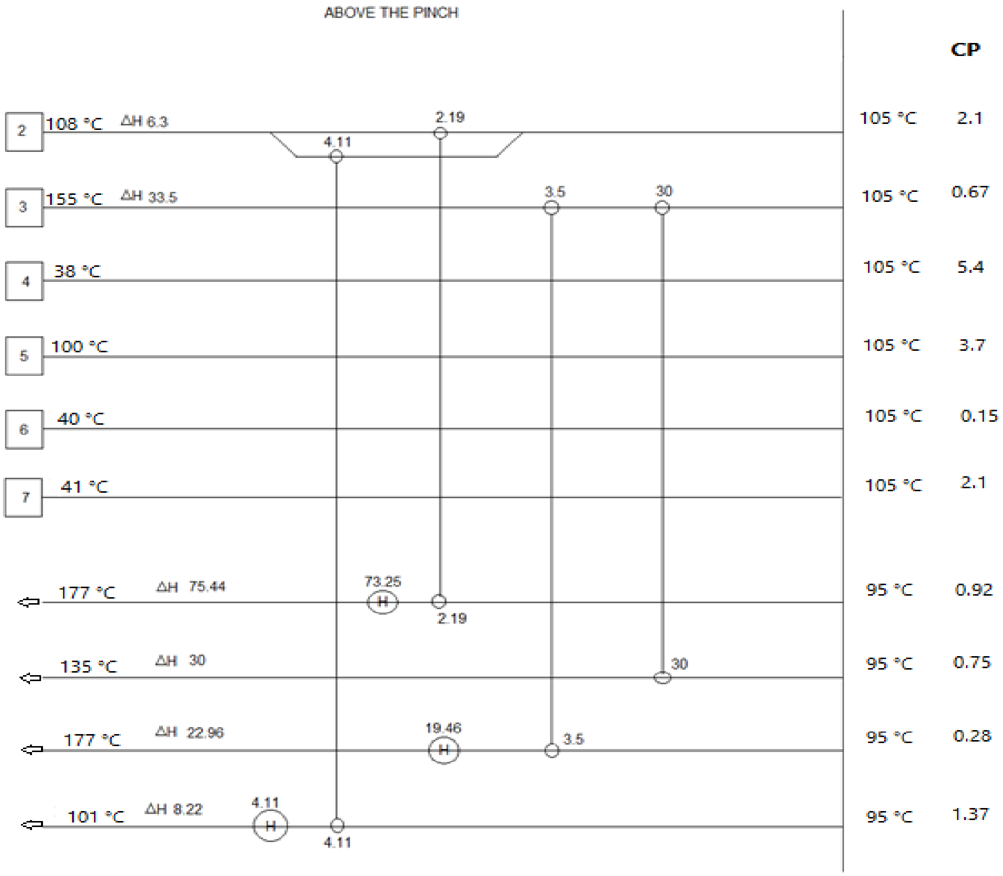


Figure 7: Design above the Pinch

2.3.2 Design Below the Pinch

Some ground rules for setting up the heat exchanger matches between the hot and the cold streams on the design of below the pinch

$CP_{hot} \geq CP_{cold}$

for the stream 2 and stream 8 match now the CP criterion is satisfied. And stream 3 , 10 match its also satisfied . The remaining cooling load on the cold streams must now be provided by the utilities. Now for the matches between streams (1 , 9) and (1 , 11) we found that the number count criterion is not satisfied (three hot streams against four cold streams) . In this case the solution is to split a hot stream by following this CP criterion

$CP_{hot} \geq CP_{cold}$.

The streams and heat load values are shown in Figure 8. From this figure we can see that the number of coolers below the pinch is (11) of which (7) coolers are utilities.

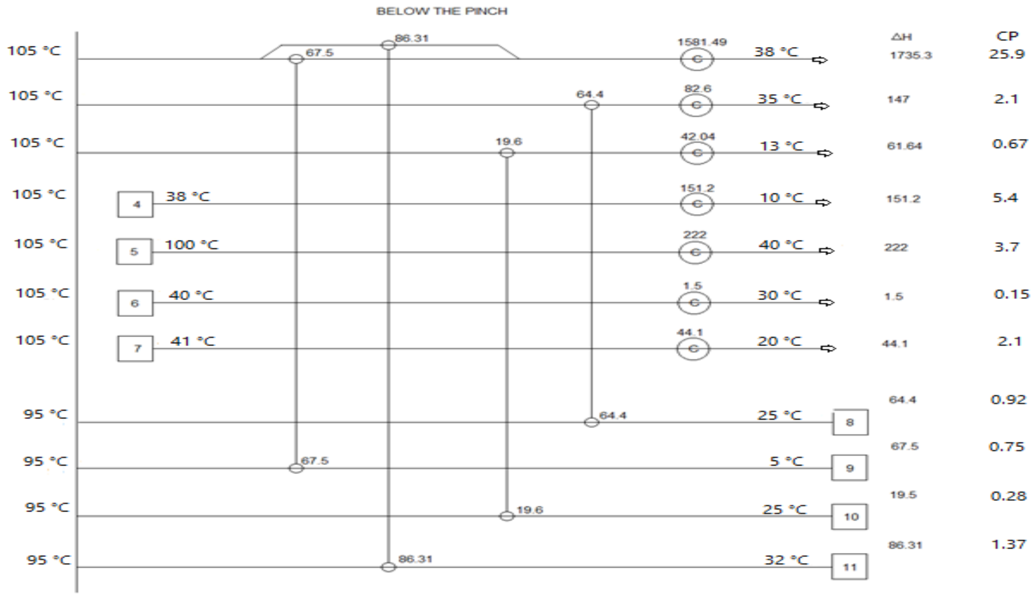


Figure 8: Design below the Pinch

2.3.3 Complete Pinch Design

The completed MER design is obtained by merging the two systems “above” and “below” the pinch, with the result shown in Figure 9. And its also shown the number of utilities used in the plant that is 10 utilities (7 coolers and 3 heaters) .

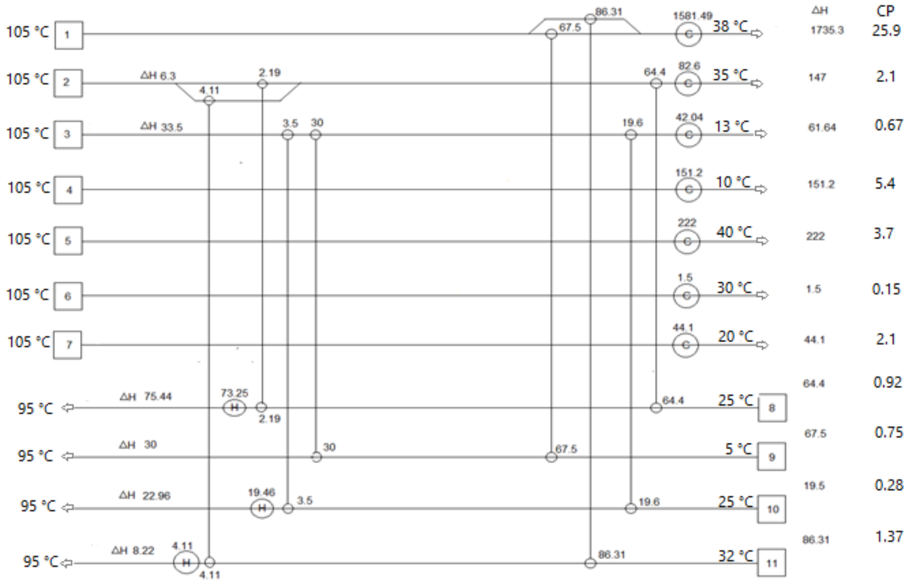


Figure 9: Complete Minimum Energy Design

3. Discussion of Results

At the end, we compare and mention some important results we came up with this study. The following results are obtained, Actual rate of energy consumption of the base case design of the plant is (279.6 Mcal/hr) while the minimum target found by the pinch analysis is (96.8 Mcal/hr).

$$\textbf{Amount of energy saved \%= 100 \% - (}\frac{\textbf{energy found by pinch}}{\textbf{base case energy}}\textbf{*100)…. (3)}$$

$$\textbf{Amount of energy saved \%= 100\% - }\frac{\textbf{96.8}}{\textbf{279.6}}\textbf{ * 100 = 100 \% - 34.62 \% = 65.38 \%}$$

This amount is just over 65 % energy savings and the number of matches is eight matches in this plant.

4. Conclusions

The main conclusions of this paper are summarized below.

1 – Pinch analysis can be used systematically to set energy targets before heat exchangers network design to ensure maximum energy saving.

2 – Revamp designs can make use of pinch analysis to come up with good analysis to reduce energy consumption.

3 – For the EDC plant there is a scope of energy savings as can be seen when comparing actual design with that predict by pinch analysis.

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