HEAT EXCHANGER NETWORK OPTIMIZATION USING PINCH TECHNOLOGY

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الملخص

الهدف من هذا العمل هو تطبيق تقنيات تقنية الضغط والتحليل التحديثي على شبكة المبادلات الحرارية الحالية لوحدة النفط الخام في شركة الزاوية لتكرير النفط من أجل تحقيق أقصى قدر من استعادة الحرارة وتقليل استهلاك الطاقة حيث يتم استخدام تحليل الضغط لتحديد تكلفة الطاقة والتكلفة الرأسمالية لشبكة المبادلات الحرارية لعملية ما والتعرف على نقطة الضغط حيث يتنبأ الإجراء أولا بتسخين التصميم بالحد الأدنى من متطلبات الطاقة الخارجية ومساحة الشبكة وعدد الوحدات حيث أصبح الاستخدام المستمر لطريقة البنش أكثر جاذبية نتيجة لدراسة الحالة حيث تم عرض المناقشة ومقارنة التصميم المقترح لوحدة النفط الخام وقد وجد أن ΔT_{min}=10°C هي أفضل ما يمكن اعتماده لأنها تعطي أفضل قيمة لدرجة حرارة مخرج شبكة المبادلات الحرارية 241 °C والتي هي مدخل سخونة الزيت الخام. حيث بلغت القيمة الاجمالية للمبادل الحراري للتصميم المقترح (41451856.58 كيلوكالوري/ ساعة) مقابل التصميم الحالي (37480729 كيلو كالوري/ ساعة) وبلغت (22563870 كيلوكالوري/ ساعة) للتصميم الحالي. وبالتالي فإن التوفير في تكلفة الوقود هو (216040.6 دولار/ساعة. شهر) والتصميم المقترح يسمح بتقليل استهلاك الطاقة والمال بنسبة 17.8%. وبالتالي فقد تم زيادة استعادة التدفئة في التصميم الجديد عن طريق إضافة مبادل حراري واحد الى الشبكة.

الكلمات المفتاحية: شبكة المبادلات الحرارية، تقنية القرص، تكرير النفط، تحسين العمليات.

Abstract

The reduced of energy consumption through improvements in energy efficiency has become an important goal for all industries, in order to improve the efficiency of the economy, and to reduce the emissions of Co_2 caused by power generation and by oil refineries plus petrochemicals during manufacturing. The objective of this paper is to investigate opportunities to increase process energy efficiency at the distillation unit of Azzawiya oil refinery in west of Libya. The main aim of the project is to locate energy savings by use of pinch technology and to assess them. At first all the required data of hot and cold streams in preheating section of distillation unit has been extracted from the available flow sheets and then pinch analysis has been conducted. The present case study is a threshold one which does not need any utilities. After running range, targeting several heat exchanger networks were designed with respect to operating conditions and different ΔT_{min}. The ΔT_{min} = 10°C was found the best one that can be adopted as it gives the best value of heat exchangers network outlet temperature (241°C) which is the input of crude oil heater. The total amount of heat exchanger for the proposed design is (41451856.58 kcal/hr) against the existing design was (37480729 kcal/hr) and it is (22563870 kcal/hr) for the existing. Hence the saving in fuel cost is (216040.6 $/month. hr) the proposed design allows reduction of 17.8% in terms of energy consumption as well as money. The heating recovery (heat exchanger duty) is increased in the new design by adding one heat exchanger to the network.

Keywords: Heat Exchanger Network, Pinch Technology, Oil Refining, Process Optimization.

1. Introduction

Process Industry integration technology has been extensively used in the processing and power generating industry over the last 35 years and was pioneered by the Department of Process Integration, UMIST (now the Center for Process Integration, CEAS, The University of Manchester) in the late 1980's and 1990's. It has extended concepts and methodologies in the design of energy based systems from the established Pinch Technology. The term "Pinch Technology" was introduced by Linnhoff and Vredeveld [1] to represent a new set of thermodynamically based methods that guarantee minimum energy levels in design of heat exchanger networks. Energy conservation remains the prime concern for many process industries while oil prices continue to increase and by attention to this issue will increase with rising energy costs and environmental constraints. Most industrial processes involve heat transfer either from one process stream to another process stream (interchanging) or from a utility stream to a process stream. In the present energy crisis scenario in all over the world, the target of any industrial process design is to maximize the heat recovery process and to minimize the utility requirements. To meet the goal of maximum energy recovery or minimum energy requirement (MER), an appropriate heat exchanger network (HEN) is required. The design of such a network is not an easy task considering the fact that most processes involve a large number of process and utility streams. The traditional design approach has resulted in networks with high capital and utility costs. With the advent of pinch analysis concepts, the network design has become very systematic and methodical [2]. Pinch Technology is a methodology, comprising a set of structured techniques, for systematic application of the first and some aspects of second laws of thermodynamics. The application of these techniques enables process engineers to gain fundamental insight into the thermal interactions between chemical processes and the utility systems that surround them. Such knowledge facilitates the improvement of the overall utility consumption, and setting process and utility system configurations prior to final detailed simulation and optimization [3-5]. Three golden rules for the designer wishing to produce a design to achieve minimum utility targets:

- Don’t transfer heat across the pinch.
- Don’t use cold utilities above the pinch.
- Don’t use hot utilities below the pinch [6].

Conversely, if a process is using more energy than its thermodynamic targets, it must be due to one or more of the golden rules being broken. As it is mentioned in following, this may be a deliberate compromise, but it is important to know that it happens. The decomposition of the problem at the pinch turns out to be very useful when it comes to network design [7]. The process needs external heating above the pinch and external cooling below the pinch. This tells us where to place furnaces, steam heaters, coolers, etc. It also tells us what steam site services should be used and how we should recover heat from the exhaust of steam and gas turbines. In the present study, the HEN of the preheat train of the Zawiya refinery’s distillation unit has been investigated. After PFD (process flow diagram) study of the unit, each

stream specification was extracted. Then in the next section, the current HEN of the unit was evaluated. Composite curves were plotted and it was revealed that we had a “threshold problem” ahead. The objective of this study is to apply the pinch technology techniques and retrofit analysis to an existing HEN of the crude oil unit in azzawiya oil refining company in order to maximize the recovery and minimum energy consumptions.

2. Methodology

To simplify the answer, from figure (1) the composition curve consists of hot and cold composites. The hot streams and cold streams are represented as straight lines on the temperature enthalpy diagram from their supply temperature to the target temperature with different heat capacity flow rates. Each of them represents the cumulative heat source and sinks respectively within the process region. Since the hot stream is to be cooled down and the cold stream is to be heated up to their target temperature, the direction of the hot stream is from the high to low temperature and the cold stream is in the opposite direction. The overlap of these two curves is representing the heat recovery by the system (Q_{REC}). Then the left duty on the left hand side of the graph represents the minimum required external cooling (Q_{Cmin}). Similarly the left duty on the right hand side of the graph represents the minimum required external heating (Q_{Hmin}).

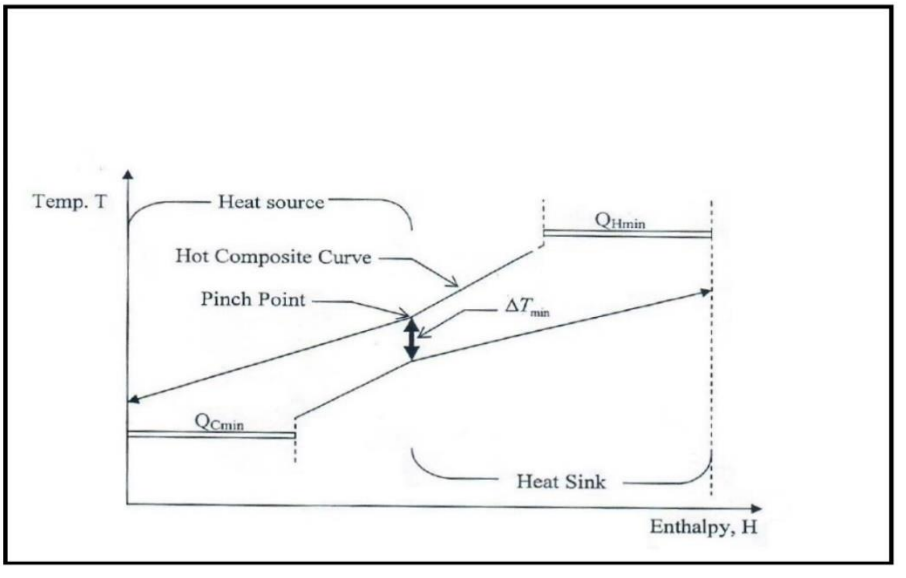

Figure 1. Composite curve and process pinch.

The location of the process pinch depends on the minimum temperature approach specified for any process between the hot and cold streams. Both the heat recovery the location of the process pinch depends on the minimum temperature approach specified for any process between the hot and cold streams. Both the heat recovery achieved and the area required to achieve that specified heat recovery are dependent on the value of ΔT_{min}[8].

2.1 Pinch Design Method

Consider a small system of heat exchanger where the process streams need to be cooled and heated from their initial (supply) temperature T_s to the initial (target) temperature T_t. The streams that require cooling are known as (hot streams) and that requiring heating are known as (cold streams). In the system the while the cold streams are the sink. For each hot and cold utility stream identified, the following thermal data is extracted from the process material and heat

- Supply temperature (T_s°C): the temperature at which the stream is available.
- Target temperature (T_t°C): the temperature the stream must be taken to.
- Heat capacity flow rate (c_p) (Kcal/Kg. °C): the product of flow rate (m) in kg/hr and specific heat (c_p) (Kcal/Kg. °C).

$$Cp = m * cp \quad (1)$$

Enthalpy change (H) associated with a stream passing through the exchanger is given by the first law of thermodynamics:

$$H = Q - W \quad (2)$$

In a heat exchanger no mechanical work is being performed:

W = 0 . The above equation simplifies to: H = Q where Q represents the heat supply or demand associated with stream. It is given by the relationship:

$$Q = Cp * (Ts - Tt) \quad (3)$$

Enthalpy change is:

$$H = C_p * (T_s - T_t) \quad (4)$$

Two methods can be used determining the utility target, the graphical and numerical. The graphical constructions are not the most convenient means of determining energy needs. A numerical approach called the "Problem Table Algorithm" (PTA) was developed by Linnhoff and Flower (1978) as a means of determining the utility needs of process and the location of the process pinch. The (PTA) lends itself to hand calculation of the energy targets [9].

2.2 Crude Oil Distillation Unit Case Study

The crude feed has a flow rate of (315580 Kg/hr) which is taken off in four fractions from the crude tower. There are two circulating refluxes (pump rounds) on the column. The streams data (mass flow rate, supply temperature and target temperature) resulting from the existing operation is shown in table (3). The total existing process to process area is (6339.88 m^2). Where the existing furnace duty supplies (22563970 Kcal/hr) to the crude feed. It is being mentioned that the column pumps around have some spare capacity. The existing network can be simulated for the envisaged throughput and this should be done under the condition which will limit the furnace duty. In this case study, there are six hot streams are: residual (RS), heavy gas oil (HGO), light gas oil (LGO), kerosene (KERO), top pump around (TPA), bottom pump around (BPA), that are to be cooled and three cold streams (crude oil, water) that are to be heated. The existing heat exchanger network are shown in figure (2). The problem table algorithm will be used for this case study, using the data from table (1) for ΔT_{min} = 10°C first determine the shifted (adjusted) temperature intervals from actual supply and target temperature. Hot streams are shifted down in temperature by ($\Delta T_{min}/2$) and cold streams up by ($\Delta T_{min}/2$) as detailed in table (2). The stream population is shown in Figure (7) with a vertical temperature scale. The interval temperatures shown in Figure (3) are set to (($\Delta T_{min}/2$) below hot steam temperature and ((ΔTmin/2) above cold stream temperature. Next, a hot balance is carried out within each shifted temperature interval according to equation (Σcphot – Σcpcold). The result is given in Figure (3) in which some of the shifted intervals are seen to have a surplus of heat and some have a deficit. The heat balance within each shifted interval allows maximum heat recovery within each interval. However, recovery must also be allowed between intervals. Now, cascade any surplus heat down the temperature scale from interval to interval. This is possible because any excess heat available from the hot streams in an interval is hot enough to supply a deficit in the cold streams in the next interval down Figure (3) shown the cascade for the problem. First assume no heat is supplied to the first interval from hot utility Figure (4). The first interval has a deficit of (-4717921 Kcal/hr), which is cascaded to the next interval? this second interval has a

deficit of (-3066978.6 Kcal/hr), which leaves the heat cascaded from this interval to be (-7784899.6 Kcal/hr). In the third interval the process has a deficit of (-4533691.4 Kcal/hr) which leaves (-12318591 Kcal/hr), to be cascaded to the next interval and so on. Some of the heat flows in Figure (4) are negative, which is infeasible (heat cannot be transferred up the temperature scale), cascade feasible, sufficient heat must be added from hot utility to make the heat flow to be at least zero. The smallest amount of heat needed from hot utility is the largest heat flow (-18439976.4 Kcal/hr) as shown in Figure (4) , that can be added from hot utility to the first interval. This does not change the heat balance within each interval, but increases all of the heat flows between intervals by (-18439976.4 Kcal/hr), giving on heat flow of just zero at interval temperature of 116 – 126°C. More than (-

18439976.4 kcal/hr) could be added from hot utility to the first interval, but the objective is to find the minimum hot and cold utility, hence only the minimum is added. Thus from Figure (4) QH_{min} = 18439976.4 Kcal/hr and QC_{min} = 7628243.7 Kcal/hr , one further important piece of information can be deduced from the cascade in Figure (4) the point where the flow goes to zero at (126°C for the hot streams and 116°C for the cold streams) this point known as the pinch point. Where the average of 121°C can have defined as the pinch point.

2. Result and Discussion

TABLE 1. Stream Date (ΔT_{min} = 10°C)

STREM/Type	m (Kg/hr)	cp (Kcal/Kg.°C)	Cp= mcp (Kcal/hr.°C)	T_s (°C)	T_t (°C)	Q= Cp∆T (Kcal/hr)
Residual/hot	93040	0.635	59080.4	319	80	14120215.6
HGO/hot	36400	0.646	23514.4	298	47	5902114.4
BPA/hot	126232	0.648	81798.34	261	192	5644085.5
LGO/hot	48920	0.605	29596.6	231	47	5445774.4
Kero/ hot	57920	0.613	35504.96	173	34	4935189
TPA/hot	341550	0.578	197416	126	53	14411368
Crude/Cold	315580	0.548	172938	20	116	-16602048
Crude/cold	315580	0.650	205127	116	332	-44307432
Water/Cold	19000	1.00	19000	80	99	-361000
Total net heating						-10811733

TABLE 2. Stream Data Temperature Adjusted

STREM/Type	Cp= mcp (Kcal/hr.°C)	T_s(°C)	T_t(°C)	Adjusted		Q (Kcal/hr)
				T_s (°C)	T_t (°C)	
Residual/hot	59080.4	319	80	314	75	14120215.6
HGO/hot	23514.4	298	47	293	42	5902114.4
BPA/hot	81798.34	261	192	256	187	5644085.5
LGO/hot	29596.6	231	47	226	42	5445774.4
Kero/ hot	35504.96	173	34	168	29	4935189
TPA/hot	197416	126	53	121	48	14411368
Crude/Cold	172938	20	116	25	121	-16602048
Crude/cold	205127	116	332	121	337	-44307432
Water/Cold	19000	80	99	85	104	-361000
Total net heating						-10811733

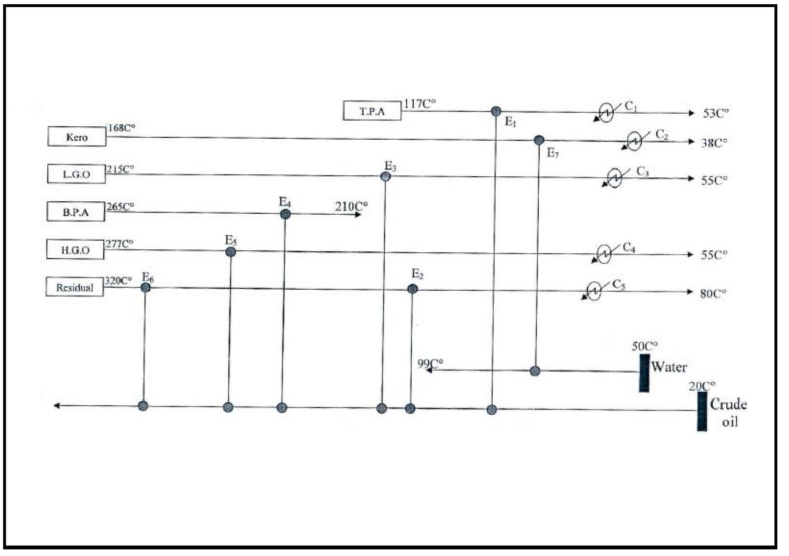

Figure 2. Existing network for the case study

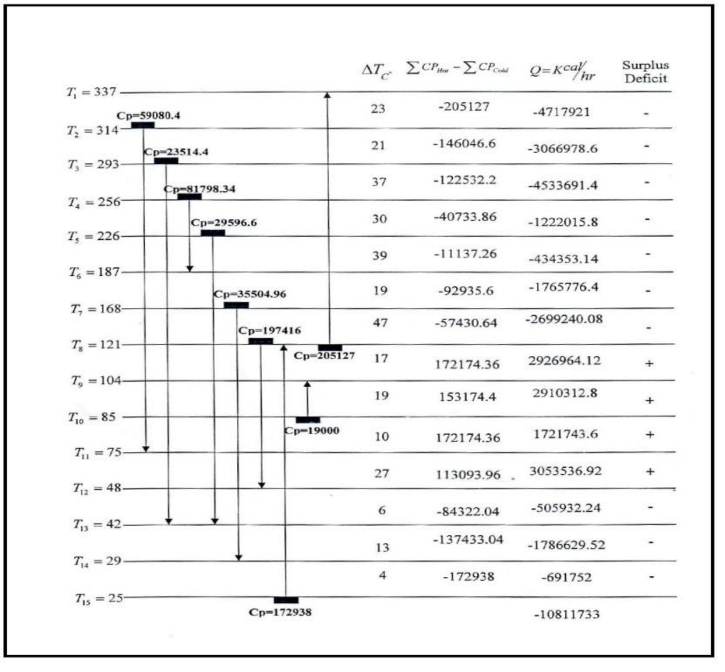

Figure 3. Temperature intervals

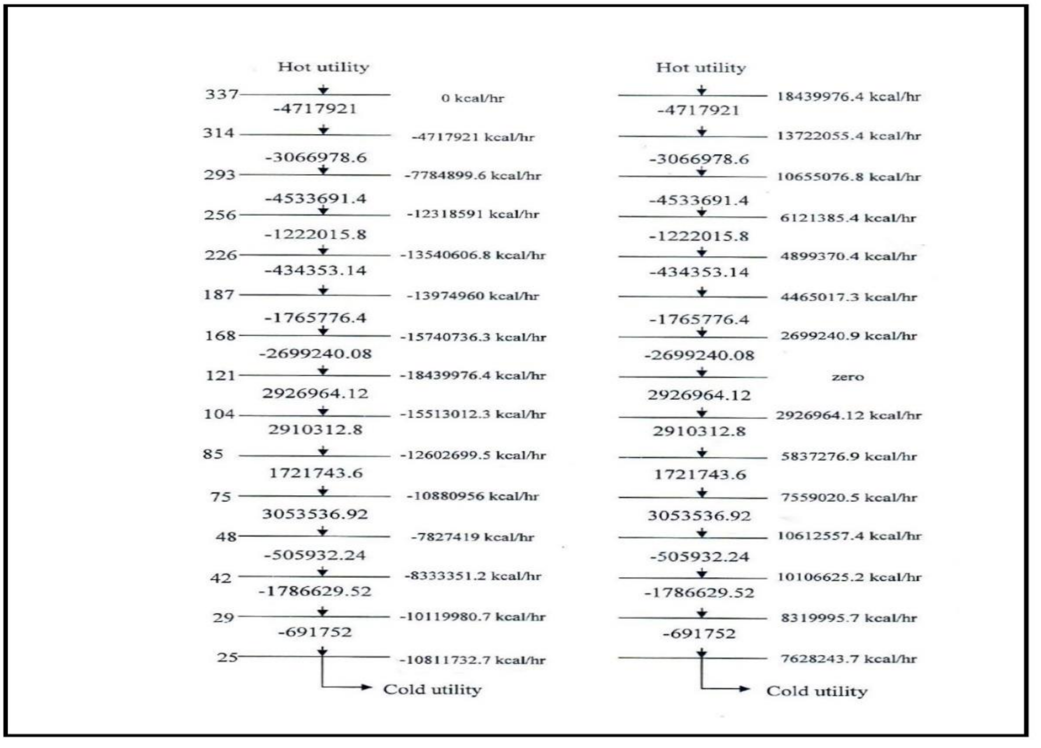

Figure 4. Cascade diagram

3.1 Energy Target Results

Energy targets were set based on composite curves and minimum temperature (ΔT_{min}). After determining the optimal value of (ΔT_{min}), the hot and cold composite curves are combined and represented in a graph of temperature- enthalpy, in the form of the complex composite curve.

3.2 Heat Exchanger Network Design

The pinch design method developed earlier followed several rules and guidelines to allow design for minimum utility or maximum energy recovery in the minimum number of units occasionally, it appears not be possible to create the appropriate matches because one or other of the design criteria, cannot be satisfied. Figure (5) shows the design above pinch, cold utility must be not used above the pinch, which means that all hot streams must be cooled to pinch temperature by heat recovery.

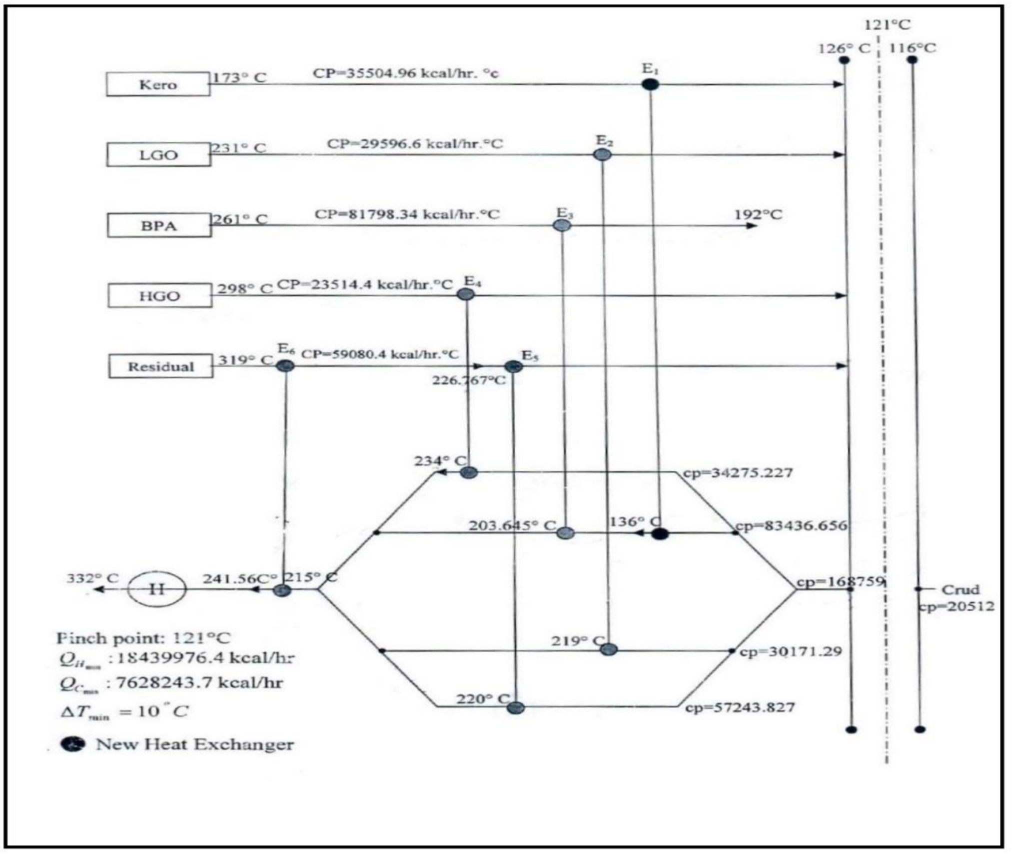

Figure 5. Design above the pinch

There are five hot streams and one cold stream to be splitting to satisfy the rules as shown in Figure (5) now each hot stream has a cold partner to match with that capable to cooling it to the pinch temperature. Thus in addition to the (C_p) inequality criteria introduced earlier, there is a stream number criterion above the pinch such that: $N_H \leq N_C$ (Above the pinch) Where: N_H = number of hot streams at the pinch and N_C = number of cold streams at the pinch. In case of higher number of cold streams then hot streams in the design above the pinch this will created a problem, since hot utility can be used above the pinch. Thus starting with ΔT_{min} at pinch for temperature differences to increase moving away from the pinch [10]. $Cp_H \leq Cp_C$ (Above pinch).

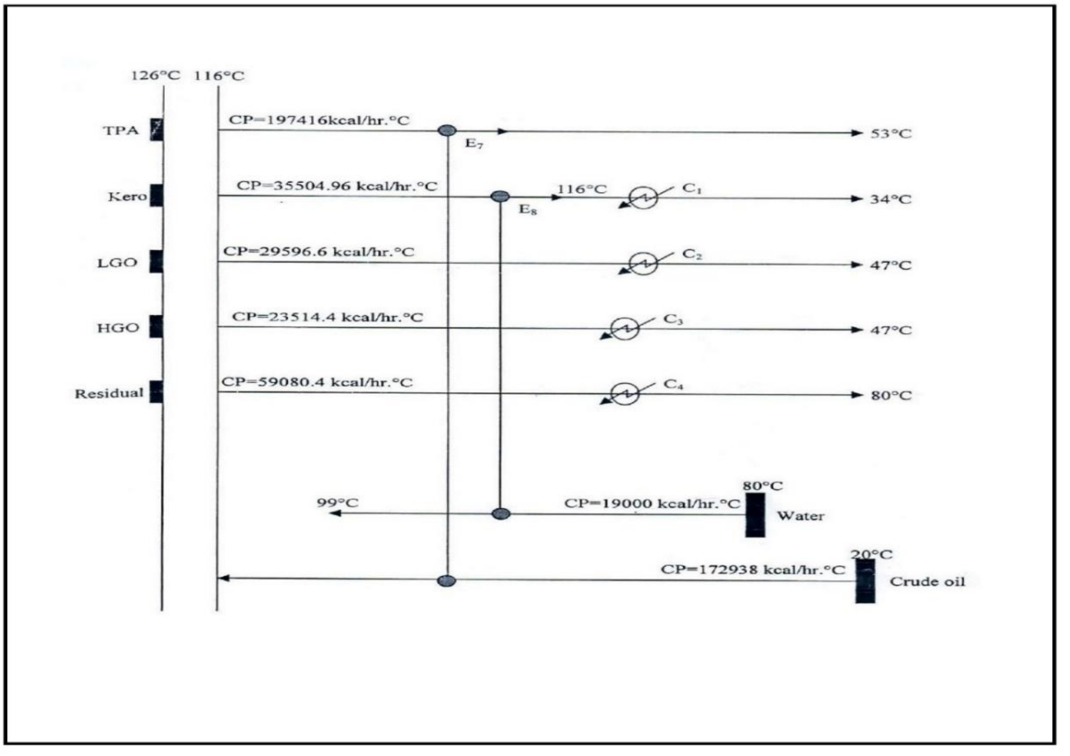

Figure 6. Design below the pinch.

By contrast, now consider part of a design below the pinch as shown in figure (6). Here hot utility must not be used, which means that all cold streams must be heated to pinch temperature by heat recovery. There now tow cold streams and five hot streams in Figure (5) regardless of (Cp) values one of the cold streams cannot be heated to pinch temperature without some violation of the ΔT_{min} constraint. Each cold stream has a hot partner with which to match and capable of heating it to pinch temperature. Thus there is stream number criterion below the pinch such that: $N_H \geq N_C$ (below pinch).

Had there been more hot streams than cold below the pinch, this would not have created a problem since cold utility can be used below the pich. $Cp_C \geq Cp_H$ (below pinch).It is note that the (Cp) inequalities given by equation only apply at below the pinch and when both ends of the match are at pinch condition. Had there been more hot streams than cold below the pinch, this would not have created a problem since cold utility can be below the pinch.

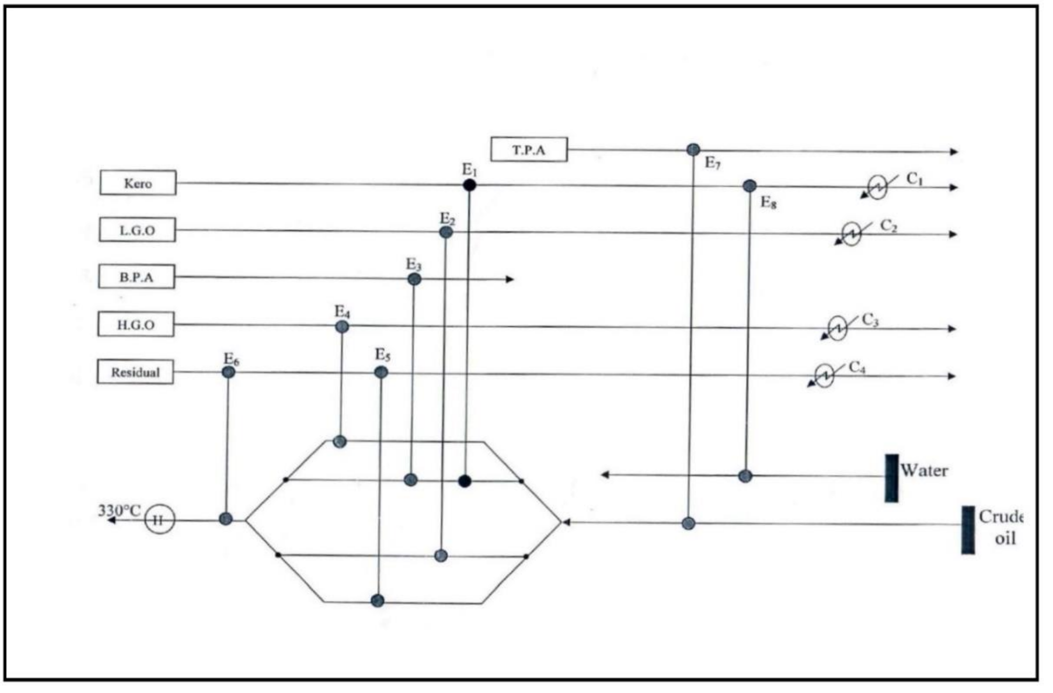

Figure 7. Final design

By coupling the design above the pinch and below the pinch a complete design of the network can be obtained as shown in Figure (7).

Table (3) represented the summary of the difference between the actual case (existing design) and the modified design of heat exchanger network and shown various parameters such as number of units heating and cooling utilities and total of heat exchanger area, etc. As it shown this table the heater inlet temperature was improved leading in energy saving by 17.3% in heating utility also cooling utility was reduced by 23.4% all of this was achieved by added one heat exchanger and reallocate of some of heat exchanger.

TABLE 3. Comparison between Existing and New HEN

No	Description	New design	Existing design
1	Total amount of heat exchanger (Kcal/hr)	41451856.58	37480729
2	Heating utility duty (Kcal/hr)	18551685.88	22563970

3	**Cooling utility duty (Kcal/hr)**	**9824874.12**	**12827533**
4	**number of heat exchanger**		
	Heat exchanger	**8**	**7**
	coolers	**4**	**5**
	Heater	**1**	**1**

Using pinch technology for analyzed the existing network as discussed previously the saving in energy can be achieved by applying this technique. It is to be noted that any saving in hot utility lead to equal saving in cooled utility.

4. Conclusion

The continuous application of pinch Technology is becoming more attractive In this section, the result of the case study as discussed earlier are presented and the proposed design for the crude unit is compared with existing design. The 10°C value of ΔT_{min} was found the best one that can be adopted as it gives the best value of heat exchangers network outlet temperature (241°C) which is the input of crude oil heater. The total amount of heat exchanger for the proposed design is 41451856.58 Kcal/hr, against the existing design was 37480729 Kcal/hr, the heating utility duty is 18551685.88 Kcal/hr and it is 22563970 Kcal/hr for the existing Hence, the saving in fuel cost is 216040.6 $/month, the proposed design allows reduction of 17.8% in terms of energy consumption as well as money. The heating recovery (heat exchanger duty) is increased in the new design by adding one heat exchanger to the network. From the results and discussions presented previously, the following conclusions can be drawn:

1. Pinch design method allows engineering to get a better design (modification) with better saving (benefits).

2. Utilities costs are the dominating costs in refineries network problem. 3. 17.8% fuel saving can be achieved if the optimal design reported here is adopted. Saving in order of money (Libyan Diners) can be achieved if the proposed design is applied.

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