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Design of Heat Exchanger Networks in Heat Integration of CDU and HVU using a Pinch Design Method

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Abstract : Energy is a critical issue was never stopped tobe discussed. The efforts of energy saving have always been conducted. Heat integration is one of the techniques used to reduce the energy requirements of processes with high energy consumption, especially in refinery plant. Heat integration can be conducted in a single unit or multiple units. In this paper we investigated the heat integration in the separation units of an oil refinery, i.e., a Crude Distillation Unit (CDU) and a High Vacuum Unit (HVU).

The result obtained that the simultaneous heat integration of CDU and HVU was better than that of sequential one. The heating duty of simultaneous heat integration (CDU and HVU) reduced to only 8 % of the heating duty of sequential heat integration. The best $\Delta Tmin$ value at 10 K both of sequential and simultaneous heat integration. The cooling duty obtained for the simultaneous heat integration was 0.011 MW.

In this paper, splitting of streams was applied in the simulation to facilitate heat exchange to keep the minimum heating and cooling duties.

Keywords : Heat Integration; Sequential; Simultaneous; Heat Exchanger Networks; Stream splitting.

1. Introduction

Energy costs in a chemical process are one of the largest contributors tothe operating costs of a plant. Hence,a number of ways have been proposed to reduce energy costs. Heat integration is one way to reduce energy requirements.The heat exchanger network (HEN) from process streams greatly affect heat integration. The first step in the design of HEN is to find the pinch temperature for both hot and cold streams to reach the requirement of minimum external utilities through the Problem Table Algorithm (PTA) / temperature interval method using a given minimum temperature difference , and later it can be optimized in targeting levels before developing a network structure. The purpose of this method is to obtain aheat exchanger network fora given minimum temperature difference (ΔTmin)with maximum heat recovery (MER), and the minimum number of heat exchangers. Determination of the optimum temperature difference (ΔTmin)will increase the amount of energy being exchanged. From hereit is expected that one can build aheat exchanger network with a minimum utility need.

On a plant that consists of several process units, heat integration can be conducted internally in each unit process itself or multiple units at once.Sequential heat integration is the configuration of heat exchanger networks conducted internally within the units independently in a process, while simultaneous heat integration is the configuration of heat exchanger networks conducted combining all units in a process.

In general, heat integration between multiple unitsis better than internallyintegration because there are more opportunitiesto exchange hot and cold streams. However, capital costs increase due to the need for longer piping configurations. A constraint may be that the two streamsare locatedfar away, leading to intolerably long pipe-lengths[1]. The first heat exchanger networks formultiple unit processes were proposed by Ahmad and Hui, (1991)[2]. The paper describedareas of integrity, which are regions typically defined on the basis of several requirements, such as operational flexibility (e.g., start-up, shut-down, control, and operational independence), safety (e.g., emergency shut-down, explosive materials, and hygiene) and plant layout (e.g., maintenance, access, and roads).A simple example in their paper showed that the recovery of heat was more efficient than the recovery and exchange of heat in separate steps.). Numerous heat integration techniques have been proposed[3,4,5,6].

Both sequential and simultaneous heat integration are intended to maximize heat recovery to reduce utility demand.To determine which process was more efficient, we conducted heat integration in a refinery crude oil plant with several different units. Chen etal., showed that the simultaneous approach was relatively easy to implement and achieved higher profits and lower operational costs. In a power plant example, a higher net efficiency was found through simultaneous heat integration than through the sequential heat integration [7].In this paper we have compared between sequential heat integration and simultaneous heat integration. In addition to the problem of heat integration, when the streams of a process are off-balance, the streams need to be split. In most cases, stream splitting was determined by trial and error. In this paper, the stream splitting was calculated.Two units of CDU and HVU are investigated in crude oil refinery plant.

Heat integration consists of one heat capacity flowrate of cold stream and a few hot streams. A plant with these streams has the potential to be heat integrated for energy savings, although it may need splitting. The efficiency of a process is defined by a minimal use of energy and is characterized by an optimum design of a heat exchanger network. The design of a heat exchanger network is an important unit operation that contributes to the efficiency and safety of many processes.

In this paper, sequential and simultaneous integration networks are presented to determine the heat-integration network with minimum energy consumption using pinch design methods (PDM)[8].Heat integration was performed for an oil refinery by coupling aCrude Distillation Unit(CDU) anda High Vacuum Unit(HVU). These unitstypically require the largest energy consumption in an oil refinery plant[9].

Heat integration was simultaneously performed in a single step that heat matched all streams.The design of the integration involved the pinch method and consisted of two stages: the identification of a target and the determination of a design.The target was energy savings and the design was a heat exchanger network.

Methods / Experimental

Computer Simulation

The first step in the simulation was to specify the composition of the crude oil in an assay and blending component. The next step was to design a base case CDU and HVU scenarios using Aspen plus 7.3[10]is shown in Figure 1. The Pinch Design Method (PDM) was used to obtain heat matched to create configuration of heat exchanger networks. Various ΔT min in heat matched are set at 10 K, 15 K, 20 K, 25 K, 30 K, 35 K and 40 K. The next procedure was creating a problem table, and the cascade diagram to obtain pinch temperature, minimum hot and cold utilities.

The following assumptions were made for the formation of a countercurrent and shell and tube HENs: constant heat capacitiesand no phase changes, respectively.

Case Study 1sequential heat integration for CDU

The Crude Distillation Unit consisted of a preflash column and a pipe still,as shown in Figure 1[11].Crude oil (Mixcrude- stream no. 7)at a flow rateof 564.8 ton/h from a desalting process was heated from 300.15 K to 499.82 K, sent through a furnaceand fed to the preflash column. The preflash column constituted 10 theoretical stages and operated at 308.2 kPa. The preflash column produced lightenednaphthathat was removed as a top product using a partial condenser.

Naptha (stream no.1) was cooled from 349.82 K to 313.15 K using a cooler. The bottom product of the preflash column was withdrawn at a flowrate of 470.7ton/h, sent to a processing furnace and further vaporizedto approximately 3 % volume, and sent to a pipe still. The furnace operating temperature and pressure were 503.82 K and 325 kPa, respectively. The pipestill constituted 25 theoretical stages and consisted of a condenser, three coupled side strippers and two pumpsin a circuit[12]. The first side stripper removed Kerosene- stream no.3, the second side stripper was an LGO (Light Gas Oil- stream no.4), and the final side stripper was an HGO(Heavy Gas Oil- stream no.5). All hot streams were cooled to 313.15 K using coolers. The top product of the pipe stillwasheavynaphtha (HNaptha- stream no. 2), which cooled to 313.15 K. The bottom product Res-CDU (residue of CDU- stream no. 6)was removed at a flow rateof 218.3ton/h.

The Res-CDU was cooled to 313.15 K, sent to storage, and subjected to a High Vacuum Unit (HVU). The processes in Crude Distillation Unit are presented in Figure 1.

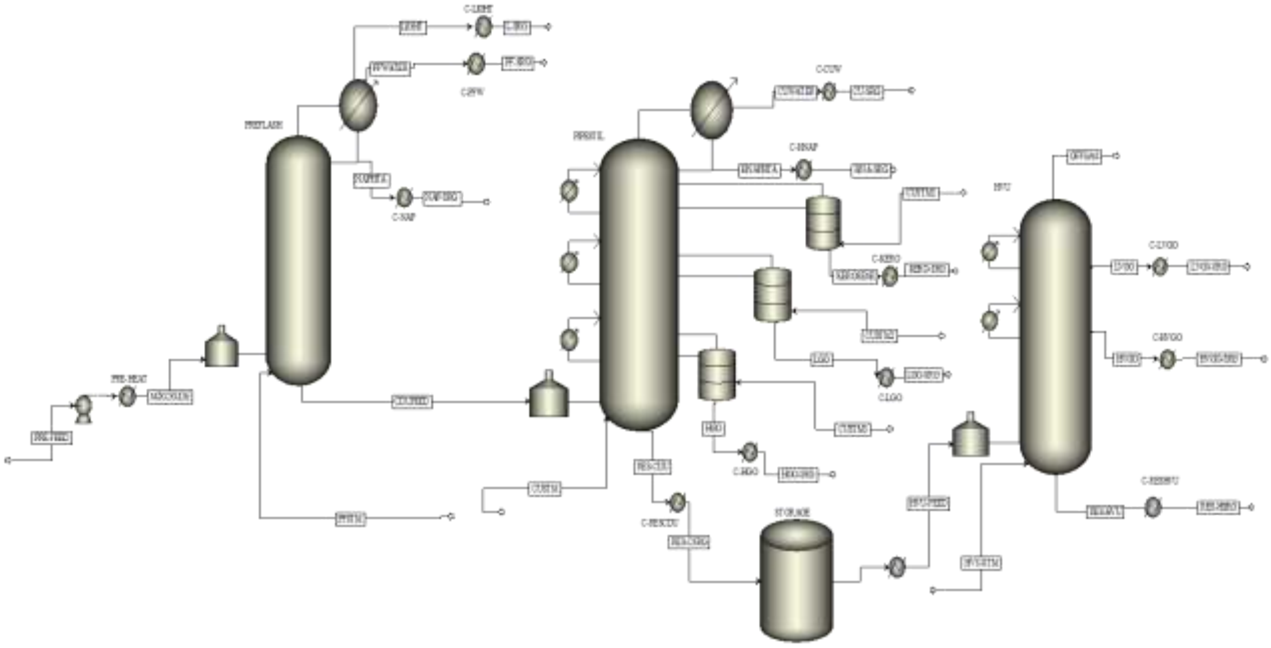


Figure 1. Process Flowsheet: The Crude Distillation Unit and High Vacuum Unit

The CDU process was designed with 1 (one)preheater with a heat load (QH) of 76.5 MW and 6 (six) coolers with a total heat load (QC) of76.7 MW.

Case study 2 sequential heat integration for HVU

A High Vacuum Unit separates reduced crude from a pipe still into Off-gas, Light Vacuum Gas Oil (LVGO- stream no. 8), Heavy Vacuum Gas Oil (HVGO- stream no.9), and Residual Vacuum Oil (Res-HVU- stream no. 10). The bottom product of the CDU (Res-CDU) was introduced at a flow rate of 218.3 ton/h from storage at 313.15 K and was heated to 699.82 K before entering the HVU. The HVU comprised 10 theoretical stages and operated at 202.65 kPa. The LVGO, HVGO and Res-HVU products were cooled using a cooler to 313.15 and then flowed into storage. A flowsheet of the High Vacuum Unit (HVU) is shown in Figure 1.[13]

A base casesimulation showed that the HVU feed (stream no.11) was heated from 313.15 K to 699.82 K with a heating duty (QH) of 59.7 MW; subsequently, 3 coolers were required to cool the products with total cooling duties (QC) of 40 MW.

Case Study 3 – Simultaneous Heat Integration for CDU and HVU

In the studied operating units, more opportunities for heat exchange were available if the heatintegrations were simultaneously performed. In this case, all of streams in the processes (CDU and HVU) to heat exchanged and considered in a processes unit.The total number ofstreamsto be exchangedwas 10,consisting of 8 hot streamsandtwocoldstreamsof the Mixcrudeand. Heat matches were divided into the streams that required matches aboveandbelow thepinchpoint. In the cases for matches above the pinch point,there were fewer coldstreamsthanhotstreams, i.e., the Mixcrudecold streamwould have to be split into 8streamsand the HVU-Feed cold stream would have to be split into 2streams to meet the feasibility criteria, for a total of 10 coldstreams . The hot streamRes-CDU was split intotwostreams tofulfil the energyneeds ofthe existingcoldstreams. Oncethe integrationwas determined above the pinch point, 12HEsand5heaters were required.

Number of Units

Before the process streams exchanged, the target number of units required is equal to number of streams minus one. The target for the minimum number of units (H, HE and C) is given by equation:

$$N_{units} = S - 1 \qquad (1)$$

The correct cost data is essential for determined profitable unit processes after heat integration. In this paper, High Pressure (HP) steam was used to heating utilities was supplied at temperature 723.15 K and returned at 673.15 K, while the cooling water 298.15 K at inlet and 303,15 K at outlet temperature.

Result and Discussion

Sequential heat integration of CDU

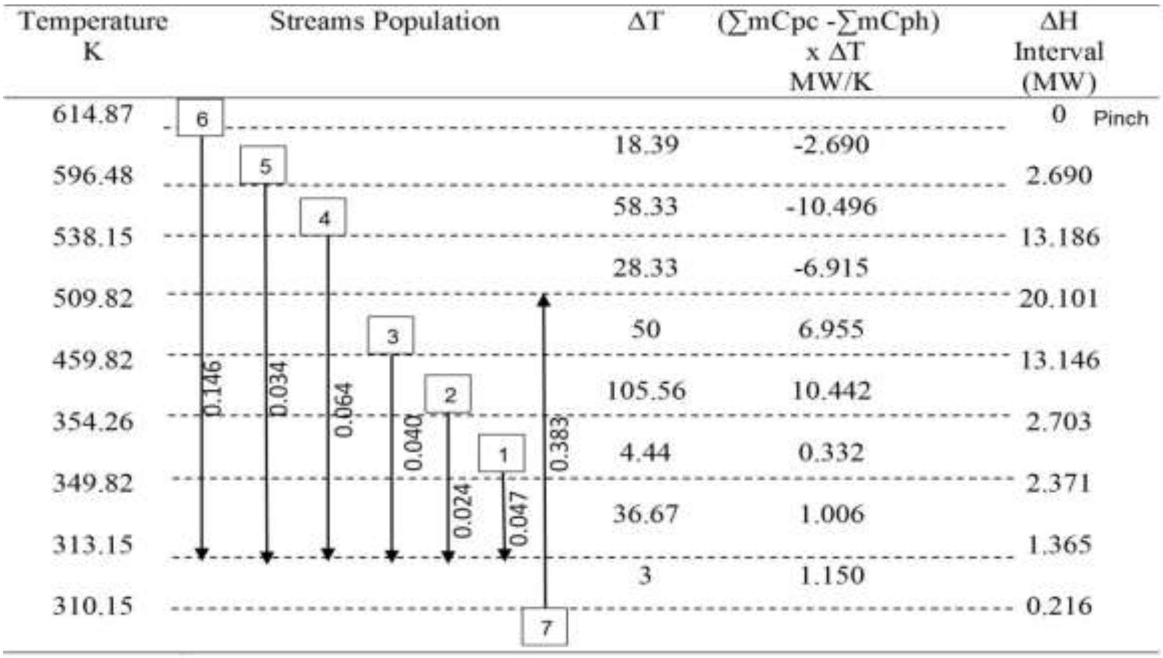


Figure 2a. Problem table: Temperature interval heat balances for CDU at ΔTmin = 10 K

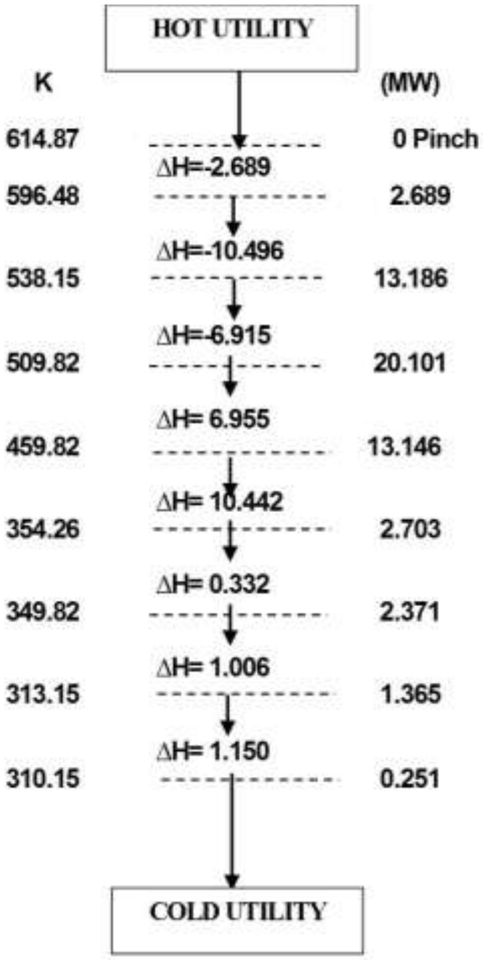


Figure 2b. Problem table: cascade diagram for CDU at ΔTmin = 10 K

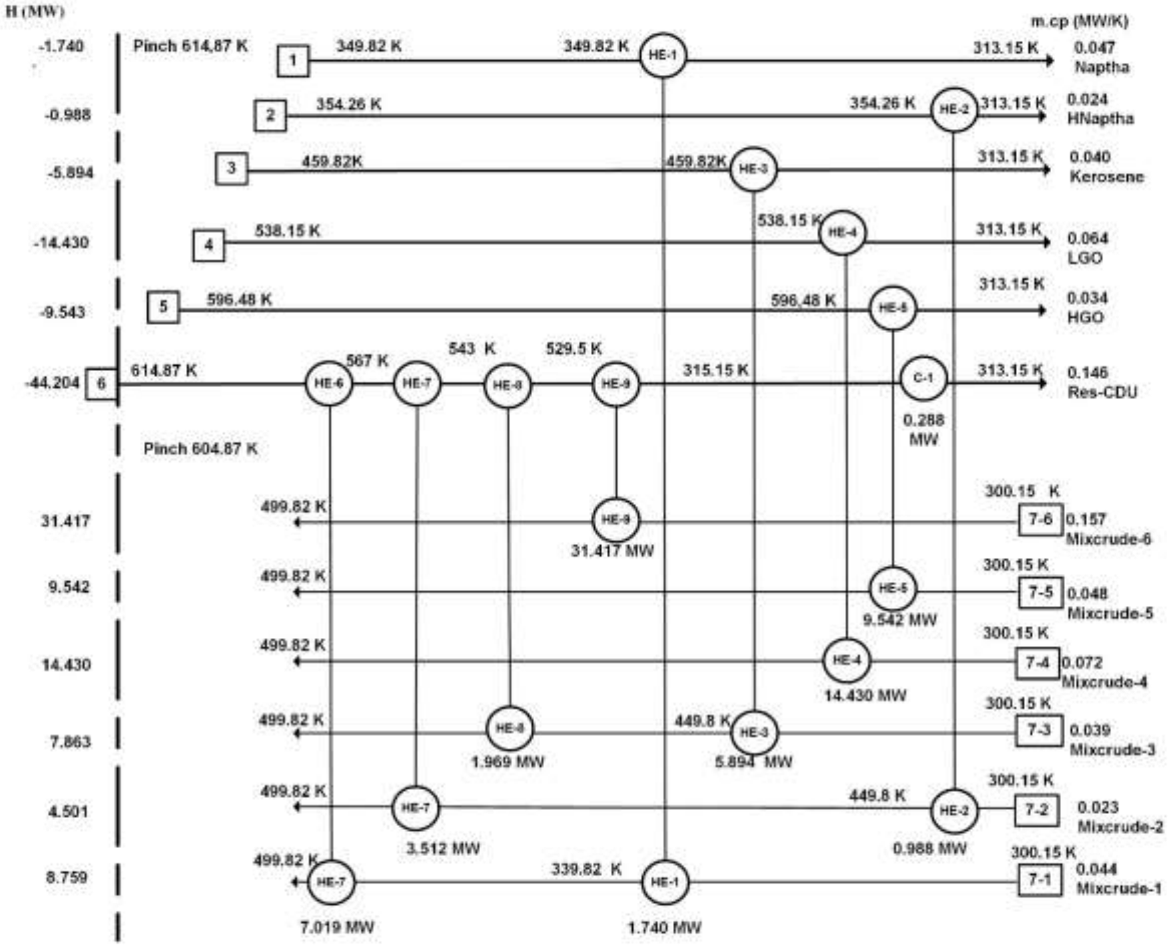


Figure 3. Grid diagram heat exchanger network configuration for sequential heat Integration of CDU at ΔTmin = 10 K

The problem table and cascade diagram for all of stream on CDU described at Figures2a and 2b.Figure 2a shows that all of streams are plotted at the same curve, where the upward line represents all of cold streams and downwardline represents all of the hot streams. Pinch point for the hot stream at 614.15 K and 604.15 K cold stream (ΔTmin = 10 K). Hot utility is 0MW, cold utility requirements is 0.288 MW, while the hot utility is not needed because the hot stream is sufficient to heat the cold stream by means of exchanged heat through a heat exchanger. Therefore, Figure 3 can also indicate that is CDU has potential to reduce energy consumption by heat integration. In this paper the CDU which consisted of 6 hot streams (Naptha /stream-1, HNaptha/stream-2, Kerosene/stream-3, LGO/stream-4, HGO/stream-5, Res-CDU/ stream-6) and only 1 cold stream (Mixcrude/stream-7).Therefore, heat integration cannot be directly achieved. The reason is the temperature differences and possibility to give or receive heat, the cold stream must be split to pair with the hot streams in such a way that a minimum temperature difference (ΔTmin) can be achieved. So if cold stream possesses very high heat capacity, the change temperature would be small and maybe the heating with other stream would be possible. The following steps were used to determine the proper splitting ratio.

1. Cold stream splitting was determined based on achieving targetedheat matches with the lowest temperatures.

2. Ifthe temperature ofa hot streamwas lowerthan that ofa split cold stream, then the targettemperature ofthe heat exchange was $TT_{cold} = TS_{hot} - \Delta Tmin$.

3. Calculate mCp cold stream to be split:

$$mCp = \frac{\Delta H_{cold}}{(TT-TS)_{cold}}, \text{ where } \Delta H_{cold} = \Delta H_{hot}. \quad (2)$$

4. The cold stream was split based on the mCp calculation. The split cold streamswere heat matched with the various hot streams. All hot streams were cooled to 313.15 K, while the cold streamswere heated to 499.82 K, i.e., below the highest temperature of all hot streams.Step 1 to step 4 were repeated until all hot and cold streams were heat matched.

The heat capacity flowrate of the split cold streams at ΔTmin = 10 Kare shown in Table 1. The cold stream was split into 6 cold streams and paired with the hot streams.

Table 1: The heat capacity flow rate of the cold streams after splitting at ΔT = 10 K

No.	**Cold Stream**	**TS**	**TT**	**mCp**	**Enthalpy (ΔH=Q)**
		(K)	**(K)**	**MW/K**	**kW**
7-1	Mixcrude-1	300.15	499.82	0.044	8.759
7-2	Mixcrude-2	300.15	499.82	0.023	4.501
7-3	Mixcrude-3	300.15	499.82	0.039	7.863
7-4	Mixcrude-4	300.15	499.82	0.072	14.430
7-5	Mixcrude-5	300.15	499.82	0.048	9.542
7-6	Mixcrude-6	300.15	499.82	0.157	31.417

Based on the new heat capacity flowrate of the cold stream, we can design a heat exchanger network configuration for Pinch analysis, as shown in Figure 2a-2b.. The pinch temperature for the hot stream was 614.82 K, and the temperature for the cold stream was 604.82 K. Figure 3shows Grid diagram heat exchanger network configuration for sequential heat Integration of CDU at ΔTmin = 10 K.

The configuration HEN consistedof 9 heat exchangers and1cooler. Figure 3 shows that the heat load to the cold stream can be provided by the hot streams so that noexternal heat is required. However, the hot streams required onecooler with a total heat load of QC = 0.288 MW. Figure 2 and 3 described heat matched between hot stream and cold stream. Hot stream 1 is heat matched with mixcrude 1; hot stream 2 with mixcrude 2; hot stream 3 with mixcrude 3; hot stream 4 with mixcrude 4; hot stream 5 with mxcrude 5 but hot stream 6 heat matched with many mixcrude streams that have not reached the temperature target (mixcrude 1,2 and 3).

Sequential heat Integration of HVU

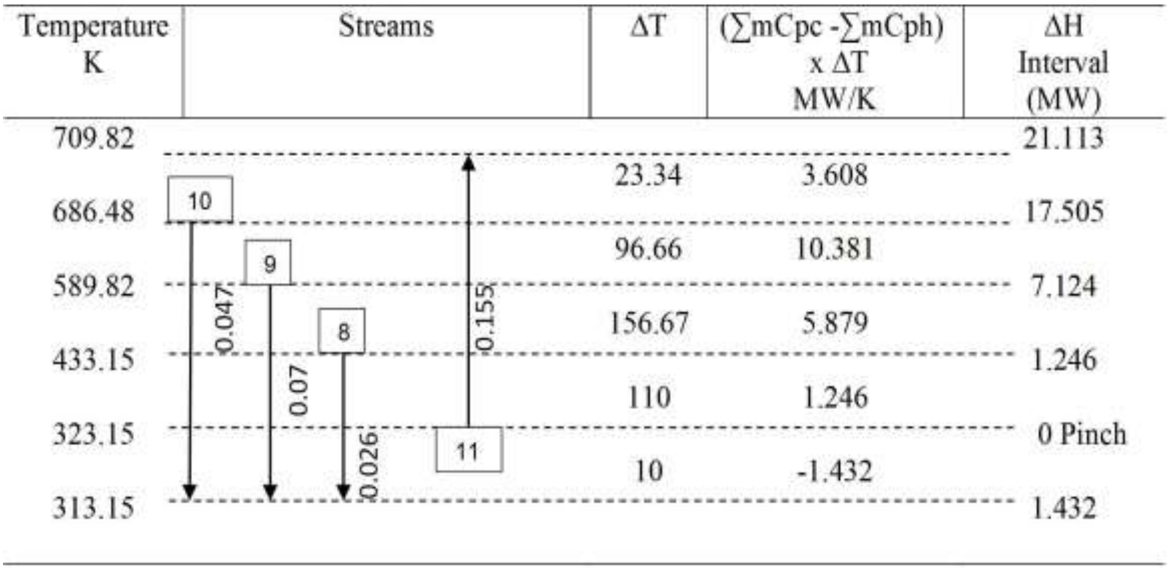
A base case simulation showed that the HVU feed was heated from 313.15 K to 699.82 K with a heating duty (QH) of 59.8MW; subsequently, 3 coolers were required to cool the products with total cooling duties (QC) of 40 MW. The streams involved in the process are presented previously in Figure 1.From Figure1, it can be seen that the process streams consisted of 3 hot streams,that is hot stream-8 LVGO, hot stream-9 HVGO, hot stream-10 Res-HVU and only 1 cold stream-11 HVU-Feed.Heatintegrationcan only beperformedbysplittingthe cold stream into 3coldstreams. Therefore, we split the cold stream into 3 streams. The heat capacity flowrate of the cold streams are presented in Table 2 with cold stream-11-1 is HVU-Feed1, cold stream11- 2 is HVU-Feed2 and the last cold stream-11-3 is HVU-Feed3.

Table 2: Heat capacity flow rate of split cold streams for HVU-Feed at ΔTmin= 10 K

No.	**Cold Stream**	**TS (K)**	**TK (K)**	**mCp, (MW/K)**	**Enthalpy (ΔH=Q) (MW)**
11-1	HVU-Feed 1	313.15	699.82	0.027	10.233
11-2	HVU-Feed 2	313.15	699.82	0.070	27.119
11-3	HVU-Feed 3	313.15	699.82	0.058	22.423

The problem table and cascade diagramfor all of stream on HVU presented in Figures 4a and 4b. Figure 4a shows that all of streams are plotted at the same curve, where the downward line represents all of cold streams and upwardline represents all of the hot streams. Pinch point for the hot stream at 323.15 K and 313.15

K cold stream (ΔTmin = 10 K). The cold utility requirement is 1.43 MW and hot utility requirements is 21.1 MW. Hence, hot and cold utilities requirementis reduced.



Temperature K	Streams	ΔT	(∑mCpc -∑mCph) x ΔT MW/K	ΔH Interval (MW)
709.82				21.113
		23.34	3.608	
686.48				17.505
		96.66	10.381	
589.82				7.124
		156.67	5.879	
433.15				1.246
		110	1.246	
323.15				0 Pinch
		10	-1.432	
313.15				1.432

Figure 4a. Problem table: Temperature interval heat balances for HVU ΔTmin = 10 K

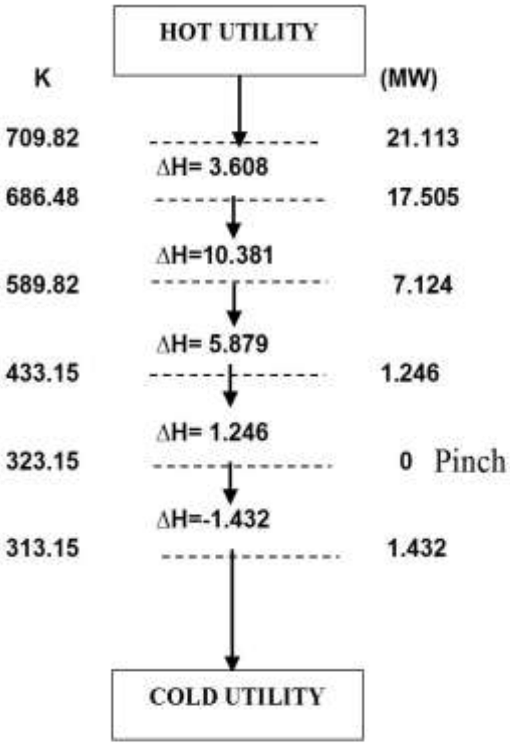


Figure 4b. Problem table: cascade diagram for HVU at ΔTmin = 10 K

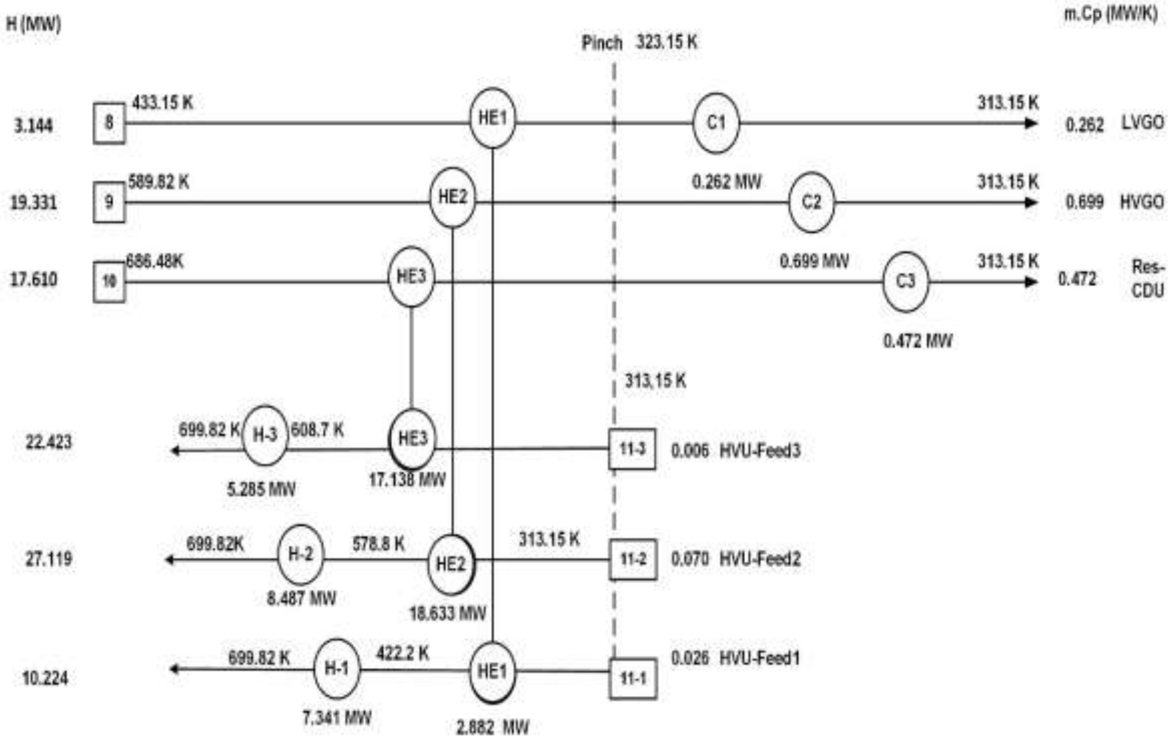


Figure 5. Grid diagram heat exchanger network configuration for sequential heat integration of HVU at ΔTmin = 10 K

After splitting the cold stream, heat matches were determined between cold stream and hot stream. Figure 5 shows the configuration of the Heat Exchanger Networks for sequential heatintegration of the HVU. The pinch point for the hot stream was 323.15 K and for the cold stream was 313.15 K. The configurationconsistedof3HEswith amaximumtotalheat loadrecovery of 37 MW, 3heaterswitha totalheatload (QH) of 21.1 MWand3coolers with a total heat load (QC) of 1.43 MW.

Based on these configurations, the total heating and cooling load between two unit processes can be estimated as follows:

$$\sum QC \text{ Sequential} = \sum QC \text{ CDU} + \sum QC \text{ HVU} \qquad (3)$$

$$\sum QH \text{ Sequential} = \sum QH \text{ CDU} + \sum QH \text{ HVU} \qquad (4)$$

Table 3 shows the heating and cooling duty for sequential heat integration, which is found The total number of units equal to 19 units. According to eq. 1, the number of units is 19 units. Indeed, the number of units in the CDU less than that obtained when using eq.1, but to the number of units HVU slightly larger than that obtained using the eq.1. Therefore, sequential heat integration for HVU is not profitable.

Table 3: Heating and cooling duties of CDU and HVU forsequential heat integration

ΔTmin, (K)	Total Heating Duty CDU+HVU ∑ QH, MW	Total Cooling Duty CDU+HVU ∑ QH, MW	Number of Units CDU	Number of Units HVU
10	21.11	1.76	10	9

Simultaneous Heat Integration of CDU and HVU

The problem solving of heat integration simultaneous was carried out into two area pinch, above pinch and below pinch. After preparing the heat matches above the pinch point (323.15 K for hot streams and 313.15 K for cold streams), heat matches were determined for streams below the pinch point. To fulfil the feasibility criteria, the cold stream split was not the same as that used for the above pinch point scenario. Here for above pinch, the Mixcrude cold stream was split into 8 streams , and that of the HVU-Feed was split into 2 streams represents in Table 4. The heat capasity flowrate of the hot streams remained unchanged, but the hot stream-6 was split into 2 streams, which are shown in Table 4 for above pinch.The streamsinvolvedin the processare presentedin Table4,5,6 and7, whereas configurations of heat exchanger in grid diagram are shown in Figure 6 for above pinch and Figure 7 for below pinch.

Table 4: Heat capacity flowrate of split cold streams CDU and HVU simultaneous heat integration at above pinch point (ΔTmin = 10 K)

No.	Cold Stream	TS (K)	TT (K)	mCp, MW/K	Enthalpy (ΔH), MW
7-1	Mixcrude-1	313.15	499.82	0.047	8.859
7-2	Mixcrude-2	313.15	499.82	0.024	4.488
7-3	Mixcrude-3	313.15	499.82	0.026	4.893
7-4	Mixcrude-4	313.15	499.82	0.040	7.504
7-5	Mixcrude-5	313.15	499.82	0.074	13.789
7-6	Mixcrude-6	313.15	499.82	0.070	13.043
7-7	Mixcrude-7	313.15	499.82	0.034	6.289
7-8	Mixcrude-8	313.15	499.82	0.068	12.664
11-1	HVU-Feed-1	313.15	699.82	0.047	18.290
11-2	HVU-Feed-2	313.15	699.82	0.107	41.476

Table 5: Composition of split hot streams Res-CDU at above pinch point(ΔTmin = 10 K)

No	Hot Stream	TS (K)	TT (K)	mCP, MW/K	Enthalpy (ΔH) MW
6-1	Res-CDU1	614.87	323.15	0.044	-12.696
6-2	Res-CDU2	614.87	323.15	0.103	-30.043

Table 6: Heat capacity flowrate of split cold streams CDU and HVU simultaneous heat integration at below pinch point.

No.	Cold Stream	TS	TK	m.cp	Enthalpy
		(K)	(K)	(MW/K)	(ΔH),MW
7-1	Mixcrude-1	300.15	313.15	0.031	0.402
7-2	Mixcrude-2	300.15	313.15	0.049	0.641
7-3	Mixcrude-3	300.15	313.15	0.026	0.337
7-4	Mixcrude-4	300.15	313.15	0.037	0.475
7-5	Mixcrude-5	300.15	313.15	0.018	0.240
7-6	Mixcrude-6	300.15	313.15	0.020	0.262
7-7	Mixcrude-7	300.15	313.15	0.054	0.698
7-8	Mixcrude-8	300.15	313.15	0.036	0.472
7-9	Mixcrude-9	300.15	313.15	0.033	0.429
7-10	Mixcrude-10	300.15	313.15	0.079	1.025

Table 7: Heat capacity flowrate of split hot streams Res-CDU at bellow Pinch Point(ΔTmin = 10 K)

No	Hot Stream	TS (K)	TT (K)	mCP, MW/K	Enthalpy (ΔH) MW
1	Res-CDU1	323.15	313.15	0.044	0.435
2	Res-CDU2	323.15	313.15	0.107	1.030

Figure 6 shows that configuration of heat exchanger network for simultaneous heat integration at above pinch have 14 units' heat exchangers and 4 heaters (total 18 units), whereas the number of stream equal to 20. According to eq.1, the number of unit equal to 19. So, the simultaneous has less units than estimated from the eq. 1.

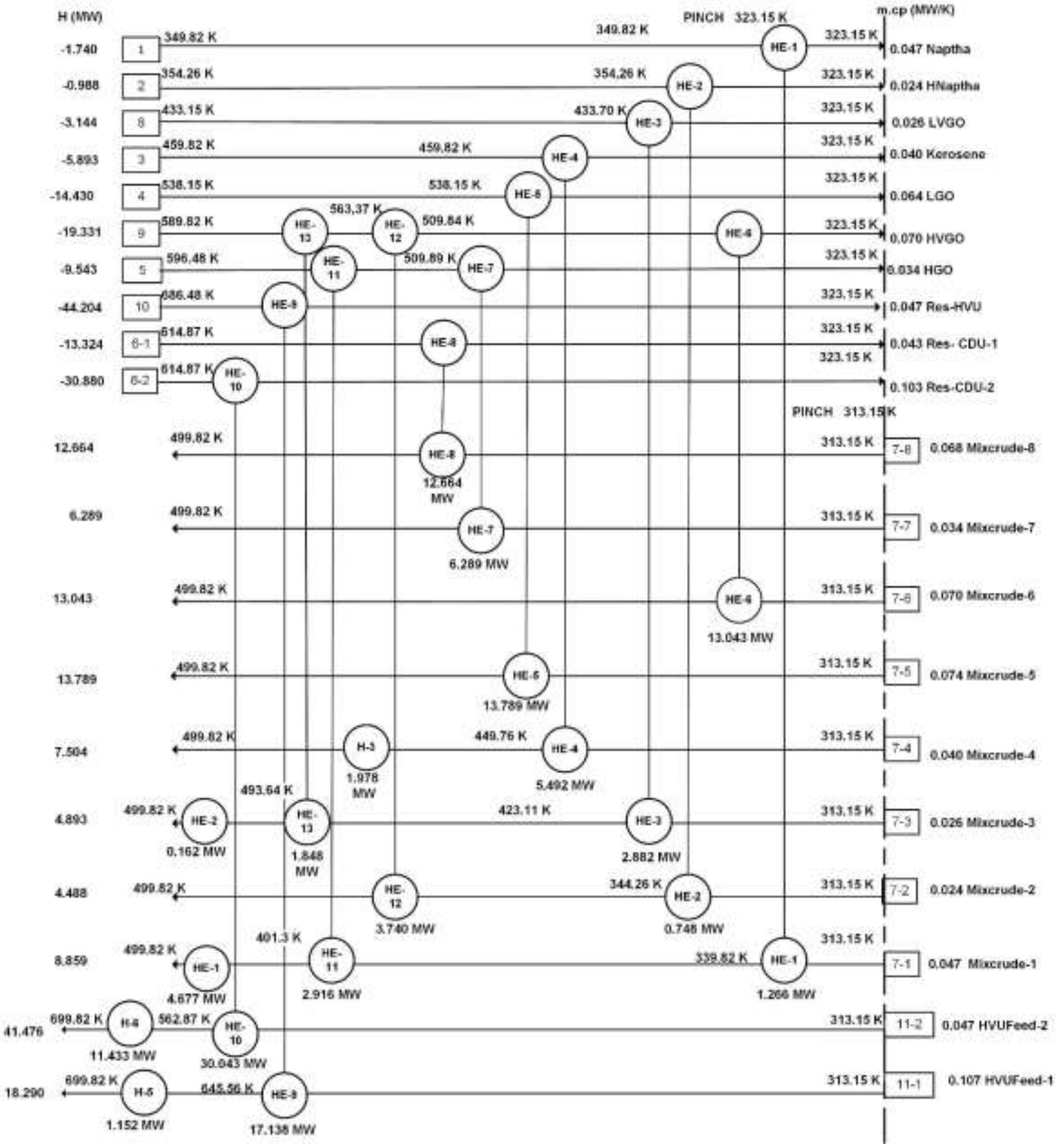


Figure. 6. Grid diagram heat exchanger network configuration for simultaneous heat integration of CDU and HVU at Tmin = 10 K, above pinch

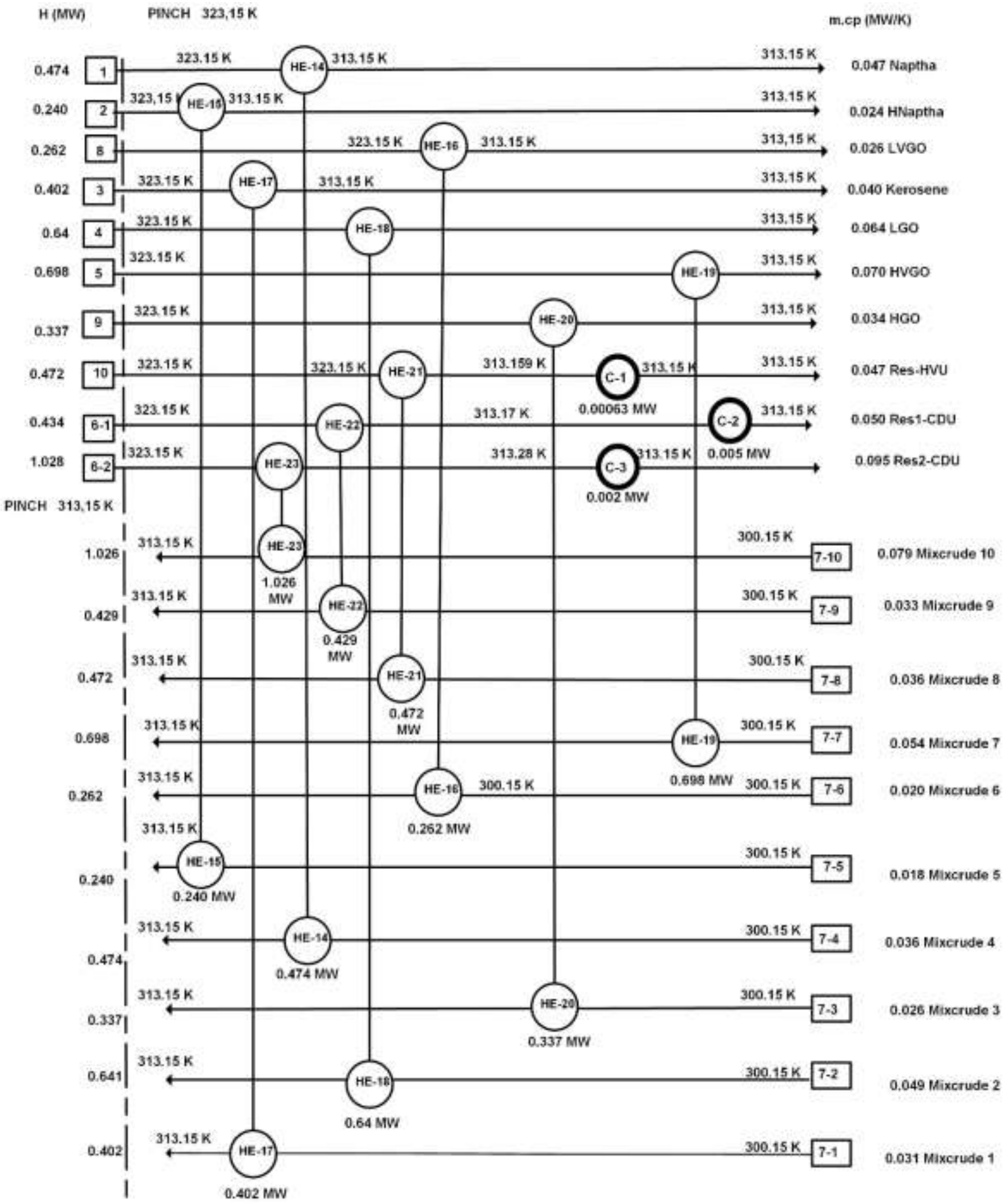


Figure 7. Grid diagram heat exchanger network configuration for simultaneous heat integration of CDU and HVU at Tmin = 10 K, below pinch

The problem solving at below pinch are shown in Figure 7. The composition of cold stream and hot stream were changed. The cold stream-7 was split into 10 streams, and the hot stream-6 was split into 2 streams. The heat capacity flowrateafter stream split represent in Table 6 and Table 7

Figure 7 shown configuration heat exchanger network for simulation heat integration at below pinch. The number of units were 13 units consist of 10 heat exchangers and 3 coolers, whereas the hot streams and cold streams amounted to 20 streams. According to the eq.1, the number of units calculated was 19. So, the number of unit is less than estimated.

Tables 8 and 9 show heating duty and cooling duty for sequential and simultaneous heat integration at ΔTmin 10 K. From Tables 8 and 9a comparison between simultaneous and sequential heat integration shows that energy savings obtained is equal to 8 %. Accordingly, simultaneous heat integration is better than sequential heat integration for heat integration between CDU and HVU in this paper. Despite the number of unitsin simultaneous heat integration is nearly 2 times more than sequential heat integration, but the objective of this work is the energy target, which is more dominant in cost. Energy cost is a continuously operating cost charged during the plant was running, while the number of units is the capitalcost whichis charged only when the plant is first established. Thus lowering energy costs will greatly increase the efficiency of the plant.

Table 8: Heating duty of CDU and HVU for sequential andsimultaneous heat integrationat ΔTmin = 10 K.

Sequential MW	Simultaneous MW	Saving MW	Saving %	Number of Unit	
				Seq.	Simult.
21.11	19.40	1.71	8	19	34

Table 9: Cooling duty of CDU and HVU for sequential andsimultaneous heat integration at ΔTmin = 10 K.

Sequential MW	Simultaneous MW	Saving MW	% Saving
1.647	0.11	1.636	99.3

Table 10: Heating duty of CDU and HVU after sequential and simultaneous heat integration at various ΔT min

ΔTmin, K	Sequential MW	Simultaneous MW	Saving MW	% Saving
10	21.11	19.40	1.71	8.00
15	22.33	21.90	0.426	4.66
20	24.82	24.40	0.425	1.95
25	27.32	26.90	0.424	1.90
30	29.81	29.39	0.423	1.70
35	32.31	31.39	0.357	1.11
40	34.80	34.22	0.578	1.66

Table 11: Cooling duty of CDU and HVU after sequential and simultaneous heat integration at various ΔT min

ΔTmin, K	Sequential MW	Simultaneous MW	Saving MW	% Saving
10	1.647	0.011	1.636	99.3
15	2.861	2.508	0.353	12.3
20	5.354	5.003	0.352	6.6
25	7.850	7.500	0.350	4.5
30	10.345	9.996	0.349	3.4
35	12.840	12.484	0.356	2.8
40	15.335	14.830	0.505	3.3

For various ΔTmin of 15K,20 K, 25 K, 30 K, 35 K and 40 K, The heating duty and cooling duty are shown in Tables 10 and 11.

From the presented data, the heat duties can be expressed as:

$$Q_{recovery} = \sum_{i=j}^{j} Q_{hi\ above\ pinch} + \sum_{i=j}^{j} Q_{ci\ below\ pinch} \qquad (5)$$

$$Q_{\text{heating duty}} = \sum_{i=k}^{k} Q_{ci} - Q_{\text{recovery}} \quad (6)$$

$$Q_{\text{cooling duty}} = \sum_{i=k}^{k} Q_{hi} - Q_{\text{recovery}} \quad (7)$$

where

$$Q_{\text{h above pinch}} = \text{mCp}\ (TP_h - TS_h) \quad (8)$$

$$Q_{\text{h below pinch}} = \text{mCp}\ (TT_h - TP_h) \quad (9)$$

$$Q_{\text{c below pinch}} = \text{mCp}\ (TP_c - TS_c) \quad (10)$$

Tables 9 and 10 also show that the deviation of the heating or cooling duty with ΔTmin deviation 5 K obtained 2.496 MW, so that value can be predicted as follows;

$$Q'_{\text{heating duty}} = Q'_{\text{cooling duty}} = \sum mCp_h \text{ x a} \quad (11)$$

where

$Q'_{\text{heating duty}} = Q'_{\text{cooling duty}}$isdeviation of heating or cooling duty from another heat integration on various ΔTmin. The formulas above (Eq. 15) cannot be applied if the one or more hot streams are not in the same pinch point area. In this case, from tables 10 and 11 show the deviation heating duty or cooling duty at ΔTmin 10 K until 35 K is 2.496 MW, but in contrast to previous on ΔTmin 35 K to 40 K is 2.259 MW. This is due on T 40 K, one of the hot stream i.e. naphtha is below the pinch point therefore eq.9 cannot be applied.

The heating duty (QH) at ΔTmin = 10 K after heat integration was negligible. This indicated that the pre-heaterfor heating the CDU feed was not necessary because the heat recovery of the heat matches between the hot and cold streams had the same heating duty the CDU feed required. After heat integration, the heat recovered was 76.5 MW. The heat load of the preheater of the CDU feed was 76.5 MW. Therefore, theheating duty of the preheater can be fulfilled by heat integration.

Conclusions

The bestΔTmin wasfound to be 10K for both sequential and simultaneous heat integration. The lower the temperature difference, the greater the surface area of the heat exchanger, and consequently, the greater the capital cost. However,the heat exchanger cost was negligible when compared with the energy costs.

Energy savingsusingsimultaneousheatintegrationwas greater thanthat of sequentialheat integration because the temperature level in the sequential heat integration cannotimprove the number of heat exchange between hotstreams and cold streams.The results are consistent with the goal of heat integration between processes to make the plants more economical and profitable. Processes operating at one location can be integrated. If the heat energy from a hot stream can be recovered, the overall plant energy consumption level can be lowered. The heat transfer between the processes can reduce energy usage.However, sequential heat integration is an available option if all streams (hot streams and cold streams) are situated above the pinch point and if the total mCp of the cold streams >the total mCp of the hot streams, and vice versa for the simultaneous technique.

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Nomenclatures

Seq.	Sequential
Simul.	Simultaneous
ΔT	Temperature difference, K
a	ΔTmin difference , K
C	Cooler
H	Heater
HE	Heat Exchanger
MA	Mixcrude Above pinch temperature
MB	Mixcrude Bellow pinch temperature
mCp	Mass flow rate capacity, MW/K
QC	Heat load for cooling,MW
QH	Heat load for heating, MW
QR	Heat load for recovery, MW
TP	Pinch temperature, K
TS	SupplyTemperature , K
TT	Target Tempearture, K
Subscripts	
c	cold stream
h	hot stream
j	hot stream number jth =1,2...n
k	cold stream number kth = 1,2,..n

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