

Application of Pinch Technology for Heat Integration in Crude Distillation Process (Case Study of Old Port Harcourt Refinery)

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Abstract

Crude distillation processes generate significant quantities of excess heat that are often wasted due to inefficient heat exchanger networks (HENs) and outdated process configurations. In response to escalating energy costs and stringent environmental policies, the adoption of systematic energy integration techniques such as pinch technology has become increasingly essential. This study applies pinch technology to a crude distillation process with the aim of minimizing external utility consumption and enhancing energy efficiency through effective heat integration. The objectives include assessing the existing heat exchanger networks, identifying the pinch point, determining the maximum energy recovery potential, and redesigning the network to achieve optimal thermal integration. An evaluation of the existing Heat Exchanger Network (HEN) within the Crude Distillation Unit (CDU) of the Port Harcourt Refinery was conducted as a case study to identify energy inefficiencies and provide insights for an optimized network redesign. By applying the principles of Pinch Analysis, this study systematically employed a series of analytical steps to identify key thermal constraints within the crude distillation process. The method began with temperature shifting, which incorporates the minimum approach temperature of 15°C between the hot and cold streams to account for practical heat transfer limitations. This was followed by interval analysis, where the shifted temperatures were arranged in descending order to define distinct temperature intervals and facilitate the calculation of heat surpluses and deficits across each range. Through this systematic approach, the pinch temperature was determined to be 147.5 °C, signifying the critical temperature point beyond which no additional heat recovery is feasible without violating process constraints. The Grand Composite Curve (GCC) analysis revealed a maximum recoverable heat of 419.52 kW, indicating significant potential for internal energy recovery. A sensitivity analysis was performed using a developed MATLAB program to investigate the influence of the minimum approach temperature (ΔT_{\min}) on the shape of the composite curves and interaction of the hot and cold composite curves. It was observed that as ΔT_{\min} decreases from 25 to 10 °C, the hot and cold composite curves moved closer, with significant overlap observed. This overlap indicates higher potential for heat recovery and reduced external utility requirements. Furthermore, the redesigned HEN, based on an assumed overall heat transfer coefficient of 1 kW/m²°C, required an estimated total heat exchanger area of 24.40 m².

Keywords: Pinch Technology, Heat Integration, CDU, Matlab Simulation, MER, Energy Efficiency.

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I. INTRODUCTION

The crude distillation unit (CDU) serves as the primary processing unit in petroleum refineries, where crude oil is separated into different fractions based on their boiling point ranges. These fractions include light gases, naphtha, kerosene, diesel, gas oil, and atmospheric residue, which are subsequently processed in downstream refining units. The separation process relies on thermal energy input, making CDU one of the most energy-intensive units in refinery operations (Gary, Handwerk, & Kaiser, 2007). The crude distillation unit (CDU) is the most energy-intensive section of a refinery, accounting for up to 40% of total fuel consumption (Jenkins & Smith, 2019). In this unit, crude oil is preheated in a train of heat exchangers before entering the furnace and distillation column. However, conventional heat exchanger networks (HENs) are often inefficient, leading to high energy consumption and operating costs. The CDU's energy consumption arises primarily from heating the crude feed to temperatures typically between 340–370 °C before it enters the atmospheric distillation column. This heating is achieved through a combination of a preheat train, which recovers heat from hot product streams, and a fired heater or furnace, which supplies the additional heat required to reach the target temperature. On average, the CDU accounts for about 30–40% of the total energy consumed in a refinery, underscoring its significance in overall refinery energy management (Jassim & Altaie, 2020).

Heat exchanger networks (HENs) form an integral part of the CDU, as they enable heat recovery by transferring energy from hot product streams to the incoming cold crude feed. This process reduces the fuel requirement of the furnace, thereby lowering operating costs and minimizing environmental impacts. However, inefficiencies in the design or operation of HENs often lead to suboptimal heat recovery, resulting in excessive utility consumption. Studies have shown that poor heat integration can cause furnace duties to increase by 15–20% beyond optimal levels (Smith, 2016).

Pinch technology provides a structured framework for reducing heat consumption in the CDU by analyzing temperature and enthalpy profiles of process streams to identify energy recovery potential. Through this approach, refiners can minimize hot utility requirements (fuel for furnaces) and cold utility needs (cooling water or air coolers). Research has demonstrated that applying pinch analysis to CDUs can reduce energy consumption by 10–25%, depending on the degree of inefficiencies in the original heat exchanger network (Klemeš, Varbanov, & Walmsley, 2018).

Crude oil refining is the cornerstone of the petroleum industry, serving as the foundation for converting naturally occurring hydrocarbons into usable fuels, chemicals, and feedstocks. The refining process involves a series of physical and chemical operations designed to separate and convert crude oil into valuable fractions such as gasoline, diesel, jet fuel, kerosene, liquefied petroleum gas (LPG), and heavier residues (Gary *et al.*, 2007). Among these operations, crude distillation is the primary and most significant step, as it provides the initial separation of crude oil into components based on their boiling point ranges. Understanding crude oil refining and, more specifically, the crude distillation process is crucial because it determines not only the yield distribution of products but also the energy efficiency and environmental performance of refineries.

Crude oil is a complex mixture of hydrocarbons, containing paraffins, naphthenes, aromatics, and varying amounts of heteroatoms such as sulfur, nitrogen, oxygen, and trace metals (Speight, 2014). The exact composition of crude oil depends on its geographical origin and reservoir conditions, leading to significant variability in processing requirements. For example, light crudes are rich in naphtha and kerosene fractions, making them easier to process, while heavy crudes contain high concentrations of residues and asphaltenes, which demand additional upgrading (Manning & Thompson, 1995). This diversity in crude composition dictates the design and operating conditions of crude distillation units (CDUs).

II. MATERIALS AND METHOD

2.1 Materials Used

The following materials are used in this research:

- i. Operational data from old PHRC
- ii. MATLAB Software
- iii. Literature data

2.2 Method Used

Pinch analysis is a deterministic method for process integration that determines theoretical minimum hot and cold utility requirements and prescribes heat – exchanger network (HEN) structure that attains maximum process – to process heat recovery without violating a pre – specified minimum approach temperature ΔT_{min} (Linnhoff & Hindmarsh, 1983). For crude distillation units (CDUs), the preheat train often contains many hot side streams (pumparounds, side draws) and cold side streams (crude feed, side – cut feeds) with wide temperature ranges – making pinch analysis an effective tool for retrofit and revamp planning (Smith, 2016). This section presents the mathematical formulation of the pinch analysis applied to the heat exchanger network (HEN) of the Old Port Harcourt Refinery Crude Distillation Unit, as illustrated in Table 1. The analysis is further integrated with heat exchanger design equations to enable the practical realization of Maximum Energy Recovery (MER).

Table 1: Problem table for a heat Exchanger for old PHRC

stream	Inlet Temperature (°C)	Outlet Temperature (°C)	Mass flow rate (Kg/s)	Specific capacity (KJ/Kg °C)	heat	Heat duty (KW)
Crude storage	from 25	137	232.2889	2.1022		56299.86
Crude Desalter	from 129	202	116.1444	2.5215		47077.44
Hot kero PA	221	155	186.9444	2.9203		21864.04
Mild residue	230	164	72.4416	2.5158		11815.88
Hot kero	233	168	32.2333	2.9869		5628.82
Hot LDO	257	207	56.0000	2.8449		7768.70

Source: Port Harcourt Refinery, Alesa – Eleme

2.3 Maximum Energy Recovery and Heat Exchanger Network Redesign

In this study, the method is designed to guide the determination of Maximum Energy Recovery (MER) targets and the redesign of the Heat Exchanger Network (HEN). By applying the principles of Pinch Technology, this study systematically employs temperature shifting, interval analysis, heat cascade modeling, and network synthesis to enhance energy efficiency and promote economic sustainability.

2.3.1 Data Extraction and Stream Definition

The crude distillation heat exchanger network (HEN) is characterized by identifying all process streams requiring heating or cooling. For each stream i , the following data are defined:

- i. Supply Temperature: $T_{s,i}$ [°C]
- ii. Target Temperature: $T_{t,i}$ [°C]
- iii. Heat Capacity Flow rate: $C_{p,i} = \dot{m}_i c_{p,i}$ [KW/°C]

The heat load for each stream is expressed as:

$$Q_i = C_{p,i}(T_{s,i} - T_{t,i}) \quad (1)$$

where $Q_i > 0$ for hot streams (to be cooled) and $Q_i < 0$ for cold streams (to be heated). The problem table is set up as shown in Table 3.2 below;

Table 2: Process streams in an industrial plant

Process stream number	Stream type	Inlet Temperature (°C)	Outlet Temperature (°C)	Heat capacity rate (KW/K)	\dot{Q} (KW)
1	Cold	25	137	488.3177	56299.86
2	Cold	129	202	292.8581	47077.44
3	Hot	221	155	545.9337	21864.04
4	Hot	230	164	182.2486	11815.88
5	Hot	233	168	93.6990	5628.82
6	Hot	257	207	159.3144	7768.70

The task is to find the optimal network of heat exchangers, external coolers and heaters with respect to the capital and annual operating cost. The maximum heat that can be transferred in a heat exchanger is limited by the minimum allowable temperature difference between hot and cold streams (ΔT_{min}). The temperature level at which ΔT_{min} is observed is called Pinch point and the analysis to find this temperature with respect to the laws of thermodynamics is called pinch analysis or pinch technology.

2.3.2 Temperature Shifting

The interval calculated in table 3.2 above requires an ideal heat transfer within a heat exchanger that cool the stream down to the minimum temperature of $\Delta T = 0$. It means that the heat exchanger area is infinite. i.e; $\Delta T_{min} \rightarrow 0; \Rightarrow$ heat exchanger size and price $\rightarrow \infty$

This of course is not possible in practical applications and $\Delta T_{min} \neq 0$ is always valid. In order to decrease the size of heat exchanger to an acceptable level with reasonable price, it is assumed there always exists a temperature preferably ΔT_{min} . The assumed value of ΔT_{min} is decreased from the hot streams which in turn means the hot streams will be cooled by ΔT_{min} °C. To account for the minimum approach temperature (ΔT_{min}), the supply and target temperatures are shifted. For hot and cold streams:

$$T_{s,i}^i = T_{s,i} - \frac{\Delta T_{min}}{2} \quad (2)$$

$$T_{t,i}^i = T_{t,i} - \frac{\Delta T_{min}}{2} \quad (\text{hot streams}) \quad (3)$$

$$T_{s,j}^i = T_{s,j} + \frac{\Delta T_{min}}{2} \quad (4)$$

$$T_{t,j}^i = T_{t,j} + \frac{\Delta T_{min}}{2} \quad (\text{cold streams}) \quad (5)$$

The optimum value of ΔT_{min} for refinery process has been determined by Linhoff (1998) to be in the range of 20 to 40°C. Hence, a value of 25°C is used in this work.

Equations 3.2 – 3.5 ensures that no heat exchanger violates the pinch condition. A new temperature interval is then calculated as shown in Table 3.3.

Table 3: Temperature interval for $\Delta T_{min} = 25^\circ\text{C}$

Interval number	Temperature interval (°C)	Stream numbers	\dot{Q}_{cool} [KW]	\dot{Q}_{heat} [KW]
1	232 – 208	6	3823.5456	0
2	208 – 205	5 + 6	759.0402	0
3	205 – 202	4 + 5 + 6	1305.7860	0
4	202 – 196	2 + 4 + 5 + 6	2611.5720	1757.1486
5	196 – 182	2 + 3 + 4 + 5 + 6	13736.7398	4100.0134

6	182 – 143	2 + 3 + 4 + 5	32053.3707	11421.4659
7	143 – 139	2 + 3 + 4	2912.7290	1171.4324
8	139 – 137	2 + 3	1091.8674	585.7162
9	137 – 130	1 + 2 + 3	3821.5359	5468.2306
10	130 – 129	1 + 2	0	781.1758
11	129 – 25	1	0	50785.0408

2.3.3 Interval Energy Balance

For a given interval, we calculate the amount of heat to be supplied to the plant (called Q_{heat}) and how much heat must be taken from the plant (called Q_{cool}). The relationship between these external heating and cooling requirements can be written as:

$$\Delta Q = Q_{cool} - Q_{heat} \quad (6)$$

Table 4 below shows the temperature intervals and their stream number (s) for the system under study.

Interval number	Temperature interval (°C)	Stream numbers
1	257 – 233	6
2	233 – 230	5 + 6
3	230 – 221	4 + 5 + 6
4	221 – 207	3 + 4 + 5 + 6
5	207 – 202	3 + 4 + 5
6	202 – 168	2 + 3 + 4 + 5
7	168 – 164	2 + 3 + 4
8	164 – 155	2 + 3
9	155 – 137	2
10	137 – 129	1 + 2
11	129 – 25	1

The shifted temperatures are arranged in descending order to define temperature intervals. In each interval k , the net heat capacity flow is:

$$\Delta C_p^k = \sum C_{p,h}^k - \sum C_{p,c}^k \quad (6)$$

Where:

$\sum C_{p,h}^k$ = sum of hot streams heat capacities in interval k .

$\sum C_{p,c}^k$ = sum of cold streams heat capacities in interval k .

The heat balance in interval k is:

$$\Delta H^k = \Delta C_p^k \cdot \Delta T^k \quad (7)$$

2.3.4 The Problem Table Algorithm (PTA)

In this method, the temperature intervals can be described as thermal blocks connected to each other in series as illustrated in figure 3.4 below. Every temperature interval can be regarded as a network (or sub-network) that could be optimized with respect to the maximum energy recovery within the process. Such coupling is also called cascade coupling.

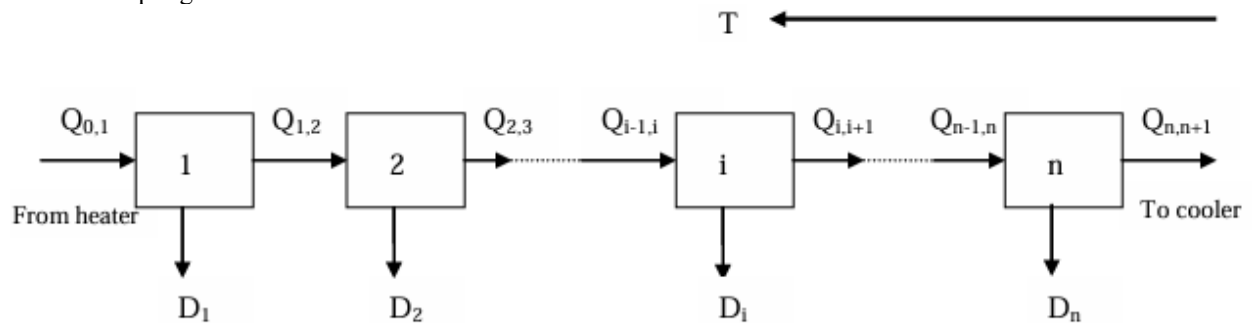


Figure 1: Schematics of a serial network connection

The excess energy, which is usually called deficit, for an arbitrary subnetwork i can be obtained from:

$$D_i = (T_i - T_{i+1}) \left[\sum (\dot{m}C_p)_{cold} - \sum (\dot{m}C_p)_{hot} \right] \quad (8)$$

Where;

T_i = upper temperature in the arbitrary temperature interval i

T_{i+1} = lower temperature in the arbitrary temperature interval i

These important conditions are valid:

$$D_i < 0 \Rightarrow \text{need for cooling}$$

$D_i > 0 \Rightarrow$ need for heating

The energy balance for the arbitrary block i can be calculated by:

$$\dot{Q}_{i+1,i} = \dot{Q}_{i-1,i} - D_i \quad (9)$$

Where;

$\dot{Q}_{i-1,i}$ = supplied heat for each block

$\dot{Q}_{i+1,i}$ = removed heat from each block

The heat cascade distributes enthalpy across temperature intervals. The cumulative enthalpy for interval k is:

$$H_{k+1} = H_k + \Delta H^k \quad (10)$$

The minimum value of the cascade defines the hot utility requirement:

$$Q_H^{min} = -\min(H_k) \quad (11)$$

The final cascade value defines the cold utility requirement:

$$Q_C^{min} = -H_{final} \quad (12)$$

2.3.5 Pinch Point Identification

The pinch point corresponds to the temperature interval where the heat cascade is zero after adjusting for utilities.

At this point:

$$Q_H^{min} \neq 0, Q_C^{min} \neq 0 \quad (13)$$

Equation (3.11) forms the thermodynamic bottleneck of the system.

III. RESULTS AND DISCUSSION

3.1 Design Simulation Results

The design equations were implemented using MATLAB 2020 ODE 45 solver from Matworks using Mixed-Integer Nonlinear Programming (MINLP) approach, which simultaneously handles the discrete exchanger network structure and continuous heat load variables.

The heating and cooling effect under steady state condition (constant heat capacities and temperatures) are:

$$Q_{heat} = 488.3177(137 - 25) + 292.8581(202 - 129) = 76070.2237KW$$

$$Q_{cool} = 545.9337(221 - 155) + 182.2486(230 - 164) + 93.6990(233 - 168) + 159.3144(257 - 207) = 62116.1868KW$$

These heat effects must be supplied by external heater and cooler such as steam water and cold water. The idea is now to find the lowest possible Q_{heat} for this system.

The temperature interval and external heating and cooling effects are as shown in Table 5 below.

Table 5: Temperature interval and external heating and cooling effects

Interval number	Temperature interval (°C)	Stream numbers	\dot{Q}_{cool} [KW]	\dot{Q}_{heat} [KW]	ΔQ [KW]
1	257 – 233	6	3823.5456	0	3823.5456
2	233 – 230	5 + 6	759.0402	0	759.0402
3	230 – 221	4 + 5 + 6	3917.358	0	3917.358
4	221 – 207	3 + 4 + 5 + 6	13736.7398	0	13736.7398
5	207 – 202	3 + 4 + 5	4109.4065	0	4109.4065
6	202 – 168	2 + 3 + 4 + 5	27943.9642	9957.1754	17986.7888
7	168 – 164	2 + 3 + 4	2912.7292	1171.4324	1741.2968
8	164 – 155	2 + 3	4913.4033	2635.7229	2277.6804
9	155 – 137	2	0	5271.4458	-5271.4458
10	137 – 129	1 + 2	0	6249.4064	-6249.4064
11	129 – 25	1	0	50785.0408	-50785.048

From Table 5 above, it means that a cooling effect of 17986.79 KW must be supplied to interval 6 so that the process stream can deliver the lowest needed temperature 168°C. Also, in interval 6, the need for external cooling is 17986.79 KW which is the largest cooling demand and must first be supplied by external cooling to the process. In pinch method, this external cooling must be first supplied to the system at the respective temperature interval and then all other temperature intervals must be updated according to its cooling demand.

The temperature interval and external heating and cooling effects using a temperature shift of $\Delta T_{min} = 25^\circ C$

Table 6: Temperature interval for $\Delta T_{min} = 25^\circ C$

Interval number	Temperature interval (°C)	Stream numbers	\dot{Q}_{cool} [KW]	\dot{Q}_{heat} [KW]	ΔQ [KW]
1	232 – 208	6	3823.5456	0	3823.5456
2	208 – 205	5 + 6	759.0402	0	759.0402
3	205 – 202	4 + 5 + 6	1305.7860	0	1305.7860
4	202 – 196	2 + 4 + 5 + 6	2611.5720	1757.1486	854.4234
5	196 – 182	2 + 3 + 4 + 5 + 6	13736.7398	4100.0134	9636.7264

6	182 – 143	2 + 3 + 4 + 5	32053.3707	11421.4659	20631.9048
7	143 – 139	2 + 3 + 4	2912.7290	1171.4324	1741.2966
8	139 – 137	2 + 3	1091.8674	585.7162	506.1512
9	137 – 130	1 + 2 + 3	3821.5359	5468.2306	-1646.6947
10	130 – 129	1 + 2	0	781.1758	-781.1758
11	129 – 25	1	0	50785.0408	-50785.048

Sequential Heat Balance Analysis

Table 6 presents the results of the sequential heat balance problem for the heat exchanger network (HEN) synthesis with a minimum approach temperature (ΔT_{min}) of 25°C. The sequential approach systematically determines the heat cascade across each temperature interval, ensuring that the energy targets are satisfied and that no temperature interval exhibits a heat deficit.

Table 7: Sequential Balance Problem for Table 3.2 with $\Delta T_{min} = 25^\circ\text{C}$

Interval number	Temperature interval (°C)	Sequential Balance			Max Table	
		D_i	$\dot{Q}_{i-1,i}$	$\dot{Q}_{i,i+1}$	$\dot{Q}_{i-1,i}$	$\dot{Q}_{i,i+1}$
1	232 – 208	-3823.5456	0	3823.5456	15257.5229	69866.1593
2	208 – 205	-759.0402	3823.5456	4582.5858	19081.1185	85123.7322
3	205 – 202	-1305.7860	4582.5858	5888.3718	19840.1587	85882.7724
4	202 – 196	-854.6034	6291.7926	6291.7926	20694.7621	72334.4063
5	196 – 182	-9637.1464	24711.4820	24711.4820	30331.9085	90754.0957
6	182 – 143	-20633.0748	56340.4852	56340.4852	50964.9833	122383.0989
7	143 – 139	-1741.4168	39190.2440	39190.2440	52706.4001	105232.8577
8	139 – 137	-506.2112	38461.2496	38461.2496	53212.6114	104503.8633
9	137 – 130	1646.6947	34661.9490	34661.9490	51566.2166	100704.5627
10	130 – 129	781.1758	34746.2921	34746.2921	50785.0408	100788.9058
11	129 – 25	50785.0408	-66042.6137	-66042.6137	0	0

From Table 7, it is evident that the sequential balance progresses from higher to lower temperature intervals, representing the stepwise transfer of available heat (enthalpy) across process streams. The driving temperature difference ($\Delta T_{min} = 25^\circ\text{C}$) serves as a constraint that ensures thermodynamic feasibility while influencing the energy recovery potential.

Heat deficits (Negative D_i)

Negative D_i values in the upper intervals (1–8) indicate that the process streams require additional heat, implying net heat demand in those sections. This typically corresponds to heating duties that must be supplied by process heaters or utility hot streams.

Heat Surpluses (Positive D_i)

In contrast, intervals 9 – 11 exhibit positive D_i values, signifying heat surplus zones where cooling is required. This transition is a key indicator of the pinch point location, which divides the process into above-pinch (heat deficit) and below-pinch (heat surplus) regions.

Energy Target and Heat Recovery

The heat cascade values ($\dot{Q}_{i-1,i}$) show the cumulative heat flow through successive temperature intervals. The highest value observed (56,340.49 kW at Interval 6) represents the maximum energy transfer across the network. The corresponding maximum table values ($\dot{Q}_{i-1,i}$) = 50,964.98 kW and ($\dot{Q}_{i,i+1}$) = 122,383.10 kW indicate the maximum heat flow capacity at that interval, confirming adequate energy recovery potential.

This result suggests that the minimum heating utility ($Q_{H,min}$) and minimum cooling utility ($Q_{C,min}$) can be estimated around 50.8 MW and 66.0 MW, respectively, based on the terminal cascade values. This aligns with the general rule that increasing ΔT_{min} reduces energy recovery, leading to higher external utility demands.

The observed pattern agrees with findings from Smith (2005) & Kemp (2007), who reported that increasing ΔT_{min} 25 – 30 °C typically leads to a trade-off between reduced heat exchanger area and increased utility consumption. The present result ($\Delta T_{min} = 25^\circ\text{C}$) shows a moderate recovery efficiency, consistent with Ahmad *et al.*, (2019), who demonstrated that ΔT_{min} values in the range of 20 – 30 °C provide optimal balance between capital and energy costs for refinery and petrochemical HENs

3.2 Pinch Point Identification

The pinch occurs where the cumulative heat flow (\dot{Q}) shifts direction. In this case, this occurs approximately between 139°C and 137°C (Intervals 8 – 9). At this point, the net heat cascade approaches zero, meaning that no external heating or cooling utility should cross this boundary. This observation aligns with the Pinch Analysis principle that dictates the pinch as the energy bottleneck of the process (Linnhoff & Flower, 1978)

Composite Curve

Table 8: Temperature intervals and Enthalpy flow rates for hot streams

Interval number	Temperature interval (°C)	Stream numbers	$\sum \dot{m}C_p$	$\Delta H = \Delta T \sum \dot{m}C_p$	$\sum \Delta H$
1	155 – 164	3	545.9337	4913.4033	4913.4033
2	164 – 168	3 + 4	728.1823	2912.7292	7826.1325
3	168 – 207	3 + 4 + 5	821.8813	32053.3707	39879.5032
4	207 – 221	3 + 4 + 5 + 6	981.1957	13736.7398	53616.2430
5	221 – 230	4 + 5 + 6	435.259	3917.3130	57533.556
6	230 – 233	5 + 6	253.0134	759.0402	58292.5962
7	233 – 257	6	159.3144	3823.5456	62116.1418

Table 9: Temperature intervals and Enthalpy flow rates for cold streams

Interval number	Temperature interval (°C)	Stream numbers	$\sum \dot{m}C_p$	$\Delta H = \Delta T \sum \dot{m}C_p$	$\sum \Delta H$
1	25 – 129	1	488.3177	50785.0408	50785.0408
2	129 – 137	1 + 2	781.1758	6249.3824	57034.4232
3	137 – 202	2	292.8581	19035.7765	76070.1997

All computations incorporated a minimum temperature (ΔT_{min}) of 25 °C and assumed an overall heat transfer coefficient of 1 KW/m²°C. The results are as shown in Table 5

Table 10: Result of Pinch analysis and heat exchanger parameters

Parameter	Value
Maximum heat recovered	419.52 KW
Pinch Temperature	147.50 °C
Pinch Net Enthalpy	0.00 KW
Approximate heat exchanger area required	24.40 m ²
Overall heat transfer coefficient (U)	1.00 KW/m ² °C

IV. CONCLUSION

A detailed Pinch Analysis was carried out on the Crude Distillation Unit (CDU) of the Old Port Harcourt Refinery using operational data comprising stream temperatures, mass flow rates, and specific heat capacities. Through the construction of the Problem Table Algorithm and corresponding grid diagram, the analysis successfully identified several inefficiencies within the existing heat exchanger network, notably the improper placement of heat exchangers and non-optimal stream matching. The findings revealed a considerable potential for energy recovery that remains unexploited under current operating conditions. Specifically, the analysis showed that the unused hot utility amounted to 98916.1 kW, while the unused cold utility was 8298.7 kW, indicating that the current configuration operates well below its optimal thermal performance.

The pinch point was identified at the temperature interval where the cumulative heat flow (\dot{Q}) changes direction, signifying the transition between heat surplus and heat deficit regions. In this study, the pinch occurs approximately between 139 °C and 137 °C (Intervals 8 – 9). At this point, the net heat cascade approaches zero, indicating the thermodynamic boundary beyond which no external heating or cooling utilities should be supplied or removed. This condition represents the critical temperature level for optimal heat recovery within the system. The study provides the following contributions to knowledge:

- i. Pinch Point Identification for Crude Distillation: The research successfully determined the critical pinch temperature (147.5°C), providing a clear reference for optimal heat integration.
- ii. Quantification of Energy Recovery Potential: By calculating a maximum recoverable heat of 419.52 kW, the study establishes a benchmark for energy savings achievable in the process

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