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# Heat Exchanger Network Thermal Analysis Using Hybrid Pinch Technology

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**Abstract:** This research employs hybrid pinch analysis method to evaluate the heat exchanger network (HEN) of an existing refining plant for thermal design bottlenecks. The pinch rules and thermodynamic models were used to analyze the existing network design using available heat flow data to and from each cascade to determine the pinch temperature on incremental heat changes. The pinch point was discovered at the 6<sup>th</sup> and 7<sup>th</sup> temperature interval corresponding to a process pinch of 188°C with temperature above and below pinch at 193°C and 183°C respectively. The temperature profile showed two distinct regimes: exponential and linear trend lines within 0°C and 110°C which indicated an initial uneven temperature rise that later stabilized with increment proportional to the heat flow quantity within the heat exchanger with time. Furthermore, the temperature of the crude after it passed through the preheat exchanger network in the base case was found to be 242°C but through the retrofit method 275°C was achieved resulting in 33°C temperature differential. By this approach, the base case number of heat exchangers and trains were reduced from 36 and 20 to 30 and 10 respectively and an energy saving of about 19255KJ was achieved for each second the plan was operated.

**Keywords:** Heat Exchangers, Pinch Analysis, Crude Oil, Energy

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## 1. Introduction

The demand for crude products has been on the increase since its discovery because of the wide range of application as energy source domestically and industrially especially in developing countries with limited technology on ways of harnessing, processing and reforming the available renewable energy sources (like wind, solar energy, biomass etc.). One basic method of separating crude products is by fractional distillation which involves passing it through different heat exchangers with a number of trains for heat energy exchange. Basically, heat exchangers can be applied in systems as small as simple refrigerators and air conditioners to mighty and sophisticated systems such as gas turbine and plants in processing industries. The design involves four interrelated non-isolation phases: thermal, hydrodynamic, mechanical and manufacturing design [1] which are done by design or performance analysis. The design analysis is undertaken during the initial stage of a new heat exchanger and involves

the determination of the area (A) (for estimation of the geometrical parameters of the heat exchanger) while the performance analysis aids in the selection of the optimal performance characteristics of existing heat exchangers. The design and performance analysis are determined jointly by solutions of heat transfer calculations as well as heat balance equations. Assessment of some heat exchanger facility reveals some mishap in the heater and cooler arrangement during the design and installation neglecting the existing pinch rules. Hence, it is imperative to develop a model for improving existing network of such facilities in the light of maximum heat recovery by minimizing the number of stream matches, heat exchanger area, minimizing the use of utility streams or a combination therefore. One very viable way of achieving this is by managing the energy that is available through process integration. In the light of this, it is pertinent to use hot stream energy surplus to provide for cold stream which is lacking in heat supply. The reasonable question demanding an answer is which or what way is most effective in matching the streams in

order to maximally recover energy in the system. This answer is given in two folds herewith: Pinch Technology and mathematical programming approaches applied for optimal maximum heat recovery, minimum utility utilization and the determination of optimal number of stream matches. Several researches have been conducted on HEN for optimal system performance. The study [2] applied heat exchanger analysis in optimizing a HEN and obtained a fuel saving of about 20-25% and a reduction in emission by 15-20%. The study [3] considered HEN selection in bypasses, the study [4] observed minimization of utility consumption, the study [5] suggested control of closed loop HEN pattern, and the study [6] highlighted the need for optimization in relation to the degree of freedom while the study [7] suggested controlled output selection of HEN using pinch analysis. Employing pinch analysis technique can lead to possible reduction in the number of installed heat exchangers in a facility [8]. The study [9] employed the shell and tool package of pinch analysis to decrease the number of heat exchangers in a certain facility. This research employs the hybrid pinch analysis which involves cascading the surplus heat in the temperature interval (and not all the available heat in the system) to bridge the gap of the traditional pinch method which involves manual enumeration of all the available matches and improve the energy savings when compared with other studies like the study [2]. Instead of using tabulations and figures, the solutions for the two sub problems gives the required solutions while the developed networks are compared with the existing one in the refinery for mismatch checks to enhance the overall system's performance.

## 2. Materials and Method

### 2.1. Description of Study Area

The case study for this research is the Port Harcourt Refining Company Limited (PHRC) which was established after the construction of 35,000 barrels per stream day production in 1965. Its facilities are located around Alesa-Elеме, Rivers State in Nigeria. The place of Port Harcourt Refining Company Limited in driving the Nigerian economy as a Petroleum Refining Industry is therefore very vital as it produces 47% of the overall refined products in Nigeria as shown in Table 1.

### 2.2. Data Extraction

The pinch rule was used for evaluating the heat HEN for optimum heat recovery and is put forth herewith:

1. For cold streams that exist below the pinch temperature, there should be no hot utility streams injected to heat them to their target temperatures.
2. For hot streams that exist above the temperature of the pinch point there should be no cold utility stream injected to cool them to their target temperatures.
3. Only streams that are on the same side (above or below pinch) of the network are allowed to exchange heat.

The thermal data extraction for process and utility streams are described below.

For each hot, cold and utility stream identified, the following thermal data is extracted from the process material and heat balance flow sheet.

- i. Supply temperature,  $T_s$  (°C): the temperature at which the stream was available.
- ii. Target temperature,  $T_T$  (°C): the temperature the stream must be taken to.
- iii. Heat capacity flow rate  $CP$  (kJ/S°C): the product of flow rate ( $m$ ) in kg/sec and specific heat  $C_p$  (kJ/kg°C).

In this work the specific heat values have been assumed to be temperature independent within the operating rate in line with [10]

$$CP = m \times C_p \quad (1)$$

Enthalpy change ( $\Delta H$ ) associated with a stream passing through the exchanger is given by the First Law of Thermodynamics.

First law energy equation:

$$H = Q + W, \text{ i.e } Q = m(h_2 - h_1) \quad (2)$$

(neglecting changes in kinetic energy and potential energy)

In a heat exchanger, no mechanical work is being performed, hence;  $W = 0$  (zero)

Hence, Eq (2) simplifies to:  $H = Q$  where  $Q$  represents the heat supply or demand associated with the stream. It is given by the relationship:

$$Q = C_p \times (T_s - T_T) = mC_p (T_s - T_T) \quad (3)$$

Enthalpy change;

$$\Delta H = C_p \times (T_s - T_T) \quad (4)$$

In line with the pinch analysis procedure, process data consisting of heat capacity flow rates, supply and target temperatures for the cold stream (Crude oil) and hot streams (Top pump around, Kerosene draw product, LDO product, HDO and residue) from flow sheets of the existing heat exchanger network were obtained. From overview of crude column charts the mass flow rates were obtained by multiplying their densities by the volumetric flow rates then multiplied by heat capacity to obtain the heat capacity flow rates. Only the heat capacity of kerosene was available so along with the density of kerosene, density rules were used to obtain the heat capacities of the other streams. The data was properly organized in a form suitable for use and presented as Table 1. Table 2 also shows the heat loads of the seven hot streams and the only cold stream in the "non-integrated" state contrary to the methodology adopted here. Table 1 describes the thermal condition of the base case. In this Table heat exchangers in each train, heat exchanger labels and the hot and cold streams respective inlet temperatures are listed. The total number of trains are twenty (20) while the total number of heat exchangers are thirty- six (36).

It is worthy of note that the heat exchangers used at the PHRC are combination of counter-current/co-current cross flow configuration.

**Table 1.** Thermal Condition of Base-Case PHRN Heat Exchanger Network (HEN).

S/N	Heat Exchanger Train	Number of Heat Exchangers in each Train	Heat Exchanger Label	Hot Stream Inlet Temp (°C)	Cold Stream Inlet Temp (°C)
1	1	3	10E01 A/B/C top pump around / crude	147	25
2	2	2	10E03 A/B cold LDO/crude	207	92
3	3	1	10E05 A cold RCD/crude	164	138
4	4	3	10E01 D/E/F/ top pump around / crude	147	25
5	5	1	10E02 cold kerosene / crude	168	92
6	6	1	10E04 HDO/crude	308	109
7	7	1	10E05 B cold RCD/crude	164	129
8	8	1	10E06A warm RCD/crude	204	137
9	9	2	10E07 A/B cold kerosene pump around/crude	184	141
10	10	1	10E07 A/B cold kerosene pump around/crude	233	154
11	11	1	10E08 A hot kerosene pump around/crude	221	168
12	12	2	10E10 A hot LDO/crude	257	168
13	13	1	10E11 A/B mid RCD/crude	230	189
14	14	2	10E06 B warm RCD/ crude	204	134
15	15	1	10E07 C/D cold kerosene pump around crude	184	141
16	16	1	10E08 B hot kerosene pump around/crude	233	154
17	17	2	10E10 B hot LDO/crude	221	168
18	18	2	10E11 C/D mid RCD/crude	257	189
19	19	4	10E13 A/B HVGO/crude	230	198
20	20	4	10E12 A/B/C/D LDO pump around / crude	276	202
Total	20	36			

**Table 2.** Raw Data Table.

S/N	Name	Stream Label	T <sub>s</sub> (°C)	T <sub>T</sub> (°C)
1	Top Pump Around (TPA)	H <sub>1</sub>	154	91.00
2	Kero Pump Around (Kero PA)	H <sub>2</sub>	224	140.00
3	LDO Pump Around (LDO PA)	H <sub>3</sub>	278	224.00
4	Kero	H <sub>4</sub>	193	40.00
5	LDO	H <sub>5</sub>	279	146.00
6	HDO	H <sub>6</sub>	322	65.00
7	Residue	H <sub>7</sub>	328	260.00
8	Crude oil	C <sub>1</sub>	31	242.00

Source (Port Harcourt Refining Company)

### 3. Results and Discussion

#### 3.1. Heat Exchanger Network Schemes/Options

The base case HEN is presented in Figure 1 showing the existing network while Figure 2 is grid representation of network design of culprit Heat Exchangers. Tables 3 and 5 were applied to generate the solutions that resulted in the above listed Figures which are then compared with the base case. Table 3 contains the data for analysis, the second column contains the names in the seven hot streams and only cold stream, in the third column the streams are given numerical values for ease of reference. The variables

considered are the supply temperatures (T<sub>S</sub>) and target temperatures (T<sub>T</sub>) which are the raw data. Quantity (Q) is the heat (kW) required to move supply temperature to target temperature without any matching of the streams. The heat capacity flow rates multiplied by the temperature difference (FCP x Δt) gives the quantity of heat available in any of the streams. The remaining columns contain heat capacity flow rates of all the streams, (FCPH, FCPC). Supply interval temperatures (T<sub>ints</sub>), target interval temperatures (T<sub>intt</sub>) and final temperatures (T<sub>final</sub>) which are ranked in decreasing order and these constitute the normalized data. The purpose for arranging the data thus is to enable with ease the determination of pinch temperature and utility requirements.

**Table 3.** Data Table (Raw and Normalized).

Raw Data			Normalized Data						
S/N	Name	Stream label	T <sub>s</sub> (°C)	T <sub>T</sub> (°C)	Q (kJ)	FCP ( $\frac{kJ}{s}$ )	T <sub>ints</sub> (°C)	T <sub>intt</sub> (°C)	T <sub>final</sub> (°C)
1	Top Pump Around (TPA)	H <sub>1</sub>	154	91.00	34618.8	549.50	149	86	323
2	Kero Pump Around (Kero PA)	H <sub>2</sub>	224	140.00	35983.92	428.38	219	135	317
3	LDO Pump Around (LDO PA)	H <sub>3</sub>	278	224.00	7578.9	140.35	273	219	275
4	Kero	H <sub>4</sub>	193	40.00	13770	90.00	188	35	274
5	LDO	H <sub>5</sub>	279	146.00	6566	49.00	274	140	255
6	HDO	H <sub>6</sub>	322	65.00	23130	90.00	317	60	219
7	Residue	H <sub>7</sub>	328	260.00	13081.84	192.50	323	255	188
8	Crude oil	C <sub>1</sub>	31	242.00	143729.16	583.50	36	280	149

Raw Data		Normalized Data							
S/N	Name	Stream label	T <sub>s</sub> (°C)	T <sub>T</sub> (°C)	Q (kJ)	FCP ( $\frac{kJ}{s \cdot ^\circ C}$ )	T <sub>ints</sub> (°C)	T <sub>intt</sub> (°C)	T <sub>final</sub> (°C)
				Q <sub>H</sub>	134729.46		Deficit		
				Q <sub>C</sub>	142374.16		-8999.70		

Source (Port Harcourt Refining Company)

Pinch temperature and utility requirements were then considered thus.

### 3.2. Pinch Temperature and Utility Requirements

Algorithm for the Problem Table was implemented in Microsoft Excel using the normalized data in Table 3 while the preliminary calculations and results are as shown in Table 4. Second column of Table 4 contain ranked temperature intervals between the supply and target temperatures of all seven hot streams and the only cold stream. Column 3 and 4 contain the temperature difference in each interval and the population of streams available in each interval respectively. The 4<sup>th</sup> and 5<sup>th</sup> columns contain the heat capacity flow rate of cold stream (sum CPC) and hot streams (sum CPH) in that order while column 6 is the difference between them. The product of the difference between heat capacity flow rates and the temperature differences (DeltempxDelCp) are stated in the next column which account for the heat availability (Q)

in each temperature interval before the cascading to determine the process pinch temperature. Minimal heat was added to the top to do the cascading of the first cascade “Q<sub>1</sub>”. The “Q” terms the cascade in each column were then cumulated. The second cascade Q<sub>2</sub> gave the minimum value of Q as zero (0) which is the pinch point and the optimum value of heat content and this occurred between the 6<sup>th</sup> and 7<sup>th</sup> temperature interval. The process pinch is obtained at 188°C with temperatures above / below the pinch points as 193°C and 183°C, respectively. Temperature at which the process is at thermal equilibrium is the pinch point temperature and so poses a bottleneck to further heat exchange. This therefore divides the process into two halves for better heat integration.

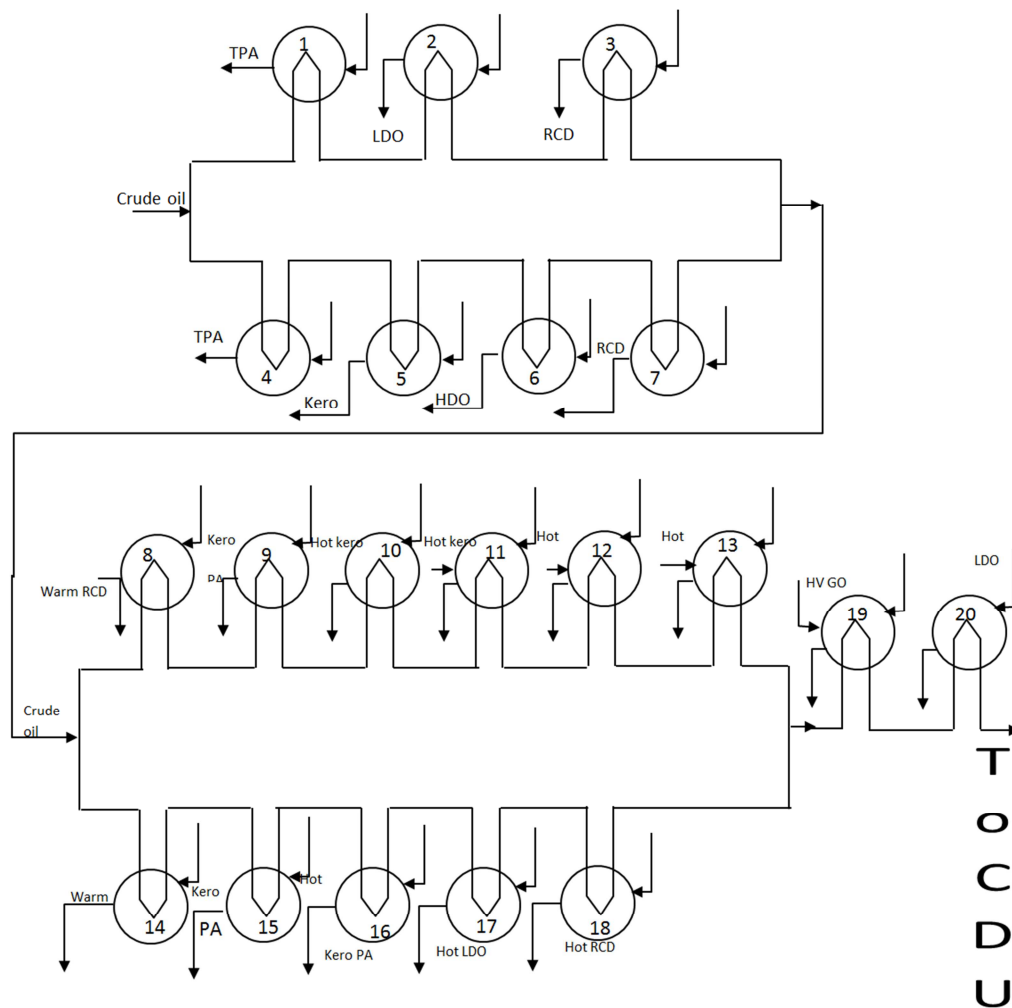


Figure 1. Heat Exchanger Network (Base Case) Showing the 20 Trains.

**Table 4.** Results of Pinch Analysis by Problem Table Method.

S/No	Interval Term	Deltemp	Interval Population	SumCPC FCP (kJ°C)	SumCPH	DelCP (SumCPC -SuCPH)	Deltemp xDelCp	Cascade Q <sub>1</sub>	Cascade Q <sub>2</sub>
								<b>0.00</b>	<b>999.98</b>
1	323	6	h7		192.38	-192.38	-1154.28	1154.28	2154.26
2	317	42	h6,h7		282.38	-282.38	-11859.96	13014.24	14014.22
3	275		6,7,c	538.50	282.38	301.12	301.12	12713.12	13713.10
4	274	1	5,6,7,c	538.50	331.38	252.12	252.12	12461.00	13460.98
5	255	1	3,5,6,7,c		471.78	111.77	2011.86	1044.14	11449.12
6	219		3,5,6,c	538.50	271.73	304.15	10949.40	-500.26	499.72
7	188	18	2,5,6,c	538.50	567.38	16.12	499.72	-999.98	0.00
8		36	2,4,5,6,c		657.38	-73.88	-2881.32	1881.34	2881.32
9	188	31	1,2,4,5,6,c	538.50	1206.88	-623.38	-8727.32	10608.66	11608.64
10	149		1,4,5,6,c	538.50	778.50	-195.00	-9555.00	20163.66	21163.64
11		39	4,5,6,c	538.50	229.00	354.50	9217.00	10946.66	11946.64
12	134		4,5,c		139.00	444.50	10668.00	278.66	1278.64
13			4,5		139.00	444.50	444.50	-165.84	834.14

Having determined the pinch temperatures, the three (3) pinch rules were tested against the back drop of retrofitting opportunities.

Table 5 shows the possibility of exploring the retrofitting existing heat exchanger network by Pinch rules. The last column in this table contains what is known as the culprit(s) which are the streams that violate the pinch rule number (3) and therefore present and depict retrofitting potentials.

**Table 5.** Thermal Condition of Base-case PHRN Heat Exchanger Network (HEN) with culprits.

S/N	Heat Exchanger Train	Number of Heat Exchangers in each Train	Heat Exchanger Label	Hot Stream Inlet Temp (°C)	Above (A)/ Below (B) Hot Pinch	Cold stream inlet Temp (°C).	Above (A)/ Below (B) Cold Pinch	Culprit (C)/ Okay (O)
1	1	3	10E01 A/B/C top pump around / crude	147	B	25	B	O
2	2	2	10E03 A/B cold LDO/crude	207	A	92	B	C
3	3	1	10E05 A cold RCD/crude	164	B	138	B	O
4	4	3	10E01 D/E/F/ top pump around / crude	147	B	25	B	O
5	5	1	10E02 cold kerosene / crude	168	B	92	B	O
6	6	1	10E04 HDO/crude	308	A	109	B	C
7	7	1	10E05 B cold RCD/crude	164	B	129	B	O
8	8	1	10E06A warm RCD/crude	204	A	137	B	C
9	9	2	10E07 A/B cold kerosene pump around/crude	184	B	141	B	O
10	10	1	10E07 A/B cold kerosene pump around/crude	233	A	154	B	C
11	11	1	10E08 A hot kerosene pump around/crude	221	A	168	B	C
12	12	2	10E10 A hot LDO/crude	257	A	168	B	C
13	13	1	10E11 A/B mid RCD/crude	230	A	189	A	O
14	14	2	10E06 B warm RCD/ crude	204	A	134	B	C
15	15	1	10E07 C/D cold kerosene pump around crude	184	B	141	B	O
16	16	1	10E08 B hot kerosene pump around/crude	233	A	154	B	C
17	17	2	10E10 B hot LDO/crude	221	A	168	B	C
18	18	2	10E11 C/D mid RCD/crude	257	A	189	A	O
19	19	4	10E13 A/B HVGO/crude	230	A	198	A	O
20	20	4	10E12 A/B/C/D LDO pump around / crude	276	A	202	A	O
Tota l	20	36						9 culprits

Source (Port Harcourt Refining Company)

Grid representation of culprits which divides HEN into above pinch and below the pinch point is demonstrated below.

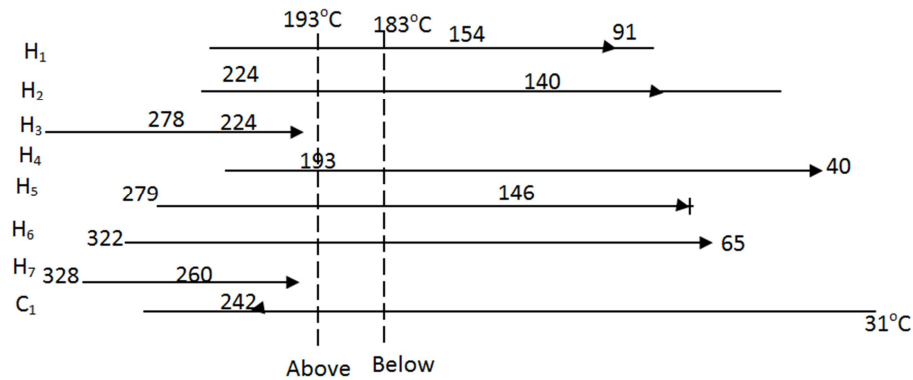


Figure 2. Grid Representation of Network Design of Culprit Heat Exchangers.

The pinch divides the HEN design problem into two sub-problems viz design above the pinch and design below the pinch. For above and below the pinch design, the method prescribes the heat capacity flow rate of cold stream must be greater than the heat capacity flow rates of hot streams and vice versa, respectively. With the grid representation it is possible to determine the heat availability above and /or below the pinch.

HEN design above pinch, requires  $F_{CPH} \leq F_{CPC}$ . The hot streams available for matching are H<sub>2</sub>, H<sub>3</sub>, H<sub>4</sub>, H<sub>5</sub>, H<sub>6</sub> and H<sub>7</sub>. In the case of the HEN design below the pinch, the criterion is  $F_{CPH} \geq F_{CPC}$  while the streams available for matching are H<sub>1</sub>, H<sub>2</sub>, H<sub>4</sub>, H<sub>5</sub> and H<sub>6</sub>.

### 3.3. Analysis of Heat Availability Above Pinch

The existence of a pinch in a heat exchanger network (HEN) is in agreement with the finite temperature difference requirement of the second law of thermodynamics. However, the most salient characteristic of pinch is that it constitutes heat recovery bottleneck. This can be explained using the thermodynamic concept of “availability of energy”.

The availability of energy of a stream could be calculated by taking the hot streams from their respective supply temperature to the hot pinch temperature of 193°C, each stream must be matched above the pinch and away from 193°C. The total heat (Q) that is available for matching is the sum of heat availability for each hot stream and these are calculated below as  $F_{CP} (T_s - T_{pinch})$ .

$$H_2: 428.58 \frac{kJ}{s} / ^\circ C (224 - 193) ^\circ C = 13279.78$$

Similarly,

$$H_3 = 11929.75 \text{ kJ/s}$$

$$H_5 = 4214 \text{ kJ/s}$$

$$H_6 = 11610 \text{ kJ/s}$$

$$H_7 = 25920 \text{ kJ/s}$$

The maximum temperature  $\left( \Delta T = \frac{Q}{FCP} \right)$  rise in the crude

oil due to matching with each of the hot streams was calculated by dividing the heat available in each stream by heat capacity flow rate of crude oil and listed in Table 6 for above pinch and Table 8 for below the Pinch.

The temperature profile of the cold crude oil stream above the pinch depends on the matching pattern of the streams with the crude oil. In this work, the following options are evaluated.

- i. Increasing order of  $\Delta T$
- ii. Decreasing order of  $\Delta T$
- iii. Increasing order of inlet temperature
- iv. Decreasing order of inlet temperature.

Should the streams be matched in increasing order of  $\Delta T$ , then the matching would be: H<sub>5</sub> – C<sub>1</sub>, H<sub>3</sub> – C<sub>1</sub>, H<sub>6</sub> – C<sub>1</sub>, H<sub>7</sub> – C<sub>1</sub> and H<sub>2</sub> – C<sub>1</sub>.

For the second option, the matching order is: H<sub>2</sub> – C<sub>1</sub>, H<sub>7</sub> – C<sub>1</sub>, H<sub>6</sub> – C<sub>1</sub>, H<sub>3</sub> – C<sub>1</sub>, and H<sub>5</sub> – C<sub>1</sub>.

For the third option the matching order is H<sub>2</sub> – C<sub>1</sub>, H<sub>3</sub> – C<sub>1</sub>, H<sub>5</sub> – C<sub>1</sub>, H<sub>6</sub> – C<sub>1</sub> and H<sub>7</sub> – C<sub>1</sub>.

While the fourth option which is the reverse of the third option is

$$H_7 - C_1, H_6 - C_1, H_5 - C_1, H_3 - C_1, H_2 - C_1.$$

The results of this analysis are contained in Table 7.

The total heat available for matching depending on the different options were evaluated. The issue of how much the cold stream temperature would rise if any of the hot streams is added to it is addressed and recorded in Tables 6 through 8. While Table 6 contains the temperature difference of the crude oil in hot streams above the pinch, Table 8 shows the temperature difference in the crude oil in hot streams below the pinch. The heat availability requirements were calculated using the product relationship between the heat capacity flow rates and temperature differences ( $Q = F_{CP}\Delta T$ ).

Table 6. Temperature Difference in Crude Oil in Hot streams (Above the pinch).

Stream	$\Delta T$ (°C)
H <sub>2</sub>	23
H <sub>3</sub>	20
H <sub>5</sub>	07
H <sub>6</sub>	20
H <sub>7</sub>	22

Depicted in Table 7 are values of temperatures in respective stream matches based on the 4 options; option 1, option 2, option 3 and option 4 which corresponds with matching the hot and cold streams in increasing order of

temperature difference, decreasing order of temperature difference, increasing order of inlet temperature and decreasing order of inlet temperature. This table presents the temperature profiles of the crude oil stream above pinch after matching with the hot streams depending on the order of options. The option 1 column was obtained by cumulating the matches of temperature differences of hot streams in Table 6 with temperature attained by crude oil after matching which is 183°C thus;

$$H_5 - C_1 = 07 + 183^\circ\text{C} = 190, H_3 - C_1 = 20 + 190 = 210^\circ\text{C},$$

$$H_6 - C_1 = 20 + 210 = 230^\circ\text{C}, H_2 = C_1 = 23 + 230 = 253^\circ\text{C}$$

$$H_7 - C_1 = 22 = 253 = 275^\circ\text{C}.$$

This shows that the crude leaves the furnace and enters the distillation column at 275°C. The quantity of heat that is required to raise the crude oil temperature by 33°C (275 – 242) was obtained through multiplication of specific heat capacity of crude oil by temperature difference of 33°C.

$$\text{Numerically, } \text{CPC} \times \Delta T = 583.50 \times 33^\circ\text{C} = 19255.5 \text{ kJ/sec}$$

The interpretation here is that, for each second the plant runs, 19255.5 kJ energy savings can be achieved.

Table 7. Option/ Match Table.

Option 1		Option 2		Option 3		Option 4	
Match	Temp (°C)	Match	Temp (°C)	Match	Temp (°C)	Match	Temp (°C)
H <sub>5</sub> – C <sub>1</sub>	190	H <sub>2</sub> – C <sub>1</sub>	206	H <sub>2</sub> – C <sub>1</sub>	206	H <sub>7</sub> – C <sub>1</sub>	205
H <sub>3</sub> – C <sub>1</sub>	210	H <sub>7</sub> – C <sub>1</sub>	228	H <sub>3</sub> – C <sub>1</sub>	226	H <sub>6</sub> – C <sub>1</sub>	225
H <sub>6</sub> – C <sub>1</sub>	230	H <sub>6</sub> – C <sub>1</sub>	248	H <sub>5</sub> – C <sub>1</sub>	233	H <sub>5</sub> – C <sub>1</sub>	232
H <sub>2</sub> – C <sub>1</sub>	253	H <sub>3</sub> – C <sub>1</sub>	268	H <sub>6</sub> – C <sub>1</sub>	253	H <sub>3</sub> – C <sub>1</sub>	252
H <sub>7</sub> – C <sub>1</sub>	275	H <sub>5</sub> – C <sub>1</sub>	275	H <sub>7</sub> – C <sub>1</sub>	275	H <sub>2</sub> – C <sub>1</sub>	275

Table 8. Temperature Differential in Crude Oil Stream (Below pinch).

Stream	Q (kJ/sec)	ΔT°C
H1	34618.5	59°C
H2	22704	39°C
H4	13770	24°C
H5	7497	10°C
H6	11520	20°C

The Pinch systematic approach obtained a preheat temperature of 27°C for the crude while the existing HEN is 242°C crude oil temperature before the crude oil passes through the furnace to attain 334°C before entering the distillation column.

### 3.4. Analysis of Temperature Profiles

The temperature profile of the cold crude oil stream depends on the matching pattern of the seven streams with the crude oil. The results from the evaluation of the pinch method using the following options are graphically presented in Figure 3 as pinch scheme 1 (increasing order of ΔT), pinch scheme 2 (decreasing order of ΔT), pinch scheme 3 (increasing order of inlet temperature) and pinch scheme 4 (decreasing order of inlet temperature).

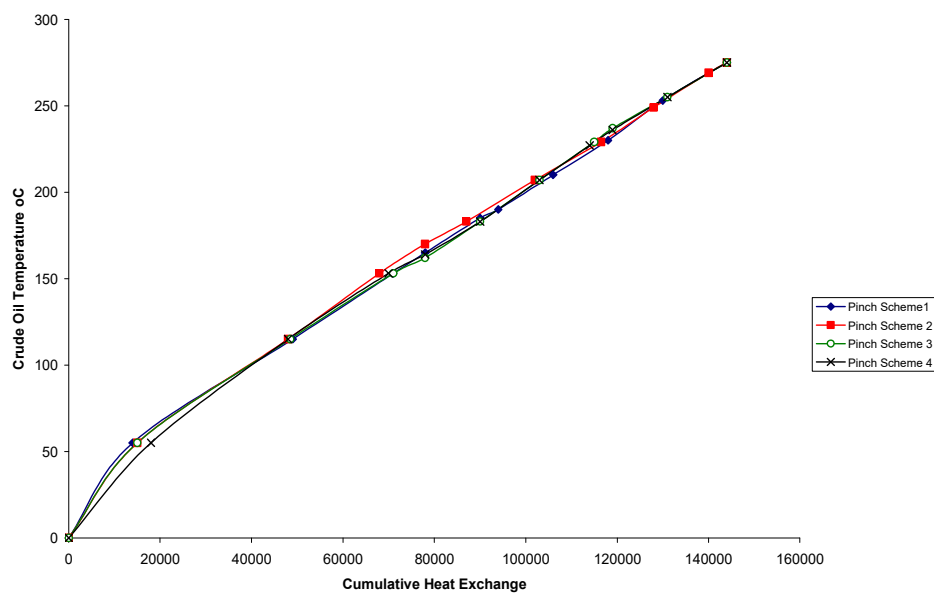


Figure 3. Crude Oil Temperature Profile Showing the Relationship between Pinch Scheme 1 to 4.

The temperature profiles of crude oil for each of the pinch schemes presented in Figure 3 show two distinct temperature regimes which were observed. While the first regime is between 0 and 110°C, the second occurs above 110°C. In the first regime, the relationship between cumulative heat exchange and crude oil temperature is exponential while from 110°C and above, it is linear. The plots give an indication that the crude oil temperature is expected to rise fast in the first temperature regime while subsequent temperature rise would be directly proportional to the heat exchange.

## 4. Conclusion

The objectives of this work as set out were fully actualized in that this research was based on a systematic and scientific retrofit procedure for effective management of energy utilization and energy auditing of Port Harcourt Refining Company (PHRC) heat exchangers. This was accomplished by the Hybrid Pinch Analysis. The possibility of exploring the retrofitting of the existing HENS using Pinch rules was conducted and the heat exchangers which constitute heat recovery bottleneck were identified and known as the culprit(s). These were the streams that violated the pinch rule number (3) and therefore depicted and presented retrofitting potentials. The process pinch point was discovered to correspond to a temperature of 188°C but in the base case the Pinch point was not known. This pinch point was debugged to make room for optimum heat exchange. The Pinch design targets a preheat temperature of 275°C in the crude oil while the existing scheme targets 242°C crude oil preheat temperature resulting in a 33°C heat recovery. Being an all heat process system, 33°C heat recovery is very remarkable. With a 33°C increase in preheat crude oil temperature there could be a higher product yield and quality improvement as well as release of less flue gases resulting in more environmental-friendly operations.

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