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Debottlenecking of Atmospheric Crude Distillation Unit of a Niger Delta Refineryfor Improved Heat Integration using Pinch Technology

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ABSTRACT: *Debottlenecking of atmospheric crude distillation unit of a Niger Delta Refinery (NDR)with a Petrochemical Unit, was carried out using pinch technology. This case study was aimed at improving the heat recovery and operational efficiency of the system.From the analysis, the pinch point was located at 247 ^{o}C with a target minimum heating and cooling duties of 80MW and 32MW respectively. The base case heat exchanger network performance indicated that the heating and cooling duties were above the target by 26% and 67% respectively. The result obtained from the debottlenecked heat exchanger network revealed energy savings of 41.32 MW which translated into 89% rate of return on investment.The pinch analysis showed that the actual heat exchanger network of the atmospheric crude distillation column was not efficient due to energy transfer bottlenecks caused by some cross pinch heat exchangers.*

KEYWORDS:*Debottlenecking, Atmospheric, Crude Distillation, Refinery, Pinch Technology, Heat Integration,.*

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I. INTRODUCTION

The petroleum processing industry is a capital intensive industry consuming much energy and the energy cost contributes significantly to the total cost [1]. To optimize profit in the industry during the energy crisis of the 1970sHohmann started a research on pinch technology, while Linnhoff and Flower developed some methodologies to advance the research. ICI plc took note of this promising technique and set up research and applications teams to explore and develop it and the technology has been employed on many chemical plants as well as in a wide range of industries [2], [3], [4].

The benefit of pinch technology includes lowering operating costs, de-bottlenecking of processes, raising efficiency and reducing capital investment [5], [6]. These are achieved through identification and quantification of the sources of inefficiencies, setting targets, and assessing the consequences of a potential modification before embarking on actual implementation [7], [5].

The refineries in Nigeria were built in the era of cheap energy, before the advent of pinch technology [5]. Therefore the design of these refineries was less than optimal with attendant issues ofexcessive energy loss, minimum energy recovery, poor processnetwork dynamics and control. Hence frequent shutdown of these refineries [6].

Currently, Nigeria has four refineries; three are located in the Niger Delta zone, with capacities ranging from of 60,000to 150,000 barrels per day whilst one is located in the North Central zone having a capacity of 110,000 barrels per day giving a total capacity of 445,000 barrels per day[8]. Yet, with these refineries, Nigeria does not have a stable supply of petroleum products mainly due to operational bottlenecks.

Therefore, the aim of this research is the application of pinch technology in debottlenecking the atmospheric crude distillation unit in aNigeria’s Niger Delta Refinery (NDR) to improve heat utilization, process integration and as well, evaluate the economic implication of the ensued modifications.

II. METHODOLOGY

2.1 Simulation

The base case for the atmospheric crude distillation unit of the NDR, was simulated using Unisim Design R380 and its preheating train is shown in fig.1. This base case consists of four (4) distillation columns, one (1) desalter, four (4) phase separators, several mixers and splitters, eighteen (18) heat exchangers, two (2) heaters and ten (10) coolers. The thermal data needed for the pinch analysis including the supply temperature (TS), target temperature (TT), heat capacity flow rate (CP), heat exchangers utilities and the duty (ΔH) of each stream were extracted from the base case simulation of the atmospheric crude distillation column and are shown in the Tables 1 and 2 for the cold and hot stream respectively.

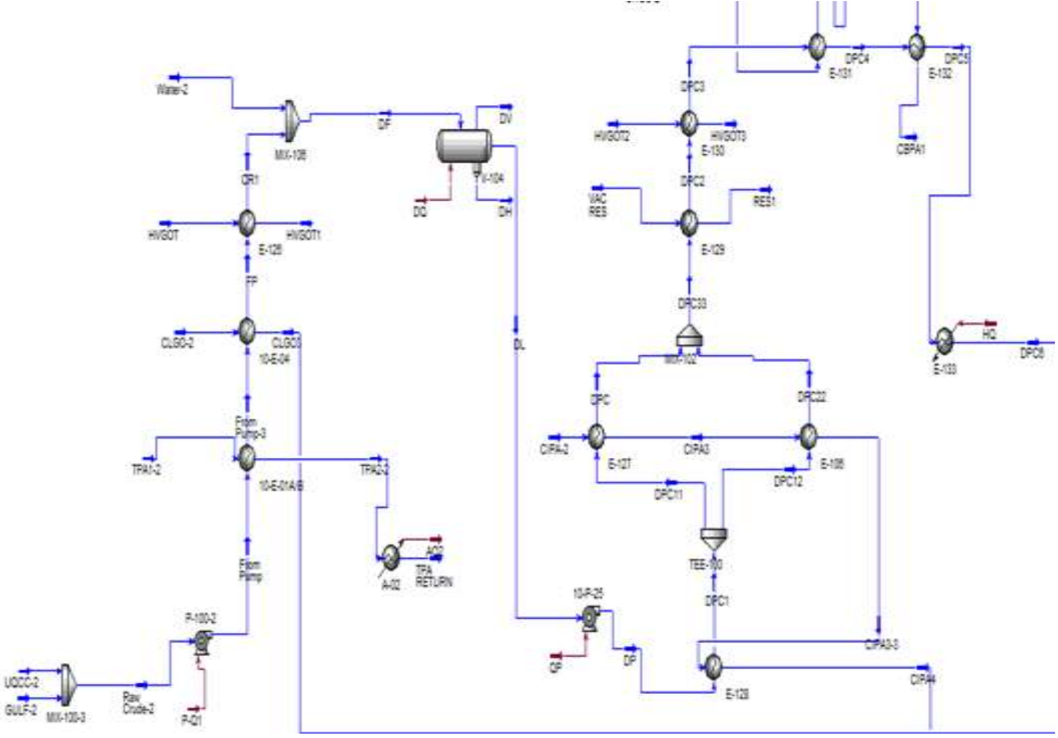

Fig.1. Preheating Train of NDR

Table 1. Cold Stream Thermal Data for Base Case Atmospheric Crude Distillation Column

STREAMS	EXCHANGER	TS	TT	ΔT	ΔH(MW)	CP(MW/C)
PF-FEED	E-01 A/B	35.54	68.48	32.94	15.56	0.472
	E-02	68.48	96.47	27.99	13.61	0.486
	E-04	96.47	130.5	34.03	17.5	0.514
	E-03 A/B	130.5	149	18.5	9.72	0.525
	E-17&E-18A/B	149	169	20	11.11	0.556
	E-06 A/B	169	190.1	21.1	11.94	0.566
	E-07 A/B/C	190.1	200.2	10.1	5.83	0.577
	E-05	200.2	212.2	12	7.22	0.602
	E-21	212.2	231.8	19.6	11.67	0.595
	H-02	231.8	240	8.2	8.06	0.983
STAB FEED	E-09	45.19	80	34.81	0.56	0.016
	E-11	80	120	40	0.71	0.018
SPLITTER FD	E-14	47.71	70	22.29	1.28	0.057
	E-15	70	99.76	29.76	1.61	0.054
	E-10	99.79	102.4	2.61	0.64	0.245
L-N PA	E-12	175.5	176.2	0.7	0.01	0.007
H-N PA	E-13	99	103.9	4.9	0.14	0.029
ATMOS FD	E-08 A/B	232.6	240.7	8.1	4.44	0.548
	E-22	240.7	281	40.3	27.50	0.682
	H-01	281	350	69	98.03	1.421

Table 2: Hot Stream Thermal Data for Base Case Atmospheric Crude Distillation Column

STREAMS	EXCHANGER	TS	TT	ΔT	ΔH(MW)	CP(MW/C)
VACCU-RES	E-22	365	280.1	84.9	27.39	0.323
	E-06 A/B	280.1	240	40.1	12.00	0.299
HGO	E-05	331	222.6	108.4	7.08	0.065
	E-11	222.6	210.9	11.7	0.69	0.059
	A-09	210.9	60	150.9	8.17	0.054
BPA	E-21	302	292	10	11.94	1.194
HVGO	E-08 A/B	292.2	261	31.2	4.64	0.149
	E-07 A/B/C	261	230	31	7.33	0.236
	E-04	230	130	100	17.44	0.174
LGO	E-12&E-13	258.8	249	9.8	0.05	0.005
	E-02	249	152	97	13.53	0.139
	A-04/07	152	70	82	9.03	0.110
	D-07	70	55	15	1.52	0.101
IPA	E-17&E-18A/B	232.6	189.5	43.1	10.97	0.255
	E-03 A/B	189.5	147.7	41.8	10.00	0.239
KERO	A-03	194.9	50	144.9	3.40	0.023
PF-PA	E-15	182.5	130	52.5	1.61	0.031
TPA	E-01 A/B	186.5	105	81.5	15.56	0.191
	A-02	105	96.45	8.55	1.50	0.175
ATM OVHD	A-01	156.1	55	101.1	20.64	0.204
H-HAPHTHA	E-14	119.8	97.5	22.3	1.14	0.051
	E-09	97.5	86.22	11.28	0.56	0.050
	A-08	86.22	40	46.22	2.16	0.047
L-NAPHTHA	E-10	197	140	57	0.63	0.011
	E-16	140	40	100	0.91	0.009
PF OVHD	A-05	134.2	45	89.2	7.19	0.081
L-NAPHTHA2	A-06	68.31	40	28.31	1.93	0.068
LPG	A-07&E-25	134.7	40	94.7	0.40	0.004

2.2 Construction of Composite Curves and Heat Exchanger Network Grid

The composite curves (figs. 1 & 2) and the heat exchanger network grid (figs. 3 & 4) were constructed with Aspen Pinch 11.1, using the thermal data in table1 and table2 as input. These curves were evaluated at a ΔT_{min} of$30^{o}C$ [9]. In the heat exchanger grid, the streams are drawn as horizontal lines, with high temperatures on the left. The hot streams are drawn on top while the cold streams below. The heat exchangers are represented by two circles joined by a vertical line while for the heat exchangers that cross the pinch, a bar is attached to the stream entering it [4],[6].

2.3 Economic Analysis

The fixed capitalcost (FCC) of the retrofit HEN was estimated using the factorial method for capital cost estimation, eqn. (1) and (2). Where PPC is the physical plant cost and PCE is the physical cost of equipment. The variable "f_n" are typical factors for estimation of project fixed capital cost, the values of these factors,f_1, f_2 ... f_{12} are adapted from Sinnot (2003)[10]

$$FCC = PPC(1 + f_{10} + f_{11} + f_{12}) \qquad (1)$$

$$PCC = PCE(1 + f_1 + f_2 + \cdots f_5)(2)$$

The heat exchangers cost (PCE) were estimated using eqn. (3). The base cost (C_B) and base capacity (K_B) are adapted from Roman and Simon (2013) [11]. The chemical engineering plant cost index (CEPCI) was used to update base cost to 2018.

$$PCE = C_B \left(\frac{K}{K_B}\right)^m CEPCI_{HX} \ (3)$$

The operating cost ofaheat exchanger which takes into account the pressure drop constraint in the system is expressed in equation (4) [12].

$$C_o = K_{el}\tau(1 + x)\frac{\Delta PV_t}{\eta_p} \qquad (4)$$

Where K_{el} is price of electric energy ($/Mwh), τ is hours of operation per year (h/yr), x accounts for the pumping power required on the other side of the heat exchanger. ΔPis pressure drop across the heat exchanger (Pa), V_t is volumetric flowrate ($M^3 s^{-1}$), η_p is pump efficiency (dimensionless)

Expanding equation (4), equation (5) is obtained which is used in this work for the estimation of the operating cost of the shell and tube heat exchangers,

$$C_o = K_{el}\tau\left(\left(\frac{\Delta PV_t}{\eta_p}\right)_{shell} + \left(\frac{\Delta PV_t}{\eta_p}\right)_{tube}\right) \qquad (5)$$

The payback period (PBP) was obtained from equation (6), where the annual cash flow (profit) was defined as cost of energy recovered by retrofit, less the annual operating cost. The unit cost of energy is adapted from Oludare (2015) [13].

$$PBP = \frac{\text{initial investment}}{\text{annual cash flow}} \qquad (6)$$

III. RESULTS AND DISCUSSIONS

3.1 Pinch Analysis Target Results

The composite curve fig. 2 which was evaluated at ΔT_{min} of 30^{o}C [9] using Aspen Pinch for the preheatingtrend in NDR crude distillation unit. The overlap between the hot and cold composite curves is 166MW, representing the maximum amount of heat recovery possible within the process. The “overshoot” at the bottom of the hot composite is 32MW, representing the minimum amount of external cooling required and the “overshoot” at the top of the cold composite is 80MW, representing the minimum amount of external heating. .

Fig. 2.showsthat the composite curve is dissected at the pinch. The pinch temperature is 262.6^{o}C for the hot stream and 232.6^{o}C for the cold stream.Above the pinch (i.e. in the region to the right) the hot composite transfers all its heat into the cold composite, leaving only the utility heating required. The region above the pinch is therefore a net heat sink, with heat flowing into it but no heat flowing out. It involves heat exchange of hot utility. Conversely below the pinch cooling only is required and the region is therefore a net heat source, requiring heat exchange of cold utility.

The Grand Composite Curve (GCC) in fig.3 provides further insights about energy flows within the process, as well as allowing a good overview of how to select suitable utility levels for heating and cooling the process. The target from GCC indicated that the system has a minimum heating load of 80MW at 364^{o}C and a minimum cooling load of 32MW at 25^{o}C. The cooling utility from the target is cheapcompared to the heating utility since it targeted at room temperature, no refrigeration is required. However, the heating load at a high temperature of 364^{o}C requires the use of a fired heater.

The GCC indicated that the system has a double pinch temperature, since there are two peaks which are close to being a pinch. The implication is that the system is sensitive to changes, any of the two peaks can become the main process pinch if a small change of process pinch stream data is made.

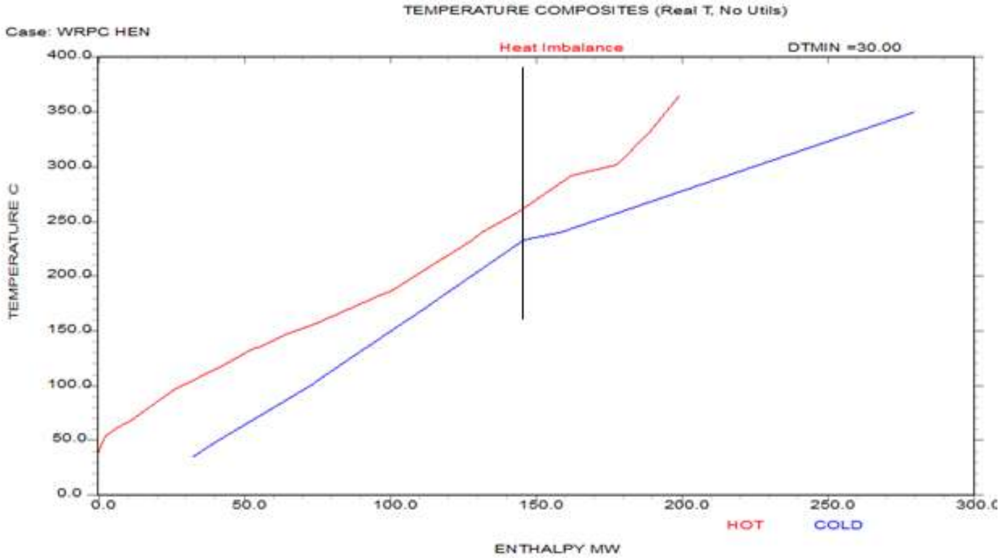

Fig. 2: Composite Curve for the NDR

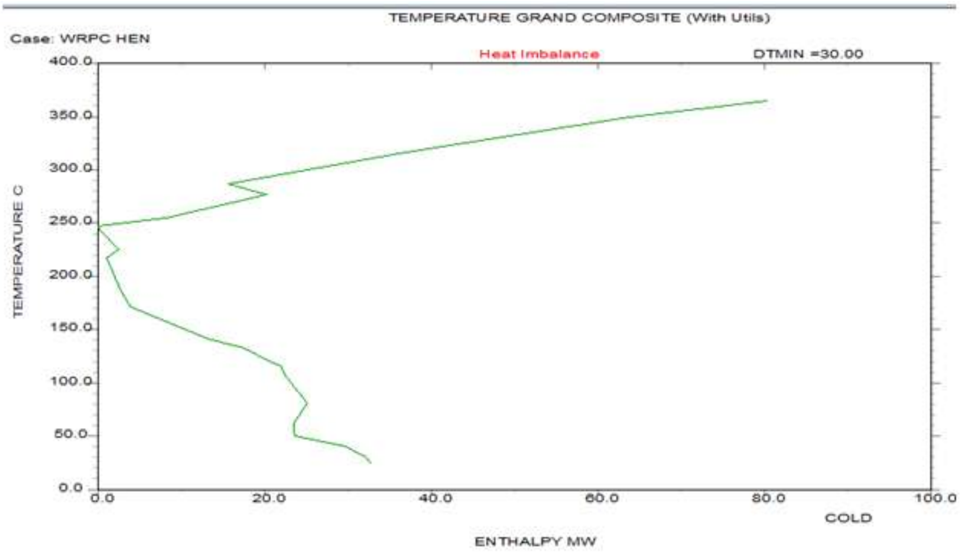

Fig. 3. Grand Composite Curve for the NDR

3.2 Heat Exchanger Network Performance

The base case heat exchanger network performance was evaluated based on the targets as shown in Table 2. The heating value is above the target by 26% and cooling value is above the target by 67%. This increase in the heating and cooling load is due to violation of pinch rule as shown in the base case HEN of NDR fig. 3. There are 3 heat exchangers violating the pinch rule, these culprit heat exchangers are clearly identified by the vertical lines attached to horizontal bars running (crossing) from left to right of the pinch location. The consequence of across pinch heat transfer is that both the cold and hot utility will increase by the cross-pinch duty[14].

3.3 Retrofit Design

Three approaches are possible for retrofit of HEN [4]. These include; starting with the existing network and working towards a maximum energy recovery (MER) design; developing an MER design as for a new plant but where choices exist favoring matches which already exist in the current networks; and starting with the existing network and identifying the most critical changes required in the network structure to give a substantial energy reduction.

Table 2: Base Case Heat Exchanger Network Performance

parameter	network value	target	% deviation
heating value (MW)	101.17	80	26.4625
cooling value (MW)	53.44	32	67
total energy demand (MW)	**154.61**	**112**	

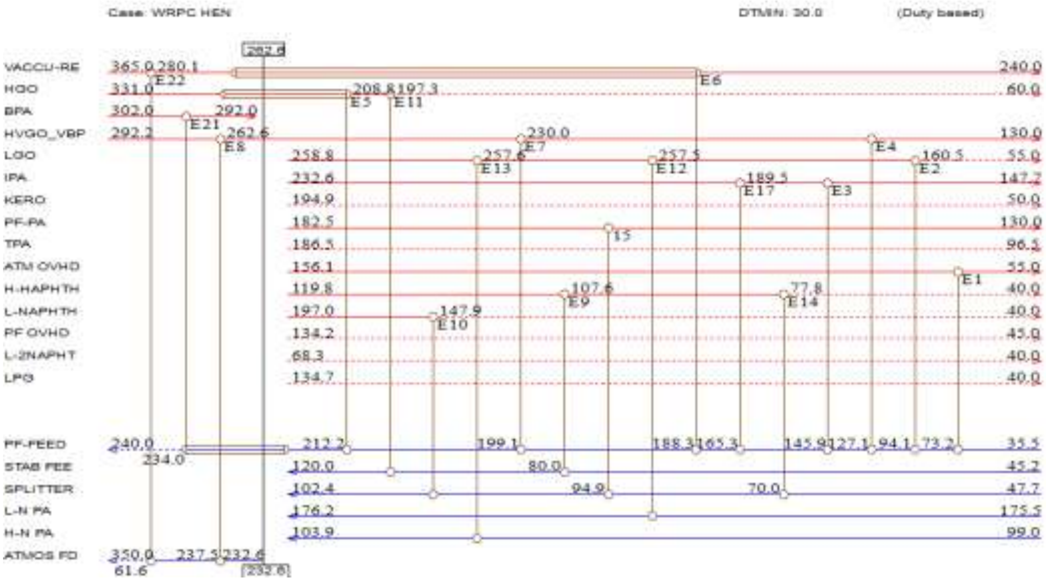

Fig. 4. Base Case Heat Exchanger Network (HEN) Grid of NDR

The later approach was adopted in this work, since starting with the existing network and working towards an MER gives an added advantage by minimizing the cost of re-piping in the HEN. Thus from the base case HEN diagram fig. 4, we look to see which of the heat exchangers are the pinch violators. Three pinch crosses were associated with, heat exchangers E5, E6 and E2.We then identify ways to add new matches to correct these problems. Four additional heat exchangers were added in the retrofit, fig. 5; HX1, HX2, HX3 and HX4, they are the shaded heat exchangers. The dotted red line depict the heating duty and the dotted blue lines the cooling duty as shown in fig. 4. The stream target and supply temperature (^{o}C) are the numbers at the two extremes of the dotted line. Thus the cooling/heating duties are CPΔT. Therefore, energy demand after retrofit is 32.86MW for cooling and 80.43MW for heating. Comparing energy demand in the retrofit with the energy target obtained in compositeand grand composite curves, figs. 2 and 3 respectively, maximum energy recoveryhas been achieved in the retrofit HEN.

3.4. Economic Analysis

The total energy demand in the retrofit HEN is 113.29MW while the total energy demand in the base case HEN is 154.61MW. therefore, the total energy recovered by retrofit is 41.32MW and this amounts to $39,667,200 at an energy cost of 0.12 $/KWH.

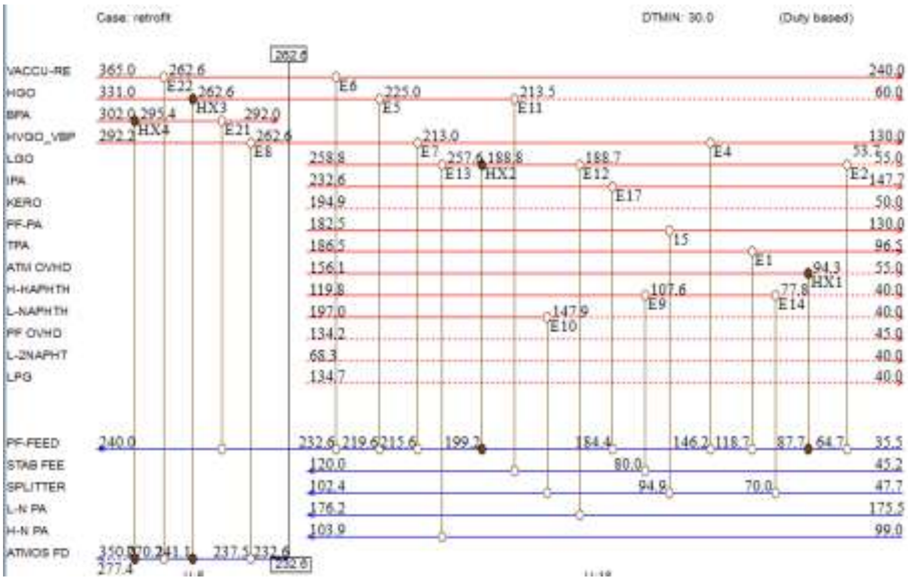

Fig. 5: Retrofit HEN of NDR

If the heat exchangers are operated for 8000 hours annually, with pump efficiency of 0.7, an annual operating cost of $33,491,069 is incurred by the four additional heat exchangers introduced in the retrofit HEN design. Considering the amount recovered from retrofit annually and the annual operating cost, an annual cash flow of $6,176,131 is expected.

A fixed capital cost of $6,933,714 was estimated for the retrofit HEN. Therefore, the rate of return (ROR) on investing in the retrofit HEN design in the atmospheric crude distillation unit of NDR is 89% and the payback period is 13 months.

IV. CONCLUSION

The base case of the NDR was simulated using Unisim Design. Pinch technology was applied in the base case design to locate bottlenecks in energy utilization and to establish of the scope for improvement. The pinch analysis revealed that the actual heat exchanger network of the atmospheric crude distillation column of the plant is not efficient due to energy transfer bottlenecks caused by cross pinch heat exchangers. The result obtained from the debottlenecked heat exchanger network gave energy savings of 41.32MW which translated into 89% rate of return on investment.

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