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ENERGY INTEGRATION OF BUTENE-1 PRODUCTION PLANT USING PINCH TECHNOLOGY

Akpa Jackson G.
Department of Chemical/Petrochemical Engineering Rivers State University Port-Harcourt, Rivers State, Nigeria

Uzono .Romokere I.
Department of Chemical/Petrochemical Engineering Akwa ibom State University Port-Harcourt, Rivers State, Nigeria

Dagde Kenneth K.
Department of Chemical/Petrochemical Engineering Rivers State University Port-Harcourt, Rivers State, Nigeria

ABSTRACT: *The increasing cost and environmental challenges associated with fossil fuels has led organizations to carry out regular energy audits and hence enforcing stringent laws to maximize and reduce cost of energy. In Nigeria, most chemical plants were built in the era when there were little or no knowledge of the concept of energy integration due to availability of cheap utility. It becomes imperative to subject such plants to various heat integration techniques to check for potential energy savings. Pinch technology is considered a straight forward, simple and efficient method for heat integration. In this research, pinch technology was used to evaluate the heat exchanger network of the Butene-1 unit of the Indorama Petrochemical Company Eleme for potential energy savings. The unit was simulated using ASPEN HYSYS (V.8.6). Process data were extracted from the simulation results and supplied to HINT (V.2.2) software for analysis. The minimum utility requirements and Pinch Temperature (57^{o}C) were obtained from the composite curve, cascade diagram and grand composite curve. The proposed retrofit heat exchanger network revealed a hot and cold utility requirement of 1064.05kW and 204.85kW respectively, compared to the hot and cold utility requirement of 1113kW and 364.46kW respectively of the existing HEN. This showed an energy savings of 4.4% for cold utility and 43.79% for hot utility. Cost evaluation of the proposed HEN was carried out, with a total annual cost of $1,971,977.267.*
KEYWORDS; Energy Integration, Butene-1, Pinch Technology

INTRODUCTION

Efficient energy management and the environmental challenges associated fossil has been a bottleneck in the process industry from the onset. Good energy management will increase profitability and cause reduction in material and energy consumption. Hence, researchers have delved into the study to enhance performance of already existing plant whiles increasing the profit margin of the plant and simultaneously reducing the effect of fossil fuel in the environment (Nakata 2004).

Energy integration is a subdivision of a broader field of process integration, Process integration can lead to a substantial reduction in energy, raw materials and water consumption which subsequently reduces the operating cost of the process whiles

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increasing profit. When process integration is applied with the aim of reducing energy consumption it is termed energy integration (Akpa & Okoroma 2012). Prior to the birth of Pinch technology, energy integration was done using the traditional energy balance but in recent times powerful simulation tools have been developed to carry out energy integration using pinch analysis which poses extinction to the traditional approach.

Pinch technology is an efficient method of energy integration based on the fundamental principles of thermodynamics. Several studies have been carried out using pinch techniques with the aim of optimizing energy in plants with intensive energy consumption using; Akpa and Okoroma (2012) presented their findings of Pinch method in the heat exchanger network of the Port Harcourt refinery. The result obtained indicated ten heat exchangers were not properly place and by implication 98916.1kW of hot utility and 8298.7kW of cold utility were not utilized. Piagbo and Dagde (2013) applied pinch analysis to the crude distillation unit of the Port Harcourt refinery, the researchers reported an estimated 84.62% and 92.31% reduction in the number of the heat exchangers used and the number of shells respectively. Also, 16.57%, 2.74%, and 13.98% reductions in the operating cost, capital cost and total cost respectively. The vacuum distillation unit of the Kaduna refinery Nigeria was subjected to Pinch analysis by group of researchers (Adejoh *et. al.*, 2013). They compared the use of the traditional approach and Pinch approach. The cold utility requirement for the traditional approach and pinch analysis were found to be 0.31MW and 0.19MW respectively, while the ho t utility requirement was found to be 0.32MW and 0.24MW. Fernwicks *et. al.*, (2014) studied the orbit Chemical industry in Kenya and published a result that showed reduction of existing nine heat exchangers to seven with a payback period of 14yrs and annual savings of 11.4%

1.1 Process Description

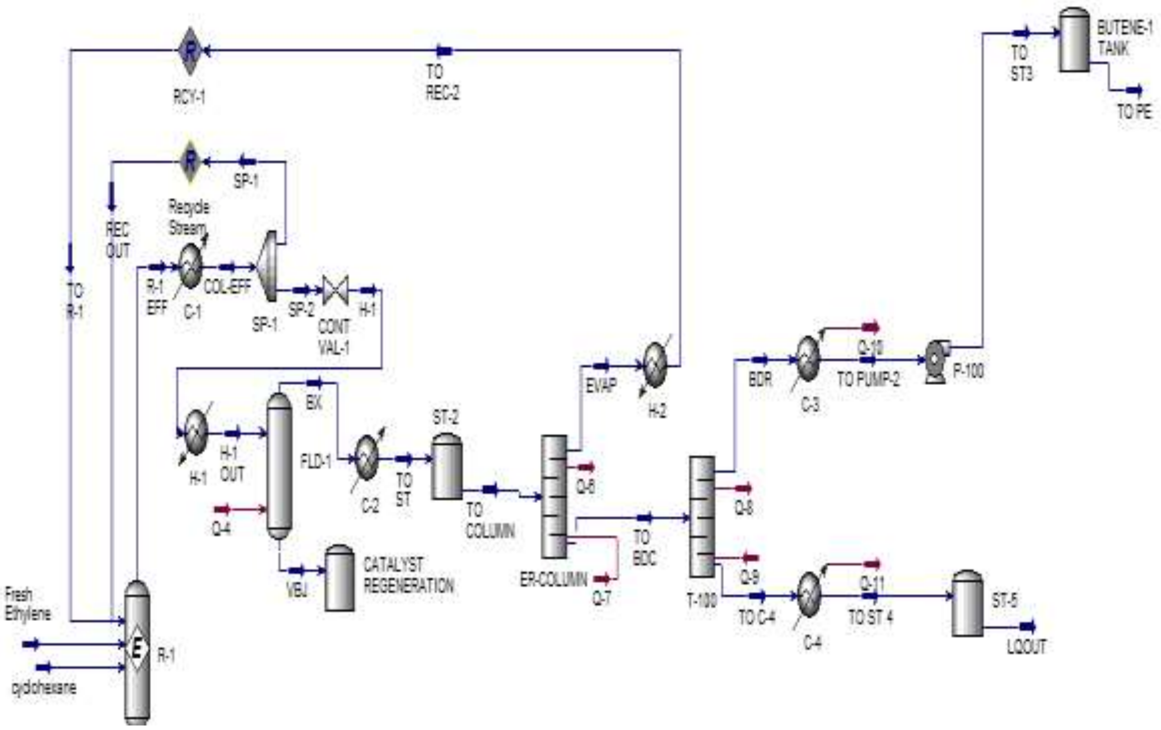

Figure 1: PFD from HYSYS simulation of butane-1 unit

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Fresh Ethylene is charged into the reactor which operates at optimum Temperature of 51℃ and pressure of 25bar along with cyclohexane which is spurge into the reactor. The cyclohexane does not in any way reacts but ensures that the reactions occurs in the liquid phase. The reactor operates in the form of a continuous stirred tank reactor CSTR only in this case the Recycle stream acts in form of a stirrer whiles the valve V-1 is closed.

$$2C_2H_4 \rightarrow C_4H_8 \quad (1)$$

The resident time for reaction to occur is 5hrs. within this period the valve attached to the reactor effluent is closed until ΔT of the reaction is within 4°C – 5℃ , this indicates that reaction has occurred.

The cooler, C-1 ensures that the temperature within the reactor is maintained at 51℃ to avoid polymer (polyethylene) formation along the tubing which could result to blockage. Hence, Temperature control of the reactor, R-1 is very important.

After reaction is established, the effluent comprises; 78.29% Butene-1, 9.7% unreacted ethylene, 4.3%. 5% spent catalyst and 7.71 C^{6+}

Effluent from reactor R-1 is subjected to series of unit operations to ensure total recovery of Butene-1 which is our product of interest. Therefore, prior to the various unit operations a deactivator (Amine) is introduced to terminate the reaction. This is necessary to prevent unreacted ethylene from being converted to polyethylene in the flash drum.

The effluent is heated from 50℃ to 110℃ before it is sent to the flash drum. The essence of this operation is to recover spent catalyst. The bottom product of the FD-1 is sent to the thin film evaporator for catalyst recovery. The overhead product of FD-1 which is composed of 83.49% of butene-1, 1.114% unreacted ethylene, 1.573% Triethylaluminate, 8.34% cyclohexane and 5.47.11% C^{6+} is stored temporarily in a drum before it is pumped to the ethylene recovery column. Ethylene recovered is recycled back to the reactor. The bottom product is further sent to a second column to obtain about 99.78% Butene-1 while C^{6+} is cooled and sent to storage.

MATERIALS AND METHODS

Materials

The materials used include; The process flow diagram of the butene-1 unit of Indorama petrochemicals, the heat exchanger data specification sheet, Operating data of the butene-1 unit, Simulation software, HYSYS version 8.6 and Pinch Analysis Application Software HINT-2.2

Table 2.1: Process stream data from PFD of EPCLbutene-1

S/N	Energy Stream	Unit Opps.	Process Temperature (℃)		Flow Rates	Duty
			Inlet	Outlet	T/h	(kw)
1	Q-2	C-1	51	45.00	4.5	4906.43
2	Q-3	H-1	45.00	110	1.4	923.55
3	Q-4	FLD-1	105.00	148.00	1.4	1117.67
4	Q-5	C-2	140.00	120.00	1.29	488.45
5	Q-6	ER-COL	n.a	n.a	n.a	Sensible
6	Q-7	ER-COL	n.a	n.a	n.a	Sensible
7	Q-8	BD-COL	n.a	n.a	n.a	Sensible
8	Q-9	BD-COL	n.a	n.a	n.a	Sensible
9	Q-10	C-3	88.00	25.00	2.15	243.98
10	Q-11	C-4	210	37.00	1.69	188.70
11	Q-12	H-2	-32	51	0.0027	0.475

Methods

Extraction of Stream Data from PFD

Stream data were gathered from the plant material and energy balance flow sheets obtained from EPCL operating records. these data consist of the streams supply and target Temperatures and the heat exchanger heat loads. it is imperative to extract these stream data during stable plant operation as suggested by Kemp (2007). Hence, sequel to these suggestions plant data were extracted during stable plant operations

Process Simulation

Production of butene-1 through Ethylene dimerization in the presence of Triethyl aluminate $(C_2H_5)_3Al$ catalyst was simulated using aspen **HYSYS** version 8.6. The plant capacity is 2.5tons of butene-1 per hour. The process conditions used where those obtained from the plant as shown in Table 2.1, standard property table was also used to obtain physical properties of reacting species

Determination of Optimum ΔT_{min}

The selection of ΔT_{min} greatly affects capital and energy cost. Energy cost increases approximately proportional with ΔT_{min} while capital cost decreases spontaneously with ΔT_{min}

The data obtained from the simulation result was imputed into the software hint 2.2 and the ΔT_{min} analysis was carried out at different temperature values using a range of 1°C-

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20°C. The analysis to obtain optimum ΔT_{min} was based on comparing the variation of ΔT_{min} with the operating cost, capital Cost, utility requirement and Pinch temperature.

Super Energy Targeting and Optimum ΔT_{min}

The main objective of super energy targeting was to analyze the existing network based on selected value of minimum Temperature for potential energy and cost savings. Thermodynamic profiles of the process using the Composite Curves (CC) and the grand composite curve were studied to determine the targets for the hot and cold utilities and the position of the pinch (Smith, 2004).

HEN Modification for Maximum Energy Recovery (MER) and HEN Relaxation

In other to achieve the energy targets a new heat exchanger network was designed with the aid of HINT 2.2. Heat exchangers violating the pinch rules i.e. working across the pinch and inefficiently placed. To do this, an algorithm was developed to act as a guide for MER above and below the pinch shown in figure 2.1 and 2.2.
The HEN was further relaxed to simplify the network and thus eliminate heat exchangers with small duty.

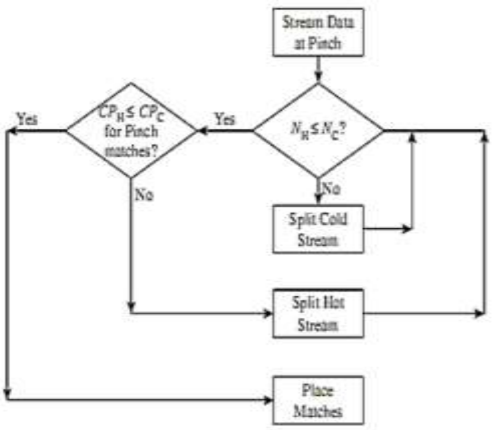

Figure 2.1: Algorithm for Above the Pinch analysis

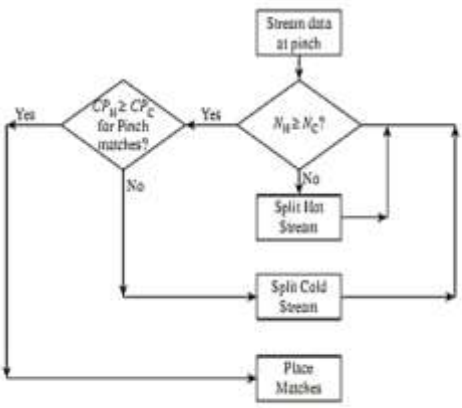

Figure 2.1: Algorithm for below the Pinch analysis

Cost Implication of Retrofit Design

The cost analysis was carried out for the final HEN developed using a plant life of 10 years.
Linnhoff and Ahmad (1990) reported the total annual cost in their study, the function they developed can be logically summarized as follows.

$$T_{ac} = I_n C_c + C_p + C_U \qquad (3.7)$$

Where,

T_{ac} total annual cost
I_n investment factor,
C_c capital cost of heat exchangers
C_p cost of power
C_U cost of utility

ISSN 2055-0197(Print), ISSN 2055-0200(Online)

RESULTS AND DISCUSSION

Results

This section of the research presents results obtained from application of Pinch technology on the Butene-1 unit of EPCL, beginning with comparing plant data with simulated data and energy targeting. Also, this section further presents the evolution of the proposed HEN for the MER and how the HEN was relaxed using the pinch relaxation principle in form of grid diagram. Finally, cost analysis of process retrofit was exhaustively discussed.

The data obtained from the simulation results were categorized into hot, cold and utility streams before it is imputed into the pinch software (HINT-2.2) for optimum ΔT_{min} analysis. The analysis was based on variation of ΔT_{min} with pinch Temperature, capital cost, operating cost and utility cost. The analysis was carried out between the range of 1^{O}C and 20^{O}C

Stream	Inlet Temperature (ºC)			Outlet Temperature (ºC)			Heat Duty (kW)		
	Plant	Simulation	% Deviation	Plant	Simulation	% Deviation	Plant	Simulation	% Deviation
Q-2	58	56	3.44	45	47	4.44	5506.09	5938.33	7.84
Q-3	45	47	4.44	115	110	4.54	850.56	808.33	4.94
Q-4	105	110	4.76	140	148	5.71	1117.67	1050.44	6.01
Q-5	140	148	5.74	110	120	9.09	488.45	500.27	2.36
Q-6	n.a	n.a	n.a	n.a	n.a	-	Sensible	-0.6896	-
Q-7	n.a	n.a	n.a	n.a	n.a	-	Sensible	18.085	-
Q-8	n.a	n.a	n.a	n.a	n.a	-	Sensible	-331.295	-
Q-9	n.a	n.a	n.a	n.a	n.a	-	Sensible	532.206	-
Q-10	88	86.6	1.59	25	25	0	243.98	263.28	7.94
Q-11	210	204.8	2.4	35	37	5.71	188.70	195.92	3.83
Q-12	-32	-32	0	48	51	6.25	0.475	0.332	3.00

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Table 3.1: Comparison of Simulated and plant data

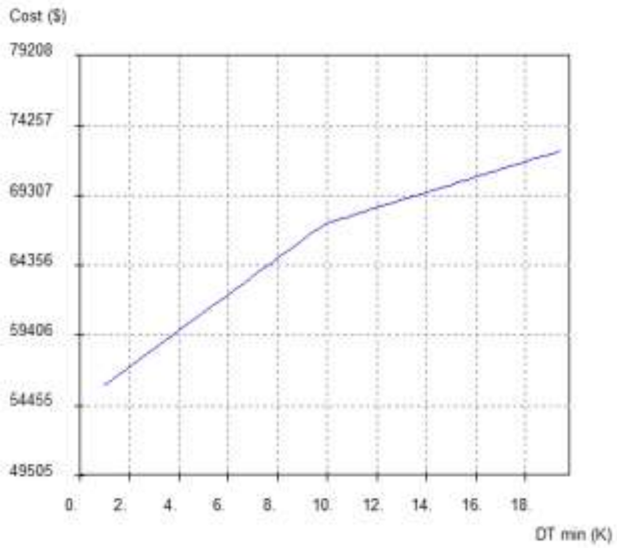

Figure 3.1: variation of minimum temperature and operating cost

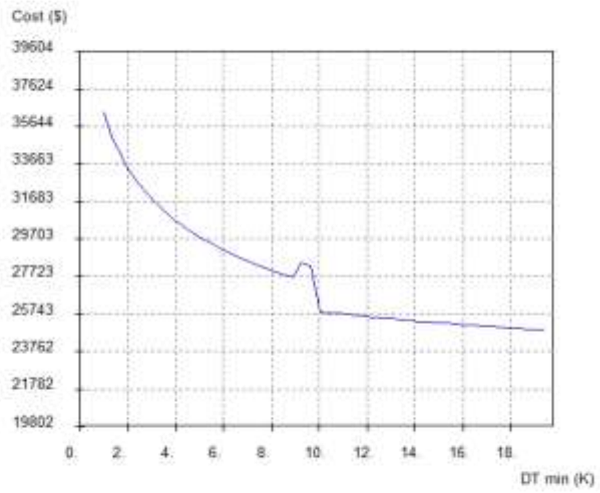

Figure 3.2 Variation of minimum Temperature and capital cost

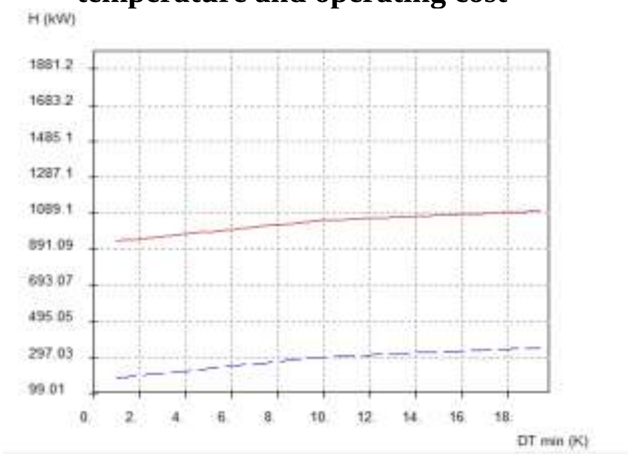

Figure 3.3 variation of minimum Temperature and utility requirement

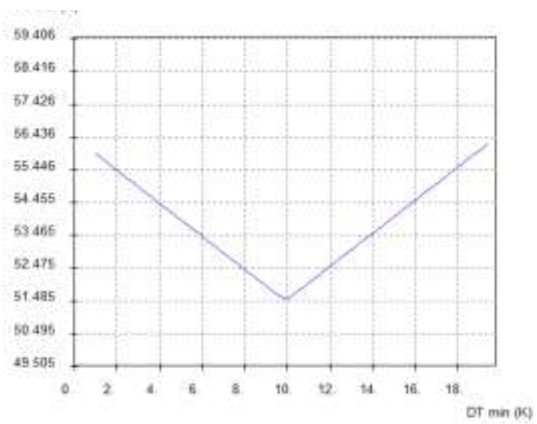

Figure 3.4; Variation of minimum Temperature and pinch Temperature

Having obtained an optimum value for ΔT_{min} energy targeting was carried out to obtain the minimum cold and hot utility requirement of the plant based on the optimum ΔT_{min} from composite curves (Costa and Queiroz 2009) .

ISSN 2055-0197(Print), ISSN 2055-0200(Online)

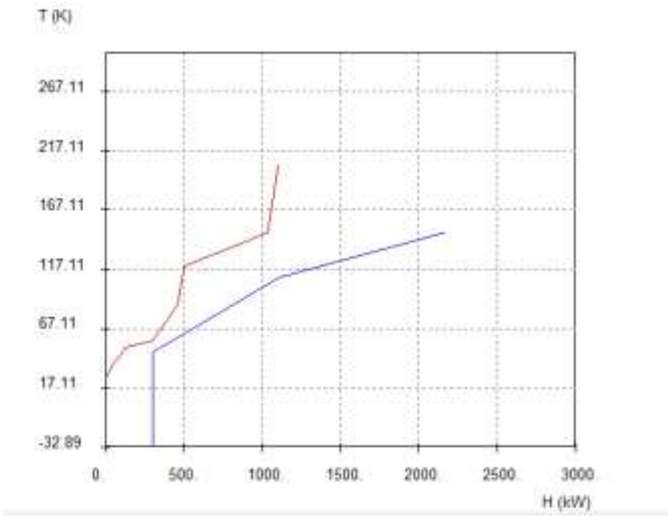

Figure 3.5: Composite curve of Butene-1-unit minimum temperature of 10^{0}C

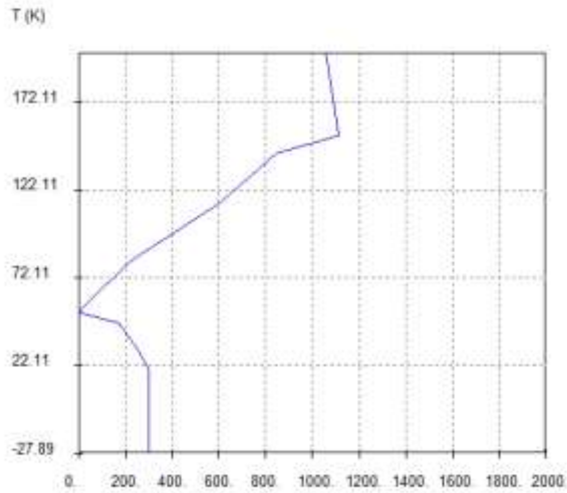

Figure 3.6 Grand composite: curve

Energy Target	Value From CC And Cascade
Minimum hot utility requirement $Q_{H,MIN}$	1064.05KW
Minimum cold utility requirement $Q_{H,MIN}$	204.56KW
Process pinch	57℃
Minimum number of units	8

Figure 3.5: Composite curve of Butene-1-unit π
temperature of 10^{0}C

ISSN 2055-0197(Print), ISSN 2055-0200(Online)

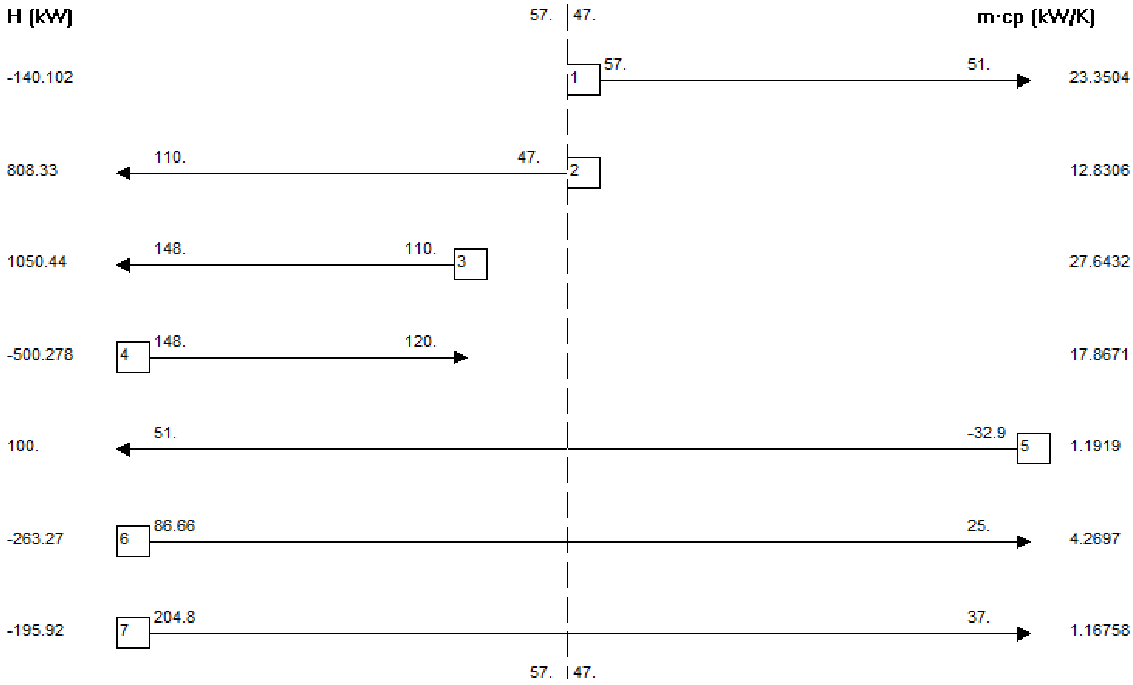

Figure 3.7: Grass root Heat exchanger network at $\Delta T_{min} = 10$℃.

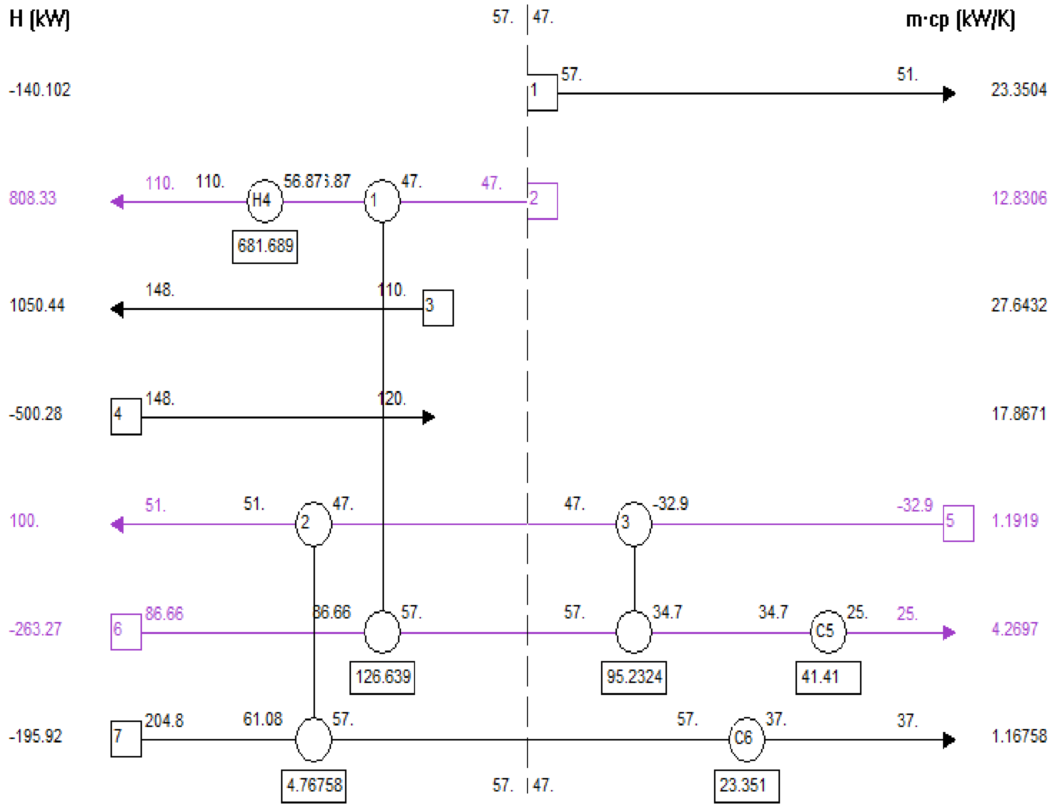

Figure 3.8: HEN for Maximum Energy Recover

ISSN 2055-0197(Print), ISSN 2055-0200(Online)

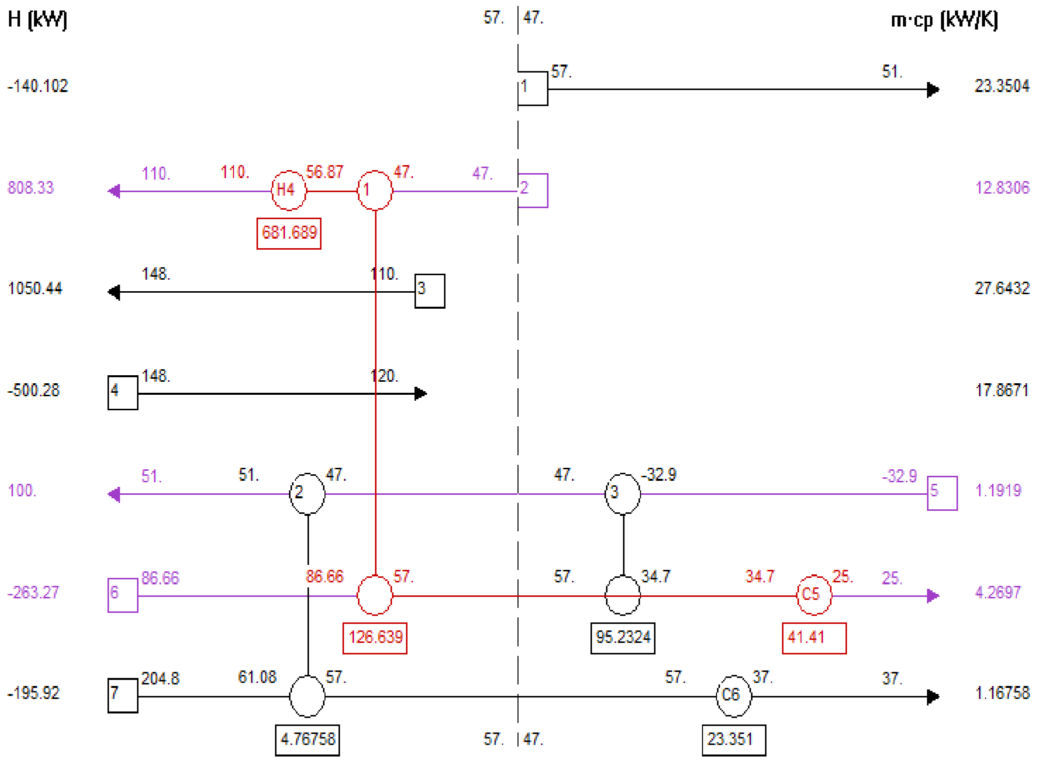

Figure 3.9: Preliminary relaxed HEN for MER showing path 4-1-5

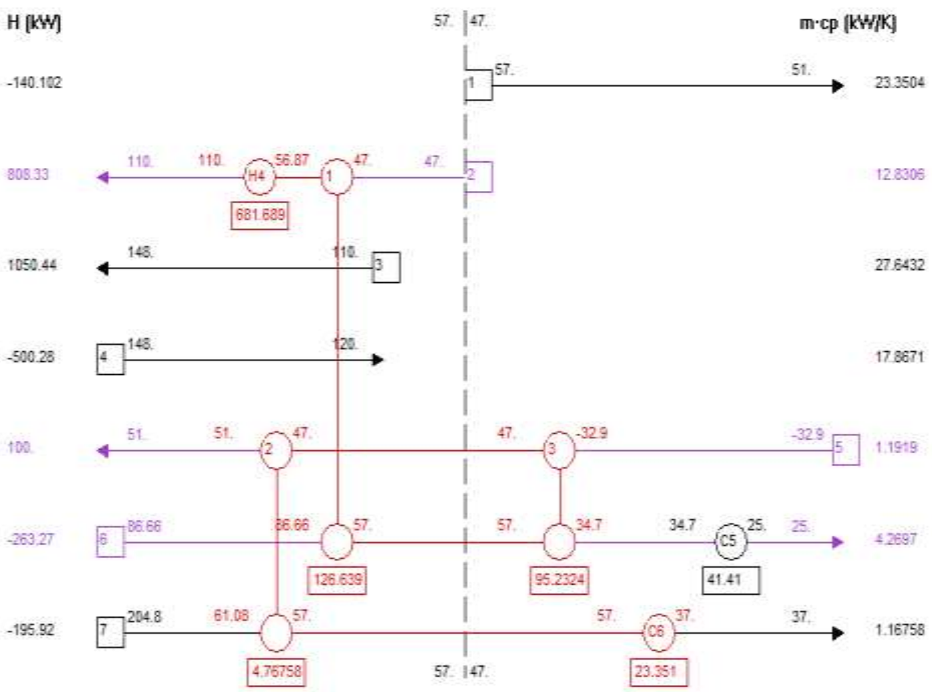

Figure 3.10: Preliminary relaxed HEN for MER showing path 4-1-3-2-6

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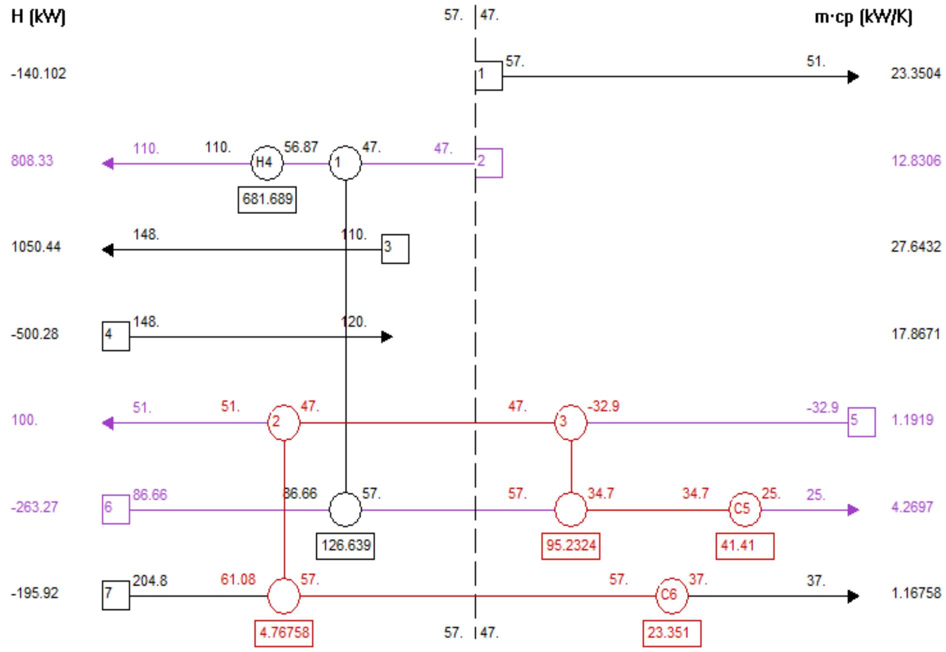

Figure 3.11: Preliminary relaxed HEN for MER showing loop 6-5-3-2-6

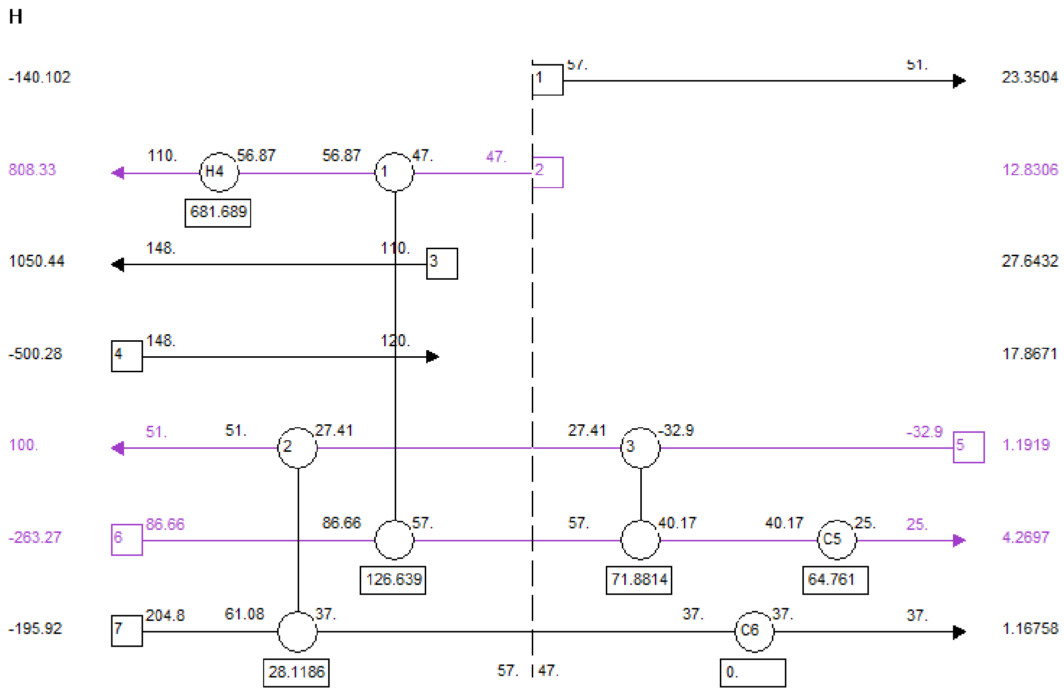

Figure 3.12: Final Relaxed HEN for MER

ISSN 2055-0197(Print), ISSN 2055-0200(Online)

DISCUSSION OF RESULTS

Comparing Simulation Results and Plant Data

Table 3.1 shows the comparison of data obtained from EPCL operational manual and the data obtained from simulation. The percentage absolute deviation of the inlet temperatures, outlet temperatures, heat duties were calculated. This is necessary to check the magnitude of the deviation of the simulated plant from the real plant.

Optimum Analysis

The operating cost of a process plant is a function of the external utility requirement of the plant, increase in ΔT_{min} value will increase the utility requirement and thus the cost of operating the plant (Rev & Fonyo 1991). For Petrochemical industries values of ΔT_{min} ranges between $10^{O}C$-$20^{O}C$ (Linnhoff & Flower 1978). Though this analysis considered Temperature range between $1^{O}C$ – $20^{O}C$.

From Figure 3.1, increase in ΔT_{min} shows a corresponding increase in operating cost, this trend continued till ΔT_{min}value equals 10°C, above 10°C there was a corresponding increase although not as rapid as it were below 10°C. ΔT_{min}=10 gave the optimum operating cost of $66,831.5. The trend of the graph conforms to the thermodynamic principle that the operating cost of Heat transfer is directly proportional to the value of ΔT_{min}.

The implication of increasing the value of ΔT_{min} from elementary thermodynamics will require more utility requirement and this will in turn cause a corresponding increase in the cost of operating the plant.

Capital cost is a function of heat transfer area, the heat transfer area increases as ΔT_{min} reduces and hence a corresponding increase in capital cost (Gundersen and Naess, 1988). This is shown in Figure 3.2, as the ΔT_{min} reduces there is a corresponding increase in the capital cost, above ΔT_{min}=10° C there is sharp increase in capital cost resulting to an oblong like shape. The optimum ΔT_{min} value lies between 9°C-10°C. for the purpose of this research a ΔT_{min}=10°C was chosen and it Gives capital cost of $25,743

In Figure 3.3 The red line shows how the hot utility varies with ΔT_{min} while the blue line indicates ΔT_{min} variation with cold utility. Utility requirement varies directly with ΔT_{min}, above 10°C the utility requirement for both and cold utility begins to increase and below 10°C the utility for both cold and hot streams reduces. From Figure 3.3 ΔT_{min} of 10°C gave hot and cold utility requirement of 1064.05kW and 204kW respectively.

Figure 3.4 shows the how ΔT_{min} changes with the pinch Temperature. Below and above 10°C the pinch temperature increases. From the diagram the optimum value for ΔT_{min} is 10°C

Sequel to the optimum ΔT_{min} analysis carried out in section 4.3 value of 10°C was the optimum minimum temperature difference. This implies that at any point in the process hot stream Temperature. T_H – Cold stream Temperature, T_C = ΔT_{min} = 10°C. This value indicates how the hot and cold composite curves will be closely Pinched.

ISSN 2055-0197(Print), ISSN 2055-0200(Online)

Composite Curve and Grand Composite Curve

Figure 3.5 shows the composite; the red curve indicates the hot composite curve while the blue curve shows the cold composite curve. The point at which the two curves comes closest (pinched) to each other gives the value of the minimum temperature difference and that is where the pinch temperature lies (Dimian, 2003). The distance between the start of the hot composite curve and the start of the cold composite curve gives the minimum cold utility requirement of the process while the gap between the end of the cold composite curve and the end of the hot composite curve gives the value for the minimum hot utility requirement of the HEN (Kovacˇ Kralj ,2009).

From Figure 3.5 the minimum hot utility requirement, minimum cold utility requirement and the Pinch temperature at the optimum minimum temperature of 10^{O}C were 1064.057kw, 204.85kw, 57ºC respectively.

Figure 3.6 shows the grand composite curve, the point where the curve touches the vertical axis i.e. net heat flow is zero gave the pinch temperature. The two end point also gives the external cooling and heating requirements. Same values obtained in sections 4.4.1 and 4.4.2 were also obtained, i.e. 1064.05KW, 204.56KW and 57ºC for hot utility requirement, cold utility requirement and Pinch Temperature respectively. Table 3.2 shows summarizes the energy targeting result obtained from composite curve, cascade diagram and the grand composite curves

HEN Analysis

Figure 3.7 shows grid representation of the grass root HEN at the optimum ΔT_{min} = 10, this HEN was studied for possible matches and stream splitting to satisfy the pinch rules whiles saving energy.
The vertical line in the grid diagram divides the network into two; above the pinch and below the pinch, Figure 3.7 showed the hot pinch temperature is 57^{0}C and the cold pinch temperature is 47^{0}C and this divides the network into two regions; above and bellow the pinch. The grid representation was useful in the modification stage to identify the heat exchangers violating the above and below the pinch principles

HEN Modifications

Table 3.3 shows feasible stream matches for above and below the pinch. Above the pinch, stream 2 can be matched with 6 and 7 while stream 5 can only be matched with stream 7. Below the pinch stream 1 can me matched 5 likewise stream 6, in cases with multiple possible matches selecting the most correct stream matches becomes rigorous and very important to the success of the research

ISSN 2055-0197(Print), ISSN 2055-0200(Online)

Above the pinch			Below the pinch	
	6	7		5
2	*	*	1	*
5		*	6	*
			7	

Table 3.3: Feasible stream Matches

HEN Design for MER

After successful stream matching, heaters and coolers are placed on streams that are not satisfied i.e. streams that could not get to their targeted temperatures.

Figure 3.8 shows HEN for MER design of the existing network. Above the pinch, ST-2 was match with ST- 6 in preference to ST-7 due to capital cost consideration of the heat exchangers that will be required for these matches. E-1 (Duty 126.639kw) raises the temperature of ST-2 from 47C to 58.7C which is less than the targeted temperature of 110C hence heater H4(681.689Kw) was installed to reach the targeted temperature and thus satisfying ST-2. Note installation of heaters and coolers requires approximately accurate calculation of the heat/cooling duty to avoid run time error from the software. Hence, the mcp values were used to multiply the temperature difference to obtain a reasonable but approximate estimate of the heating/cooling duties of heaters and coolers. ST-5 was matched with ST-7 using E-2 (4.76758KW), ST-5 is satisfied because it reaches its targeted temperature of 51C, ST-7 is not satisfied hence, C6 (23.351kw) was installed to take the temperature from 57^0C to 37^0C thus satisfying ST-7.

Below the pinch, ST-6 was matched with ST-5 and this satisfies ST-5. In other to satisfy ST-6, C5 (41.41kw) was installed. After successful matches of streams and placement of heaters and coolers, the HEN design was checked with the software to see possible pinch violation before proceeding to relaxation of the MER design.

Relaxation of The MER Network

The MER network was improved by identifying and breaking the loops and paths that exist in the network thereby decreasing the number of heat exchangers. This implies sacrificing energy recovery while reducing capital cost, this act violates the pinch rule (pinch penalty) but necessary to save cost and also to reduce complexity of the network (Sundmacher *et al.,* 2005)

Economic Evaluation of Process Modification

The cost of implementation of the proposed heat exchanger network was estimated on the backdrop of section 2.2.6. the following assumptions were made to simplify the analysis.

i. All heat exchangers in the network are operating in counter current flow
ii. Heat exchanger type; shell and Tube heat exchanger
iii. Material of construction; stainless steel.
iv. Rate of annual return interest is 20%
v. Cost of cold and hot utility $50 per unit

ISSN 2055-0197(Print), ISSN 2055-0200(Online)

vi. Operating hours per year of plant 7200hrs excluding weekends, public holidays and turnaround maintenance.
vii. Total heat transfer area will be calculated by adding the heat transfer area of all the heat exchangers n the network.
viii. Ignoring the cost of power.

Heat Exchanger	Heat Transfer Area (m^2)
H 4	0.7399
E-1	6.9852
E-2	2.8590
E-3	1.4944
C-5	0.98226
Net Area	**13.06076**

Table 3.4: Heat transfer Areas of heat exchangers in Retrofit design

Capital Cost ($)	1956960
Utility Cost ($)	24252.693
Investment Factor	0.6192
Total Annual Cost ($)	**1971977.267**

Table 3.5: Cost implication of retrofit design

From Table 3.5, the total annual cost based on Mammen (2014) approach was calculated for the relaxed network (Figure 3.12), it was found that an energy saving of 44% and 4.4% for cold and hot utility respectively.

CONCLUSIONS

The rising cost of industrial fuel and the current environmental challenges associated with fossil fuels, it is important to design and operate industrial plants in the most energy efficient way. Over the years, pinch technology has proved to be arguably one of the most efficient method of energy optimization. Pinch analysis gives the designer the pre-design thermal requirements and thermal interactions of streams in the process. This research affirms that pinch technology is a reliable tool for heat integration.

In this study pinch techniques were used to analyze the existing heat exchanger network of the Butene-1 unit of EPCL. A new HEN was proposed for energy and cost savings. After thermodynamic analysis of the streams in the process using pinch analytical tools; composite curves and the grand composite curve the energy targets were obtained as shown in Table 3.2 with a driving force of $\Delta T_{min} = 10°C$.

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The research shows the original HEN had three across the pinch violation, these violations were removed in the proposed HEN for MER design by matching streams that are feasible. The MER design was further improved to obtain the relaxed HEN by identifying loops and paths and then breaking the identified loop to reduce the number of heat exchangers. Heat exchanger E-6 was eliminated from the network with a corresponding increment of the heat duty of heat exchangers within the loop. This increase in the heat duty causes violation of $\Delta\boldsymbol{T_{min}}$ (pinch penalty) principle. The pinch violation occurs at E-2, however because the violation is minimal and the cost of correcting the violation outweighs the cost of utility to compensate for the violation, the pinch penalty is allowed.

Finally, economic Appraisal of implementation of the proposed design was carried out. The heating and cooling duty of the plant of the existing pant is 1113KW and 364.46KW respectively, while the heating and cooling requirement of the proposed design were obtained as 1064.05KW and 204.852KW with $1,971,977.267 cost of implementation

Recommendations

The study uses simulation at steady state which may not necessarily capture the plant reality. Also, the effect of pressure in the proposed design was not investigated, hence, it is recommended that the findings of this study should be subjected to high precision linear programing techniques before implementation of the proposed design. Also, the section of the plant that regenerates spent catalyst was not included in the simulation, this section comprises of a heater and a cooler. Further designs should include this sections in their retrofit designs.

REFERENCES

Akpa, J. G. & Okoroma, J. U. (2012). Pinch Analysis of Heat Exchanger Networks in the Crude Distillation Unit of Port-Harcourt Refinery; *Journal of Emerging Trends in Engineering and Applied Sciences (JETEAS) 3 (3): 475-484*

Adejoh, A. Z., Aloko D. F. & Muhammad I. J. (2013). Energy integration of vacuum distillation plant using pinch technology (A case study of KRPC VDU Unit); *Advances in Applied Science Research, 4(2):262-271*

Costa A L H & Queiroz E M. (2009). An extension of the problem table algorithm for multiple utilities targeting. *Energy Conversion and Management. 50: 1124–1128*

Dimian A. C (2003). Integrated desIgn and simulation of CXhemical processes. *Depatrment of Chemical Engineering University of Amsterdan. 13: 394-439*

Fenwicks I, M., Kinyua, R. & Aganda, A. (2014) Energy efficiency analysis using pinch technology a case study of orbit chemical industry; *IOSR Journal of Mechanical and Civil Engineering, 3(11):44-53.*

Gundersen, T. & Naess, L., (1988), The synthesis of cost optimal heat exchanger networks. Compute Chemical. Engineering. 12: 503-530

Kemp, I.C. (2007) *Pinch Analysis and Process Integration*, 2nd edition, Butterworth-Heinemann (Elsevier), Oxford, UK (authors of the first edition: Linnhoff, B., Townsend, D.W., Boland, D., Hewitt, G.F., Thomas, B.E.A.

ISSN 2055-0197(Print), ISSN 2055-0200(Online)

Kovač Kralj, A. (2009). Estimating the maximum possible internal heat integrations of individual processes. Energy, 34**:**1372-1377

Linnhoff, B. & Ahmad, S. (1990). Cost optimum heat exchanger networks, Part 1: Minimum energy and capital using simple models for capital cost, *Compute Chemical Engineering*, 14(7): 729–750. Ahmad, S., Linnhoff, B. and Smith, R. Part 2: Targets and design for detailed capital cost models, *Compute Chemical Engineering*, 14(7): 751–767.

Mammen J.J (2014) Retrofit of heat exchanger networks of a petroleum refinery crude unit (CDU) using pinch analysis. *Thesis submitted in fulfilment of the requirements for the degree of Master of Technology: Chemical Engineering, In the Faculty of Engineering, Cape Peninsula University of Technology*

Nakata, T. (2004). Energy-economic models and the environment. *Progress in Energy and Combustion Science. 30: 417-475*

Piagbo B.K & Dagde K.K (2013) Heat Exchanger Network Retrofit Design by Eliminating Cross Pinch Heat Exchangers; *American Journal of Engineering 02(05)11-18: 2320-3936*

Rev E. & Fonyo Z (1991) Diverse pinch concept for heat exchange Network synthesis: the case of different heat Transfer conditions. *Chemical Engineering Science, 46(7): 1623 1634,*

Smith R. (2005) Chemical Process Design and Integration, *John Wiley & Sons, Chichester, West Sussex, UK 3rd edition*

Sundmacher, K., Kienle, A. & Seidel-Morgenstern, A. (2005) Integrated Chemical Processes: Synthesis, Operation, Analysis and Control. Wiley-VCH, Weinhein, Germany.

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