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AREA TARGETING OF HEAT EXCHANGER NETWORK (HEN) USING A MODIFIED PINCH TECHNIQUE

Onyemachi Jerry Okechukwu[1] Oluwatosin Sarafa Azeez[*2] [1] Nile University of Nigeria Abuja
[2] Federal University of Technology Minna [1]shiek2k2@yahoo.com [2] tosin.azeez@futminna.edu.ng
(* = corresponding author)

ABSTRACT

Aspen Hysys version 8.6 which is a modified pinch tool was used to minimize the area of two heat exchanger networks problem and the results obtained were compared with those of other methods used by researchers that have solved the same problems. Stream data adopted from previous research work comprising the inlet and outlet temperatures, heat capacity flow rate, and specific heat capacity were imputed and solved for minimum area using the principle of modified pinch technology embedded in the Aspen Hysys software.The minimum approach temperature, composite curve, grand composite curve and the grid diagram representation are all series of steps employed in the methodology to achieve minimal area targeting using the Aspen Hysys. The problems solved in this research compared well with those of other researchers and even obtained a smaller exchanger area when compared with the non-linear programming technique (NLP). For instance, an area of 22.17m^{2}was obtained in the first example as against 29.84m^2 obtained by the non-linear programming techniques, resulting in a percentage difference of 25.7%. Also in the second example solved in this research, an area of 106.4m^2 was obtained against 188.9m^{2}obtained with the NLP technique which gives a percentage difference of 43.67%.The overall assessment of the results on area targeting on these problems using Aspen Hysys points to the fact that the traditional pinch technique can still obtain results that are as good as those obtained using mathematical programming techniques in heat exchanger networks (HENs).

Keywords: heat exchanger, area, Aspen, Temperature, stream

1.0INTRODUCTION

Process Integration has been used as a holistic approach to process design and optimization, which exploits the interactions between different units in order to employ resources effectively and minimize costs and other variables [1].With the increasing demand for energy in the chemical industries and its apparent cost, the heat exchanger plays a role in bridging the gap between energy demand and cost. The heat exchanger which is basically equipment used in heating up or cooling down streams with the energy exchanged with other streams [2], while the grouping of such interconnected heat exchangers in a plant of is regarded as the heat exchanger network [3, 9]. Pinch technology and Mathematical Programming techniques have both been used for the optimization of heat exchanger networks synthesis (HENS) [3, 4, 5]. The heat exchanger network as a means for energy integration is due to its ability to minimize the utilities demand of the plant and as well as other variables like the cost and area.

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Several techniques in Mathematical Programming have been used to optimize utilities, exchanger area and cost in HENS [3, 9, 12, and 13]. Pinch analysis which uses thermodynamics concept and heuristics as can be seen in [6, 10]resulted in energy integration and minimal utility demand. The principle of pinch technology has been incorporated in software like the Aspen Hysys which is used in process and energy integration. Several variables define a heat exchanger network, top among which are capital cost, annual cost and area of the network. The area of a heat exchanger network is the total space occupied by all the equipment that makes up the network.

1.1 PINCH TECHNOLOGY

The term pinch technology was introduced to represent a new set of thermodynamically based methods that guaranteed minimum energy level in the design of heat exchanger networks. Pinch technology has over the years emerged as the principal technique in process design and energy conservation [10, 11, 15]. Pinch technology software such as Aspen Pinch hasproven to be a valuable resource in the pinch analysis of complex industrial processes [9].In the laws of thermodynamics, the direction of energy flow must always be from the hot stream to cold stream, hence temperature cross over is prohibited. The cooling and heating of streams in a heat exchanger is governed by the minimum approach temperature (ΔTmin) that exists between the heat exchanger. This minimum approach temperature is the minimum temperature difference between the streams profile in the exchanger [5]. The temperature level at which the minimum temperature approach is observed is called the pinch point and it defines the minimum driving force obtainable in a particular heat exchanger.Integration of heat exchanger network where the area of the network was optimized was extensively researched by [13, 21] with relevant problem solving examples. The non-linear programming technique was used by [13] and was used to solve some problems to obtain the area target. The area targeting non-linear programming technique was used by [13] and the results were compared with those of previous researchers.

1.2 ASPEN HYSYS SOFTWARE

Aspen HYSYS is interpreted to be a comprehensive process modeling tool used by the world's leading oil and gas producers, refineries, and engineering companies for process simulation and process optimization in design and operations [9]. It is user friendly application software that works with the principle of pinch analysis that basically requires the input of data and relatively easy operational skills by users to achieve the desired results. Aspen Hysys can also be used for steady state and dynamic process modeling and simulation like plant design, process design, plant optimization and process optimization. This work uses the Aspen Hysys software to minimize the area of the heat exchanger network, and the result obtained was then compared to that obtained by other researchers that have used different techniques on same problem.

2.0. MATERIALS AND METHODS

The materials used include, the Aspen Hysys software version 8.6, Microsoft Office Visio, process flow diagram and data of three selected heat exchanger problems adopted from [13].

2.1 METHODOLOGY

The Aspen Hysys version 8.6 was used to optimize the area of the heat exchanger synthesis problem discussed in this work. Process data were collected from literature, as in this case heat exchanger analysis problem was adopted from [13]. The process data were extracted properly from the process flow diagram using the required technique for data extraction to form a stream table (heat exchanger data), and consequently the construction of the composite curve, grand composite curve, estimation of ΔTmin, grid diagram representation, and finally evaluating and analyzing the targeted result obtained with those reported by previous researchers on existing plant condition. All thiswere achieved using the Aspen Hysys version 8. The methodology adopted can be summarized as follows: Collection of data, formulation of stream tables, data extraction, construction of composite curves, grand composite curves. It should be noted that some mathematically based materials are embedded in Hysys.

2.2DATA EXTRACTION

This involves the extraction of relevant stream and cost data from the process flow diagram as presented in [13]. The data extracted include the inlet and outlet temperatures, the heat capacities flow rate, heat transfer coefficients, and the specific heat capacities of all streams in the process including that of the utility streams. The general equation for quantification of heat available in a stream is stated in Equation 1.

$Q = Cp \times F \times \Delta T$…………..Equation 1
F= mass flow rate of the stream (Kg/s)
ΔT= temperature difference (^0C)
Q = heat duty (Kw)
Cp = specific heat capacity of the stream

2.3DETERMINATION (OPTIMIZATION) OF ΔTmin

ΔTmin which is the minimum allowable temperature difference between two streams exiting a heat exchanger [14 – 17] is very important in minimization of utility usage. This is automatically determined by the Aspen Hysys software when the streams and utility load have been imputed. The ΔTmin value for petroleum related heat exchanger problems falls in the range of 20^0C to 40^0C as observed by various researchers. The value of ΔTmin is important in the determination of heat exchanger area. This can be optimized in the plot of composite curves to achieve minimum energy usage [5, 19, and 21]. The use of composite curves for mass exchange can be seen in [18, 20].

2.4 GRAND COMPOSITE CURVE

This is also known as the utility composite curve, it is a curve of the temperature and enthalpy profile of all streams in the network with the inclusion of the hot and cold utility provision. The grand composite curve also indicates the type and amount of utility to be used to satisfy the network.

2.5 NETWORK REPRESENTATION ON A GRID DIAGRAM

The grid diagram is a representation of all streams present in the network. In the Aspen Hysys used for this research, the hot streams are drawn at the top with horizontal lines running from left to right while the cold streams are drawn by horizontal line running from right to left at the bottom of the diagram. Each line of hot and cold stream has its respective supply and target temperatures at the end of the line, as well as its heat capacity value. Heat exchangers are represented on the diagram by vertical lines running through the hot and cold streams [3, 5, and 9]. Heat exchangers that violate the pinch rule are also identified by a dash line at the top of the heat exchanger.The streams are match based on their various specific heat capacities value (heat content), hot streams with low specific heat capacity value are matched with cold streams with high specific heat capacity value. In situation where process to process heat transfer based on their specific heat capacities is inadequate to satisfy all the streams, utilities (hot or cold) are used to satisfy the remaining streams.

3.0RESULTS AND DISCUSSION

Two heat exchanger analysis problems were solved in this work, which focused on the minimization of heat exchanger area (area targeting).These two heat exchanger analysis problems were adopted from [13]work on heat exchangers network and solved for minimal area using Aspen Hysys.

3.1 EXAMPLE ONE

This problem is an area targeting problem obtained from the [13] heat exchanger network analysis work. It involved five streams with different heat transfer coefficients of which one among the streams is a cold stream that required heating and the other four are hot streams that required cooling. The film heat transfer coefficient of all streams in the problem, range over two orders of magnitude, which is common with streams containing boiling or condensing streams. The value of ΔTmin chosen for this problem is that which favors utility targeting (ΔTmin =10K), hence the heating and cooling requirements for the set of data is zero. The stream data for this example is shown in Table 1.

Table1 - Stream Data for Example 1 [13]

Stream	Supply temperature (K)	Target temperature (K)	Heat capacity Flow rate (kWK^{-1})	Film heat transfer Coefficient ($kWM^{-2}K^{-1}$)
H1	443	293	0.5	2.0000
H2	416	393	2.0	0.2857
H3	438	408	0.5	0.0645
H4	448	423	1.0	0.0408
C1	273	434	1.0	2.0000
Steam	None			
Water	None			

ΔT_m = 10K (for utility targeting).

Aspen Hysys was used in solving for the area target and the result obtained was then compared with [13] who solved same problem using Non Linear Programming area targeting method and also the result was compared with [21]. The comparison of results is presented in Table 2. [21] and [13] reported same area targets of 29.84m^2 for the problem statement compared to 22.17m^2 obtained with Hysys as can be seen in Table 2, this show a difference of 25.7%. The solution obtained in this research has 2 split streams compared with 4 and 7 splits streams of [13] and [21] respectively which make the network of this solution simpler and less costly in piping.

Table 2 Comparison of areas obtained by using different techniques

	METHOD	Stream Split	AREA (m^2)	% DIFFERENCE TO HYSYS
COLBERG AND MORARI	NON-LINEAR PROGRAMMING (NLP)	4	29.84	34.6
NISHIMURA	Area Targeting Method	7	29.84	34.6
HYSYS	This research	2	22.17	0

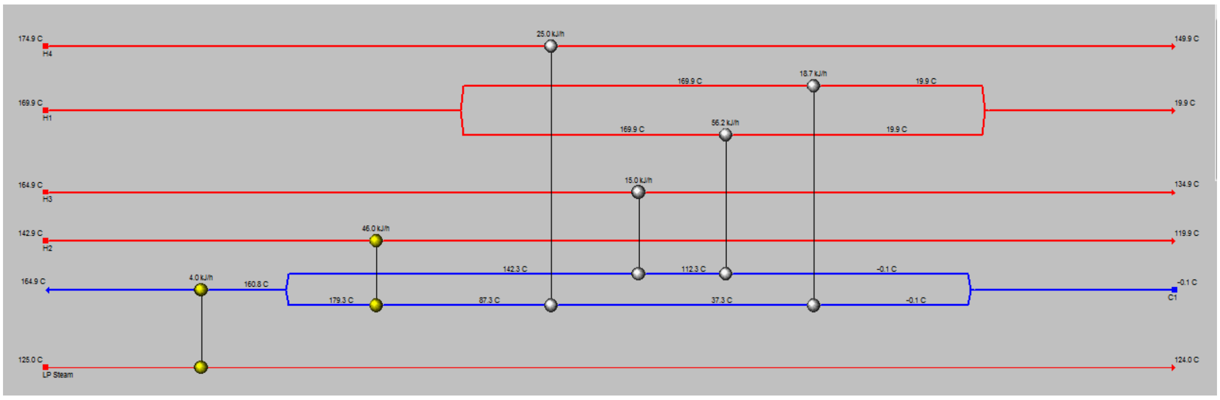

Figure 1 - HEN Structure Generated by Hysys for Area target in Example 1

Aspen Hysys was able to generate a smaller area target with a simpler grid diagram and relatively cheaper operating and capital cost.

3.2 EXAMPLE TWO

The stream data for example two is presented in Table 3 and is adapted from [13]. This set of data has heating and cooling targets of 244.2kW and 172.6Kw respectively. In this problem, minimum area is being targeted for three scenarios
a. When no limit is placed upon the stream matches.
b. For the best selection of matches corresponding to the unit target.
c. For the best selection of matches containing one match more than the unit target.

Table 3 - Stream Data for Example 2 [13]

Stream	Supply Temperature (K)	Target Temperature (K)	Heat capacity Flow rate ($kW\ K^{-1}$)	Film heat transfer coefficient ($kW\ m^{-2}\ K^{-1}$)
H1	626	586	9.802	1.25
H2	620	519	2.931	0.05
H3	528	353	6.161	3.20
C1	497	613	7.179	0.65
C2	389	576	0.641	0.25
C3	326	386	7.627	0.33
C4	313	566	1.690	3.20
Steam	650	650		3.50
Water	293	308		3.50

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The area target generated by [13], for the three case scenarios are shown in Table 4. Also it should be noted that the film heat transfer coefficients range over about two orders of magnitude. This problem was solved for area with no streams restriction by [13] using area targeting NLP which decomposes the problem at the pinch.

Table 4: Result of Area target generated by [13]for five different Scenarios

	Limit on Number of matches		
	Above pinch	Below pinch	Area (m^2)
Area targeting NLP	-	-	173.6
	7	5	176.1
	6	5	188.8
Composite curve based target	-	-	227.0
Synthesized HEN	7	5	183.9

The area of the HEN design by [13] for the “no stream restriction” problem which was decomposed at the pinch is 188.9m^2 using non-linear programming method, which is 7.3% greater than the area target generated for seven matches above and five matches below.

Aspen Hysys software which works with the principle of pinch technology and some component of mathematical programmingwas used in this work to solve for area of the network with no stream restriction and the result obtained was compared well with that of [13].
A total area of 106.4m^2 was obtained byHysys when no limit is placed on streams matching and the grid diagram generated by Hysys is shown in Figure 6 which represents a difference of 43.67% in area compared to the result obtained by [13].

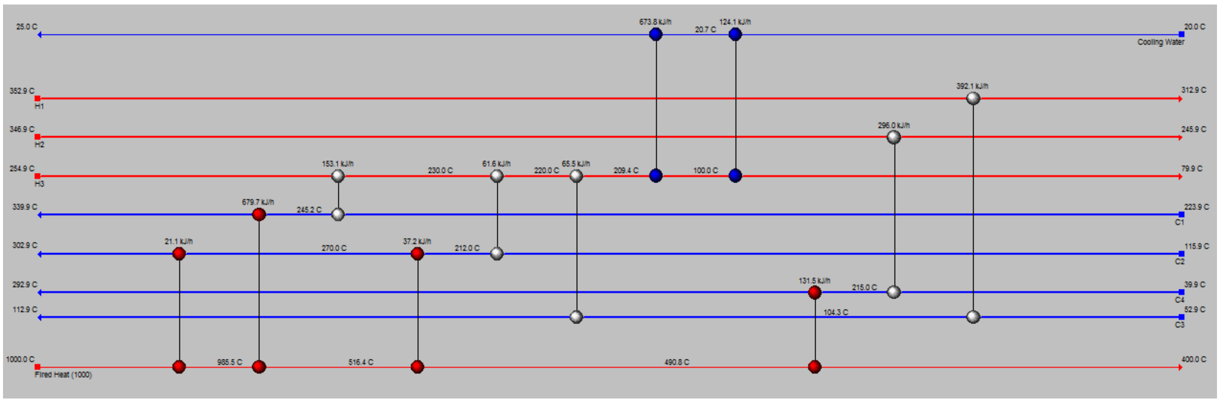

Figure 2 - Grid Diagram of the HEN synthesized for area target in Hysys for Example 2

The heat exchanger network synthesized by [13]shows seven units above the pinch position while five units are below the pinch position. This is slightly different from that synthesized in Hysys which shows six unit above and five units below the pinch point. The fewer number of heat exchanger (units) used by Hysys resulted in the HEN synthesized by Hysys having a cheaper annual cost alongside a smaller area compared to the HEN synthesized by [13]. It should also be noted that the eleven heat exchanger units used by the HEN synthesized using Hysys compared to the twelve used by [13] represent a percentage difference of 8.3 %. These differences are illustrated in Table 5.

Table5- Difference between the result obtained by [13]using area – target NPLand that obtained with Hysys

	AREA TARGET		
	NLP	HYSYS	% DIFFERENCE
NUMBER OF UNIT ABOVE PINCH	7	6	14.29
NUMBER OF UNIT BELOW PINCH	5	5	0
TOTAL NUMBER OF UNIT	12	11	8.33
TOTAL AREA	188.9m^2	106.4m^2	43.67

Hysys was able to obtain a smaller area with fewer numbers of heat exchanger units. That is, an area of 106.4m^2 was obtained with eleven heat exchangers; while an area of 188.9m^2 was obtained with twelve heat exchangers.
It can be seen that application of AspenHysys software in solving example two has resulted in a better minimum network area as compared to the result reported by [13] and obviously a cheaper capital cost, because fewer number of heat exchanger units were used.

4.0CONCLUSION.

Modified pinch technology which is embedded in AspenHysys has been shown in this work to be an effective tool in the optimization of the area of a heat exchanger network as depicted by the two examples solved using this technique.

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