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Fuzzy Analogical Gate to Select the Best Design of Heat Exchanger Network

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Abstract: ***This article shows a systematic method to choose the optimal minimum temperature in order to get a flexible HEN and more operable by utilizing the fuzzy analogical gate way for the tradeoff between two cost capital and operating for a given minimum temperature difference. By follow, three steps to choose the best minimum approach temperature 1) obtain minimum utilities target 2) obtain of the area of all HEN 3) fuzzy analogical gates to select the best minimum temperature difference. The recommended method was be conducted on two case studies well known in published literature yielded an optimum solution that is consistent with a different approach. It is clear the fuzzy analogical gate performance is completely hopeful; it is simple and has ability to be applied by manual calculations.***

Keywords: HEN, fuzzy gate, optimization

I. INTRODUCTION

To make maximum profit from chemical plant overall. We should make excellent management through integration between supply and heat elimination for process streams. Therefore, heat exchanger is the best equipment we can do this because the work theory of heat exchanger depends mainly on take heat from hot stream to make cold stream hotter and give cold stream heat to make it hotter and the other more cold. Based on quantities of heat we estimate required level and calculate area of heat exchanger. Total cost of capital and operating cost must be decreased and optimize, to obtain the best HEN design. Heat exchanger area one of factors, which effect directly in total cost.

Masso and Rudd [10] 1st clear design of the network troublesome during a rigorous manner. They suggested that for obtaining an optimum HEN design must be the total cost minimized. Through more than five hundred publication have showed we found that the cost of network in search of sahinidis and furman [1] is less than the rest of search because it made a good review on this topic. In HEN design, numerous heuristics are used. Minimization of exchangers units, utility splitting the hot and cold streams are samples for these heuristics. Although offered partially solution for our design problems, general recommendation has not offered by these heuristics. However, there are several publications on the look of HENS throughout the past 3 decades. Two approaches (Optimization method and pinch method) had been note in these researches. In HENS design Linnhoff & Hindmarsh, [8] by the pinch technique had presented and developed. The laws of thermodynamic (first and second law) have used to form this method. The main goal of this proposal is maximizing the heat recovery between all steams (hot and cold) to decrease any external utility for reducing operating cost and capital cost. Effective work has done on HEN synthesis applied two methods pinch & MINLP. Such enhancements have presented during a many articles [5-7] [11, 12, 17, and 18].

Ravagnani et al. present numerous types of articles to improve tactics for finding best HEN. Research focused in three significant fields, Pinch Analysis, Heuristics and Mathematical Programming, heuristic approaches of optimization [14]. New ways with each technique have conferred to be able to making getting ready to optimum networks for actual industrial issues.

After present all previous methods to design optimal heat exchanger network, this will give any designer Varity to select the optimal design, but must have a tool to select the best design according to the cost. Optimal ΔTmin, area and cooling and heating utility will effect on cost. One of methods to select the optimal design is fuzzy analogical gate as will be shown in this paper, how it can support the designer to take a decision.

problem description

the a system consist of numbers of hot streams (nh) which have certain of inlet temperature and target temperature (hot steams will be cooled down) , and numbers of cold streams (nc) which have certain of inlet temperature and target temperature (cold steams will be heated) ,two types of streams (hot & cold) have known heat capacity flow rate . Cold and hot utilities must be added to the system to support each stream to reach to sufficient target temperature. The overall purpose is defining the optimal structure of HEN the meets the minimum yearly cost and includes the smallest number of heat exchanger units.

II. PINCH POINT LOCATION METHOD

To obtain the optimum minimum utility target, the technique will be used is pinch point location.

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Assume one heating utility and one cooling utility and at pinch point, the system will be divided to above and below the pinch, above the pinch will be one demand heating and below the pinch will be cooling sink.

In addition, heating utility and cooling utility will achieve the required temp for process streams to be sufficient and obtain the target temperature. [9]

Assumed this process as the following equations

For hot stream

$T^P = T_i^{in}\ all\ p = i \in H$ (1)

For cold stream

$T^P = (t_j^{in} + \Delta T_{min}), all\ p = j \in C$ (2)

Heating shortage function $X_H^P, p \in P$ Include two term Q_1 *refer to content of heat for hot streams above pinch* $p \in P$ and Q_2 refer to content of heat for cold streams above same pinch. This function can be showed as the following expression function included temperature of process stream and flow rates.

$$Q_1 = \sum_{i \in H} F_i C_i \left[max(0, T_i^{in} - T^P) - max(0 - T_i^{out} - T^P)\right] \quad (3)$$

$$Q_2 = \sum_{j \in C} f_j c_j \left[max\left(0, t_j^{out} - (T^P - \Delta T_{min})\right) - max\left(0, t_j^{in} - (T^P - \Delta T_{min})\right)\right] \quad (4)$$

$$X_H^P = Q_2 - Q_1 \quad (5)$$

The maximum value of heating series deficit function $X_H^P, all\ p \in P$ is the minimum heating Q_H.

$$Q_H = \max_{p \in P} (X_H^P) \quad (6)$$

And minimum cooling, Q_C

$$Q_C = \Omega + Q_H \quad (7)$$

$$\Omega = \sum_{i \in} F_i C_i (T_i^{in} - T_i^{out}) - \sum_{j \in C} f_j c_j (t_j^{out} - t_j^{in}) \quad (8)$$

III. HEAT EXCHANGER AREA TARGETS

Addition to giving the desired data to expect energy targets. Through composite curve, we can get very important data to expect network area and energy target. To seek out the balanced composite curve, utility stream should be containing with process stream through composite curve. The balanced composite curves are divided into vertical enthalpy intervals wherever there is either a modification of slope on the hot and cold composite curves. To obtain the network successive equation is used to all enthalpy intervals enclosed the impact of separate stream film transfer Coefficients.

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$$A_{network} = \sum_k^{interval=k} \frac{1}{\Delta T_{lmk}} \left(\sum_i^{hot\ stream=i} \frac{q_i}{h_i} + \sum_j^{cold\ stream=j} \frac{q_j}{h_j} \right) \quad (9)$$

IV. FUZZY ANALOGICAL GATE

One of designing issues is the uncertainty. It is fundamental point that ought to be considered preceding the choice of a proper method to unmistakable the uncertainty. Fuzzy analogical gate offers a numerical technique to speak to unclearness and uncertainty in framework portrayal. [15]

Procedure control utilizations are one of the most important of current fuzzy logic uses. Fuzzy analogical gate are a new technique of describing several value with logic statement. It is a progressively complete plan, which utilizes the boundless variety of framework factors and their related qualities. This technique widens the scope of operation of binary logic-based systems to true multi-valued logic-based systems. Furthermore, the design and implementation of these gates for practical physical systems have proven to be efficient and simple. A symmetric and asymmetric of fuzzy analogical gate will run in sequence. Symmetric logic gate will be used first then follow by asymmetric gate (AND analogical gate then invoke analogical gate).

The following formula no 10 for AND analogical gate

$$z = x \times y = x[1 - \zeta(y, x) + y[1 - \zeta(x, y)] \quad (10)$$

Where ζ can be regarded as the member ship function of a fuzzy relation and is defined by the following exponential function:

$$\zeta(x, y) = exp\left\{-\left(\frac{ax^2 + bxy}{x^2 + y^2}\right)\right\} \quad (11)$$

The coefficients of the exponential functions are as follows: 2.28466 and -0.89817, respectively.

The fuzzy invoke gate will be run by the following equation:-

$$z = x \wedge y = x\zeta_1(y, x) + y[1 - \zeta_2(x, y)] \quad (12)$$

The coefficients of the exponential functions are as follows:

$a_1 = 1.4749267$, $b_1 = 0.92870491$,

$a_2 = 2.6317713$, $b_2 = 0.2287955$.

V. CASE STUDIES.

A. Cases study no one.

The plant in this case is one of the largest aromatics complexes, which use conventional technology. The feedstock is naphtha containing chiefly paraffin's and cyclo paraffins to produce paraffin's and aromatic compounds by reforming. The specifications for all streams data in table I. By apply our method to calculate the optimum area, hot and cold utility energy at different min approach temperature as shown in fig 1 and calculate the annualizing cost with different min approach temperature as shown in fig 2. to select the optimum design for network we applied fuzzy analogical gate As shown in table II The best fuzzy analogical gate (τ) is .678 equal to ΔTmin = 25 which also give optimum TAC equal to ($/year 3260573), the optimum network shown in fig 3. After comparison our result with previous work we found this solution is optimum as shown in tableIII.

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Table 1 plant stream data

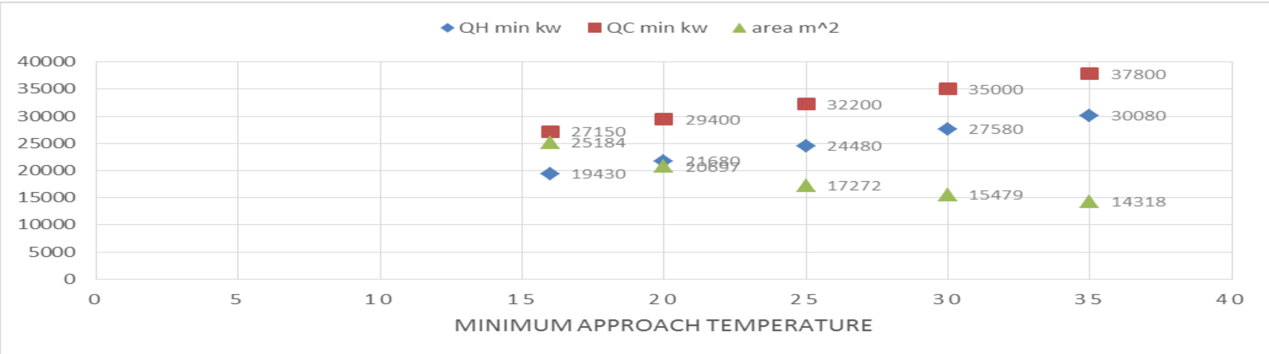
	H1	H2	H3	H4	C1	C2	C3	C4	C5	HOT UTILITY	COLD UTILITY
Supply temp TS c	327	220	220	160	100	35	85	60	100	330	15
Target Temp c	40	160	60	45	300	164	138	170	300	250	25
Heat capacity Kw/c	100	160	60	400	100	70	350	60	200		
heat transfer Coef Kw/m^2 C	0.5	0.25	0.3	0.18	0.25	0.27	0.25	0.15	0.45	0.3	0.2

Cost data;-

1- Interest rate(i) is 10% , life time (n) is 5 year

Factor of annulization is $\frac{i(1+i)^n}{(1+i)^n-1}\ yr^{-1}$

2- Cost of fuel gas is 60 $/kw.yr.
3- Unit instillation cost is 10000+350(A) $.
4- Cost of cooling water is 6 $/kw/yr.



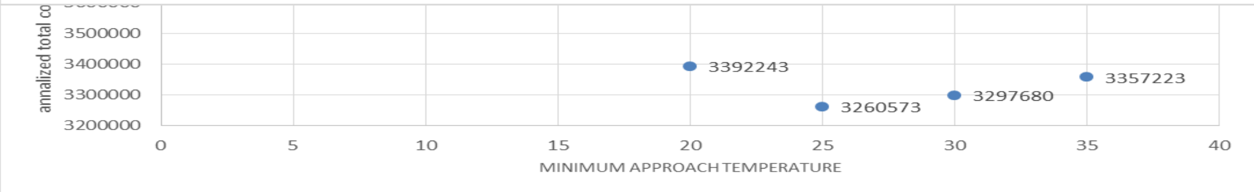


Table II The summary of results by fuzzy analogical gates for aromatics plant

Δ t min	μ QH	μ QC	μ A	† INDEX
15	1	1	0	0
20	0.833	0.833	0.378	0.375
25	0.625	0.625	0.666	0.678
30	0.394	0.416	0.817	0.401
35	0.208	0.208	0.915	0.1143

Table III compare between result of this work and previous work.

METHOD	LINH & AHMED [5]	ZHU ET AL. [19]	ZHU ET AL. [16]	LEWIN [3]	LEWIN ET AL [4]	PETTERSSON[13]	KRISHA [2]	THIS WORK
STREAM SPLIT	0	2	0	2	0	7	0	0
QH MW	25.31	26.22	26.83	25.09	25.69	24.27	25.88	24.48
QC MW	33.03	33.94	34.55	32.81	33.41	31.99	33.6	32.2
NO OF HEAT EXCHANGER	13	14	10	12	11	17	15	15
AREA M^2	17400	16630	16380	17050	16880	17473	16536	13881.5
ANALIZED TOTAL COST M$/YR	2.96	2.97	2.98	2.936	2.946	2.905	2.942	2.48

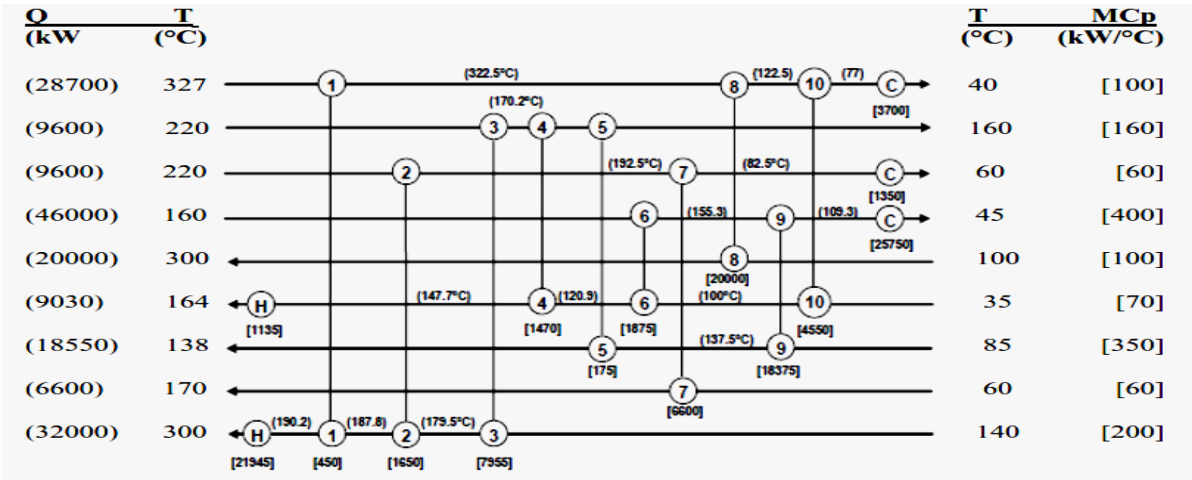


Figure 3 heat exchanger network graid at ΔTmin = 25°C

B. Cases study no two.

This case is a 10 stream problem [7, 15] streams data for this case in Table IV Stream data for 10SP1 synthesis. By apply our method to calculate the optimum area, hot and cold utility energy at different min approach temperature as shown in fig 4 and calculate the annualizing cost with different min approach temperature as shown in fig 5. to select the optimum design for network we applied fuzzy analogical gate As shown in table V The best fuzzy analogical gate (τ) is .65948 equal to ΔTmin = 17.5 which also give optimum TAC equal to ($/year 2647652), the optimum network shown in fig 6. After comparison our result with previous work we found this solution is optimum as shown in table VI.

Cost data;-

1. *Interest rate(i) is 10% , life time (n) is 10 year*

Factor of annulization is $\frac{i(1+i)^n}{(1+i)^n-1}\ yr^{-1}$

2. *Cost of fuel gas is 100 $/kw.yr.*
3. *Unit instillation cost is 60(A) $.*
4. *Overall heat transf. coefficient is .025 kw/m^2 k.*
5. *Cost of cooling water is 15 $/kw/yr.*

Table IV plant stream data.

Stream	H 1	H 2	H 3	H 4	H 5	H 6	c 1	c 2	c 3	c 4	Fuel gas	Water
Supply temperature c	85	120	125	56	90	225	40	55	65	10	200	15
Target temperature c	45	40	35	46	86	75	55	65	165	170	198	25
Heat capacity flow rate kw/c	156	50	24	1250	1500	50	467	600	180	81	-	-

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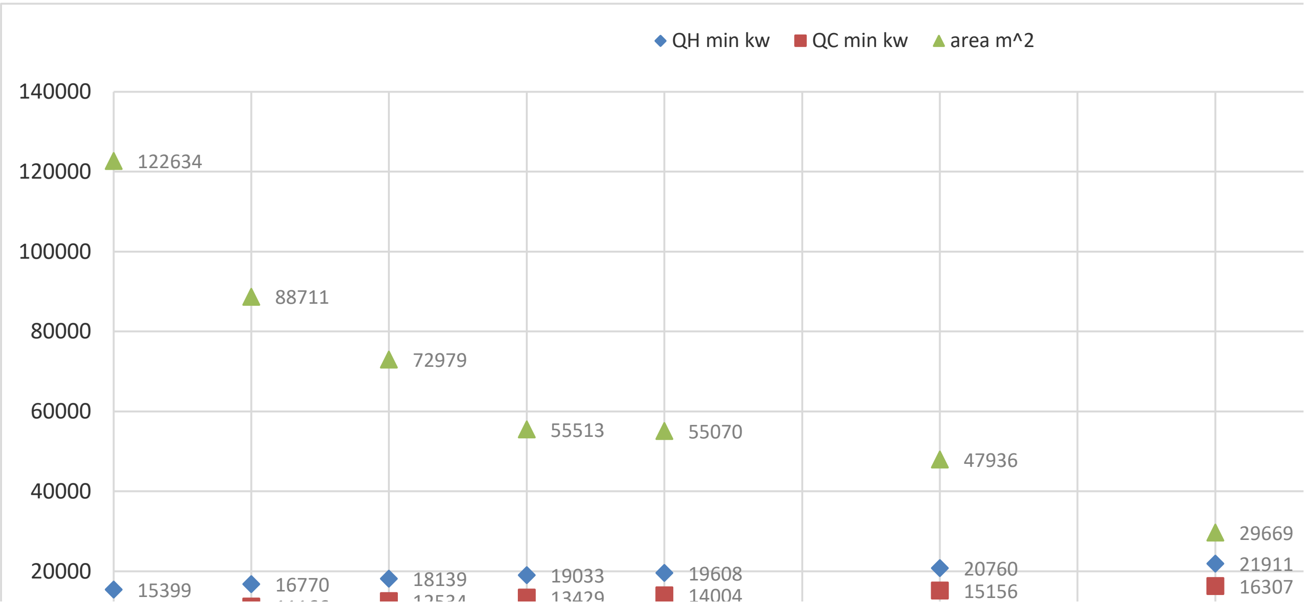

Figure 4 the effect of min approach temp on utility energy and area

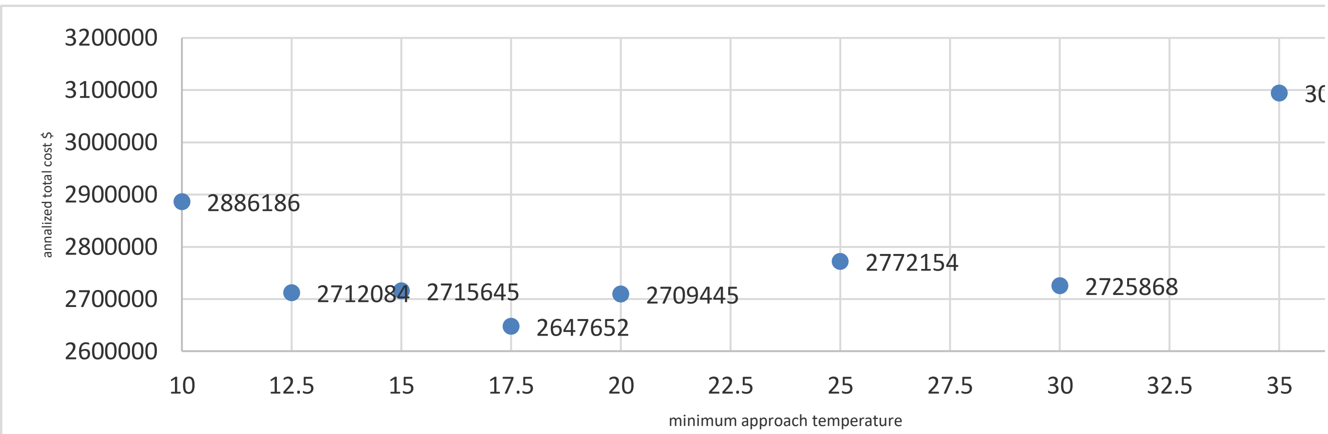

Figure 5 relation between min tapproach temp and analizing cost

Table V Summary of Results by Fuzzy analogical gate for 10SP1 problem

Δ t min	µ QH	µ QC	µ A	Ϯ INDEX
10	*1*	*1*	*0*	*0*
12.5	*0.8453*	*0.8453*	*0.3649*	*0.34371*
15	*0.6909*	*0.6901*	*0.5341*	*0.63163*
17.5	***0.59***	***0.59***	***0.722***	***0.65948***
20	*0.5252*	*0.5252*	*0.7268*	*0.5898*
25	*0.3952*	*0.3952*	*0.8035*	*0.40178*
30	*0.2653*	*0.2653*	*1*	*0.17228*

Table VI. Comparison of solutions obtained by different authors for 10SP1

case	KRISHNA[2]	RAVAGNANI[14]	AHMED[4]	PRESENT WORK
ΔT_{MIN}	19.5	24	10	17.5
Heating utility KW	20745	20529	15400	19033
Cooling utility KW	15141	14925	9796	13429
Area	56085	56006	-	55513
Operating cost $/yr	2301641	2276787	1686940	2104735
Capital cost $/yr	548513	553553	1199360	542917
Total cost $/yr	2850154	2830340	2886300	2647652

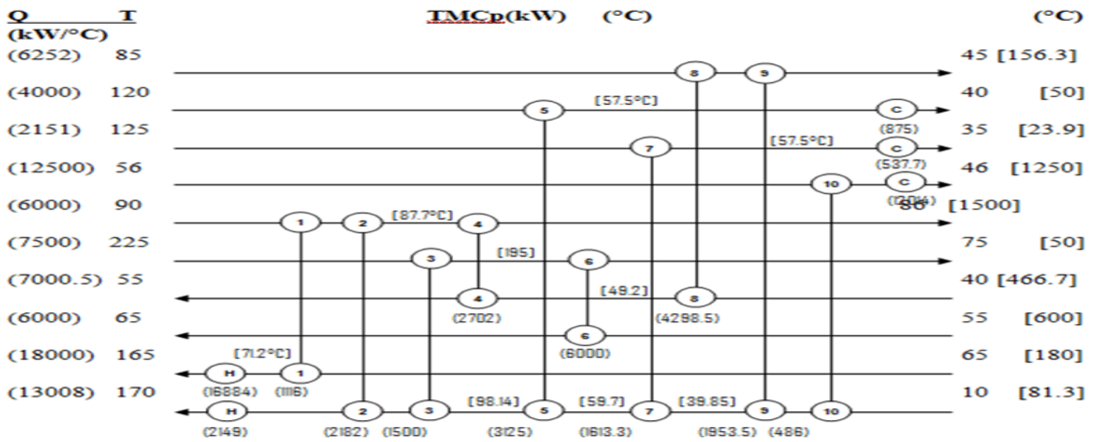

Figure 6 Optimum design for HEN at ΔTmin = 17.5°C

AS shown in table 6 the optimal HEN with cost 2104735 $/year for hot & cold utility and the total area is 55513 m^2.

VI. CONCLUSION

This article shows a systematic method to choose the optimal minimum temperature in order to get a flexible HEN and more operable by utilizing the fuzzy analogical gate way for the tradeoff between two cost capital and operating for a given minimum temperature difference. The recommended method has been conducted on two case studies well known in published literature yielded an optimum solution that is consistent with a different approach. It is clear the fuzzy analogical gate performance is completely hopeful; it is simple and can be applied by manual calculations.

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