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Alternative Procedure of Heat Integration Tehnique Election between Two Unit Processes to Improve Energy Saving

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Abstract. The energy use system in a production process, in this case heat exchangers networks (HENs), is one element that plays a role in the smoothness and sustainability of the industry itself. Optimizing Heat Exchanger Networks (HENs) from process streams can have a major effect on the economic value of an industry as a whole. So the solving of design problems with heat integration becomes an important requirement. In a plant, heat integration can be carried out internally or in combination between process units. However, steps in the determination of suitable heat integration techniques require long calculations and require a long time. In this paper, we propose an alternative step in determining heat integration technique by investigating 6 hypothetical units using Pinch Analysis approach with objective function energy target and total annual cost target. The six hypothetical units consist of units A, B, C, D, E, and F, where each unit has the location of different process streams to the temperature pinch. The result is a potential heat integration (ΔH') formula that can trim conventional steps from 7 steps to just 3 steps. While the determination of the preferred heat integration technique is to calculate the potential of heat integration (ΔH') between the hypothetical process units. Completion of calculation using matlab language programming.

1. Introduction

The system of energy uses in a production process, in this case the heat exchanger network (HEN), is one of the elements that play a role in the smoothness and sustainability of the industry itself. Therefore, an increase in the efficiency of the system of energy use is absolutely necessary [20]. One way is to heat integration between the streams involved in the process. In heat integration, unused energy in a system is used for other systems. So we get a good heat exchanger network by lowering utility usage. Optimizing Heat Exchanger Networks (HENs) from process streams can have a major effect on the economic value of an industry as a whole. So the solving of design problems with heat integration becomes an important requirement [7].

In factories consisting of several process units, heat integration can be done internally in each unit of the process itself or several units at once. The integration of heat can be done in 1 unit of process or a combination of several processes [9][3][4][10][2][8]. However, not all process units can be integrated with each other. Some of the constraints are called "area of integrity", ie areas with different conditions and operational [9]. The difference in temperature levels less than ΔTmin allowed in HE between hot and cold streams, also causes no heat integration between the units of the process. In addition to these constraints, the potential for heat integration for heat integration should be analyzed. The potential for heat integration is the ability to be integrated between heat flows and cold streams. This heat integration potential is indispensable in heat integration, as it will determine the success of an effective energy system design in an industry.

Generally, a heat integration in a combined / simultaneous process between process units is better than individual / sequential. Because the opportunity flow of process flow for interchangeability will be greater [24]. Sequential heat integration is a heat exchanger internal network configuration inside the unit independently in a process, while simultaneous heat integration is a heat exchanger network configuration that incorporates all units in a process. The design of the system of energy use is better done before the plant is established, so the continuity of the production process does not experience constraints on the system of energy use. The problem arises when a designer will decide whether the heat integration is done individually or in combination between multiple processes. Of course, before taking a long step, a designer has not been able to determine / know whether sequentially is better than simultaneously or vice versa. The difference in utility demand between sequential heat integration and heat integration is simultaneously called penalty [9]. The steps in determining the heat integration technique of the process units at a plant follow the magnitude of the penalty between the process units. If the penalty generates a value of utility needs too large then the integration of heat is done sequentially [24] [1]. In this study we conducted thermal integration with target energy and total annual cost target as the objective function, furthermore determines the potential of heat integration and provides the initial / alternative steps before initiating the design of the HEN heat exchanger system.

A simplest design method of HEN is the pinch design method (PDM) introduced first introduced by Linhoff and Vredeveld in terms of Pinch Technology [5] [14] [13]. The purpose of this method is to find the optimal network structure of the heat exchanger by setting ΔTmin as the initial step to obtain maximum energy recovery (MER), minimum heat exchanger network area [5] From this it is expected to form a network structure of heat exchanger with minimum utility requirement, because utility requirement is biggest cost component in operational of a factory, when compared with cost of capital. Some of the things required in using the pinch method include the minimum temperature difference (ΔTmin), cascade diagram to determine pinch point, composite curve, where minimum temperature difference (ΔTmin) is needed to determine how close the composite curve of heat and cold can be close so that he obtained heat recovery without violating the second law of thermodynamics [24] [6].

2. Method

Research at this stage is the study of some cases of sequential or simultaneous heat integration.

The study was conducted by heat integration of six process units, consisting of hypothetical process units A, B, C, D, E, and F, where each process flow can be seen in Table 1. The approach of heat integration method using Pinch Analysis Method. The minimum temperature difference used is 10 K (ΔTmin).

Table 1. Streams data of hypothetical unit processes

UNIT	Stream	Type	T_S (K)	T_T (K)	m.cp (MW/K)	ΔH MW
Unit A	1	Hot	473	313	12.5	-2000
	2	Cold	283	408	5.2	650
UNIT B	3	Hot	373	313	12	-720
	4	Hot	423	308	8	-920
	5	Cold	283	423	7	980
	6	Cold	283	363	2	160
UNIT C	7	Hot	453	303	8	-1200
	8	Hot	433	303	4	-520
	9	Cold	293	423	15	1950
	10	Cold	293	373	6.5	520
UNIT D	11	Hot	423	283	5	-700
	12	Cold	283	433	5.2	780
UNIT E	13	Hot	425	300	15	-1875
	14	Hot	420	308	15	-1680
	15	Cold	298	415	30	3510
UNIT F	16	Hot	410	300	2	-220
	17	Hot	410	303	3	-321
	18	Cold	300	400	5	500
	19	Cold	298	393	2.5	237.5

For step 1 is presented in Table 1. where the units are processed without distance limitations so the cost of piping is negligible, while the 2nd step minimum temperature used is 10 K (ΔTmin). For step 3, determine pinch temperature using matlab language programming. The next step is to determine the temperature of the pinch for simultaneous heat integration between the process units (limited between 2 processing units), also using the matlab language programming. Next, determines the heuristic potential of heat integration as a first step to select a heat integration technique (sequential or simultaneous) on the process units within a plant. This heuristic is determined by the concept that a process unit with excess energy can be heat integration to another process unit that requires energy, if the temperature level of the process unit with excess energy is higher than that of the energy-consuming process unit. The potential of this heat integration is determined based on the energy target (objective function).
Determining the heat integration technique that will be used in the process units in a plant is the main thing in the design. The heat integration technique to be chosen is between sequential and simultaneous. The basis of selection of integration techniques depends on the targets to be achieved. In this study to be achieved is the energy target, where the heat integration with utility requirements (QHmin + QCmin) is the minimum selected. If (QHmin + QCmin) is simultaneous < (QHmin + QCmin) sequential, then the chosen sequential heat integration is the opposite.

3. Result and Discussion

The result of the sequential heat integration (internally heat integration) hypotheticals unit processes are illustrated in Figure 1.a. until Figure 1.f. with objective function of energy target. Figure 1.a. shows a grid diagram of streams in a process A unit with two process streams consisting of 1 hot stream and 1 cold stream. Before the heat integration was done, the initial needs of the 650 MW hot utility, while the cooling water utility was 2000 MW. The heat integration is approached using the pinch method, the problem solving will be resolved where the pinch temperature as the base in the heat exchange. Pinch temperature determination can be done with problem table and cascade diagram. Heat matched using Hint software (Martin and Mato, 2008)

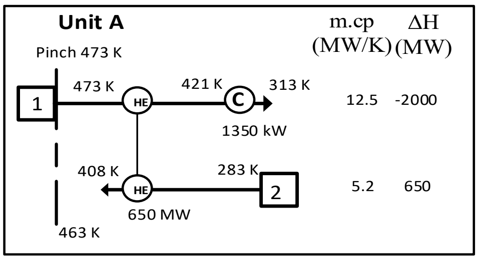

Figure 1.a. Grid diagram unit A at ΔTmin = 10 K

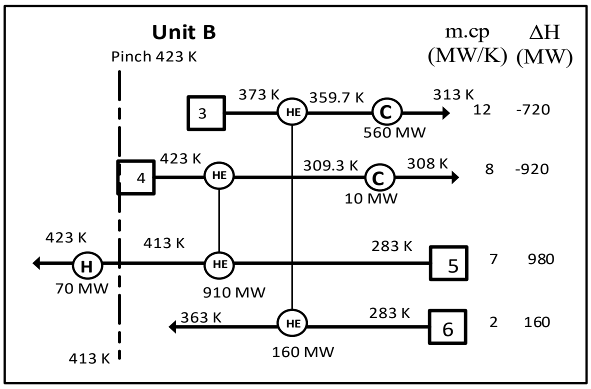

Figure1.b. Grid Diagram unit B at ΔTmin = 10 K

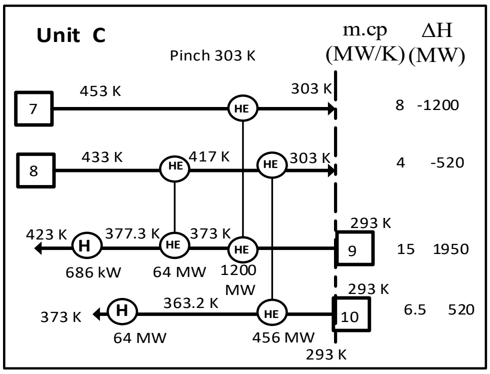

Figure 1.c. Grid Diagram unit B at ΔTmin = 10 K

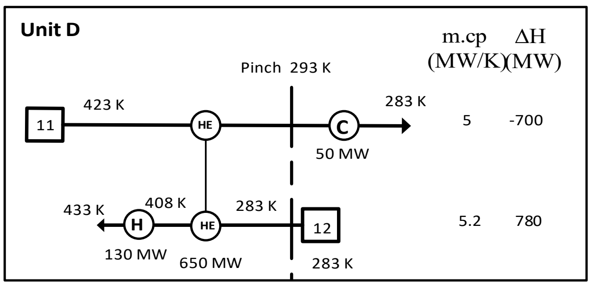

Figure 1.d. Grid diagram unit B at ΔTmin = 10 K

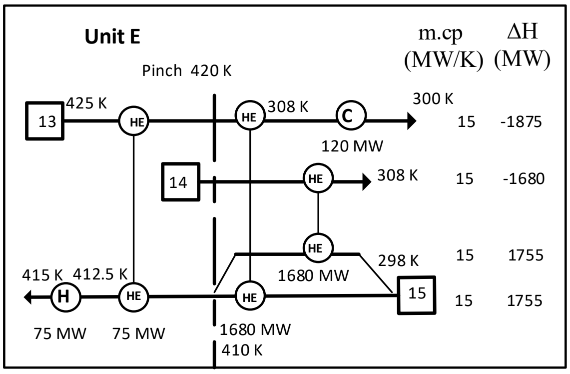

Figure 1.e. Grid Diagram unit E
at ΔTmin = 10 K

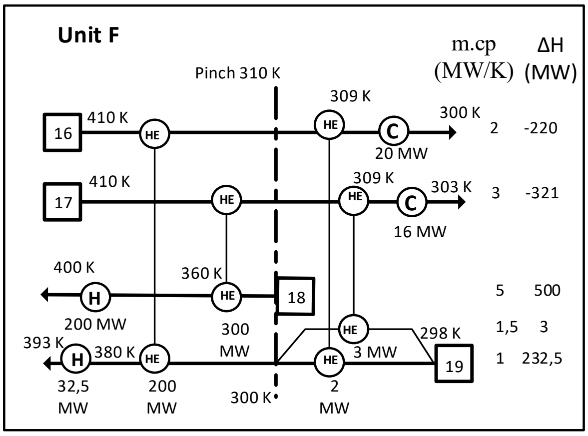

Figure 1.f. Grid diagram unit F
at ΔTmin = 10 K

In unit A process, as shown in Figure 1.a. The pinch temperature is obtained at 473 K for heat flow and 463 K for cold flow with the minimum temperature difference used (ΔTmin) 10 K. All the stream is to the left / bottom of the pinch temperature. Therefore, the solution is in accordance with the criteria of the pinch method, in which the heat flow coupled to the cold stream must have a flowrate capacity (mCp) of cold flow. Figure 4.1.a. indicates that the criteria for the process flow pair are met. Thus, heat integration can be done. The result of sequential heat integration for a 650 MW (650 MW interchangeable heat exchangeable process unit) can, in other words, reduce the demand for thermal utilities by up to 100%, and the cooling water utility requirement also decreases to 1350 MW (QCmin).

Figure 1.b. is a grid diagram image of the unit B streams, comprising 4 streams with a total heat load of QH = 1140 MW (980 + 160), 2 hot streams and 2 cold streams with a total heat load of QC 1640 MW (720 + 920). Process streams are in 2 areas of Pinch Temperature; the solution of the problem also corresponds to the location of the process flow to the Pinch Temp. In Figure 1.b. there are 4 flow areas under the pinch temperature, and only 1 flow is in 2 areas, ie no cold flow. 5. Stream no. 5 which is above the pinch temperature, because there is no pair hence installed heater (H-2) with a load of heat (QHmin) 70 MW. Under hot pin heating pinch temperatures (no 3 and 4) and cold streams (no 5 and 6) may be interchangeable, in which heat flow no. 3. paired cold stream no.6 with intermittent heat load of 160 MW. While the heat flow no. 4 paired with no. 5 with a heat load (QCmin) of 910 MW, thus the utility requirement can be reduced to 570 MW for cooling water utility and 70 MW for heat utility.

Figure 1.c. a grid diagram for process streams in Unit C, in this case all streams are above / right Pinch Temp. Therefore, the solution of the problem also with the criteria above pinch, which is not allowed to be installed cooler. So, in this case the cooling water utility is not needed. The cooling water load (QC) before heat integration is 1720 MW, after integration of cooling water load (QCmin) = 0. While heat load (QH) before heat integration is 2470 MW, after heat integration decreases to (QHmin) = 750 MW. Figure 1.c. indicating a heat exchange between cold flow and heat flow of 1720 MW.

Figure 1.d. is a grid diagram for the D unit process streams comprising 2 process streams, 1 cold stream and 1 hot stream. Using the problem table obtained pinch temperature at 293 K for heat flow and 283 K for cold flow. As in the previous process units, after obtaining the pinch temperature, all the flows in the plot are in the same curve, called the grid diagram. Thus, the location of the process streams in the grid diagram for unit D as shown in Figure 1.d., where the heat flow is in the 2 areas above and below the pinch (past the pinch temperature), while the cold flow is only in the area above the pinch. The heat load before heat integration QH = 780 MW, drops to 130 MW after heat integration. While the cooling water load before heat integration QC = 700 drops to 50 MW. The heat load is exchanged at 650 MW.

Grid diagram representing unit E can be shown in Figure 1.e. where unit E consists of 2 hot streams and 1 cold stream. Pinch temperature obtained with problem table at 420 K hot stream and 410 K for cold stream. The location of the process streams is in two pinch areas, so the solution is also different. In areas below the pinch temperature there are 3 streams consisting of 2 hot streams and 1 cold stream. In order to be paired, then the cold stream in the splitting (split) into 2 cold streams. The heat capacity ratio (mCp) splitting is adjusted to the hot heat flow capacity to be paired. In this case, a cold stream with a 30 MW heat capacity is broken down into 2 streams with a heat capacity of 15 MW each. The result of heat integration, the heat load of 3510 MW drops to 75 MW or about 21% of before heat integration. Cooling water loads drop to 120 MW from the previous 3555 MW (1875 MW + 1680 MW), in other words down to 33%.

The grid diagram for the F unit is shown in Figure 1.f., where unit F consists of 2 cold streams and 2 heat flows. Pinch temperature is obtained at 310 K and 300 K. Process streams are in both areas of Pinch Temperature, therefore the solution is different. In this case, not all process streams are in two areas of Pinch Temperature. In order to be paired then the cold stream no. 19 splitting into 2 parts with supply temperature up to Pinch Temperature (298 K - 300 K), where the flowrate capacity of 2.5 MW is broken down into 1 MW and 1.5 MW. But above Temperature Pinch flow no. 19 is not in splitting, because it meets the criteria to be paired with a heat flow that is in the same place above the Pinch Temp. The result of heat integration, heat load down from QH = 737.5 MW (500 MW + 237.5 MW) to QHmin = 232.7 MW, so the requirement of heat utility can be reduced by 32%. While the demand for cooling water utilities fell by 7 % from the original 541 MW to 36 MW. With the high percentage decrease in the need for hot utilities, the F units are highly potential for heat integration.

From Figure 1.a. up to Figure 1.f. is a grid diagram from unit A to unit F, which can describe the structure of the heat exchanger network in each unit after sequential heat integration. The location of the process streams varies in the pinch area, the area to the right of the point is called the Above Pinch (AP) while the one on the left is called Below Pinch (BP). Figure 1.a. all process flow is below the pinch point, Figure 1.b., 1.e, 1.d. and 1.f. process streams are in both pinch point areas (AP and BP). Besides, Figure 1e and 1.f. represents a process unit with a split stream process. Figure 1.c. represents a process unit with process streams located above the pinch (AP).

After sequential heat integration is done, simultaneous heat integration is performed. The simultaneous heat integration in this study is limited to only two process units. The result of simultaneous heat integration depicted in Figure 2.a to Figure 2.k. Heat integration between two or more process units can be done when the temperature level of the process stream of the unit requiring heat is lower than that of the heat release unit. To find out whether a process unit can be integrated with other process units requires potential integration. In this study, the potential of integration can be derived from the equation through case examples as shown by the grid diagram below. The criteria for determining the potential for integration in this research are energy targets, where the demand for heat utility load and cooling water utility charge are the main targets. On the other hand, the cost of capital is also taken into account to know the suitability of the integration potential obtained.

Figure 2.a. is a grid diagram of units A and unit B after simultaneous heat integration, in which process streams in both units can be interchanged. From the pinch point determination, the pinch point is located at the tip above the other flow temperature, that is 473 K. Therefore, all locations of the process flow are below the pinch temperature. If all the flow is below the pinch temperature, then the minimum heat requirement (QHmin) = 0. So, after heat integration between unit A and unit B, the requirement of heat utility is reduced 100%. Where prior to heat integration, the heat utility needs of unit A and unit B reaches 1790 MW. In view of the declining needs of its heat utilities, unit A and unit B are highly potential for heat integration. The integration of heat with the target energy objectives, then it is considered beneficial because it can save or reduce the energy needs of a process unit. While the minimum cooling water requirement (QCmin) = 830 MW (560 MW + 270 MW). The grid diagram also shows the structure of the heat exchanger network (HEN) after heat integration. The number of heat exchanger units in units A and B after sequential heat integration is seven units (Figure 1.a and Figure 1.b), whereas after simultaneous heat integration decreases to six. This indicates that if the cost of capital is calculated, simultaneous heat integration is more advantageous than sequential heat integration in units A and B.

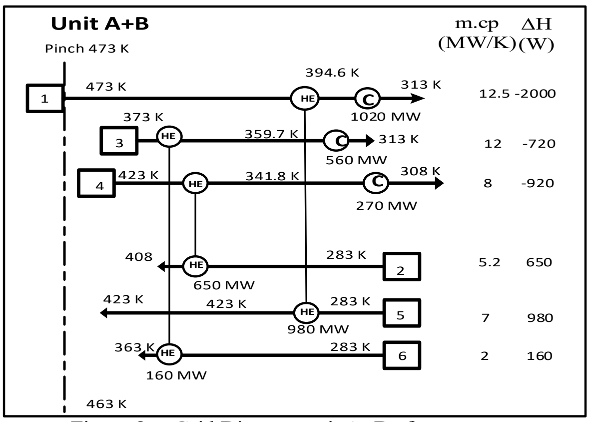

Figure 2.a. Grid Diagram unit A+B after simultaneous heat integration at ΔTmin = 10 K

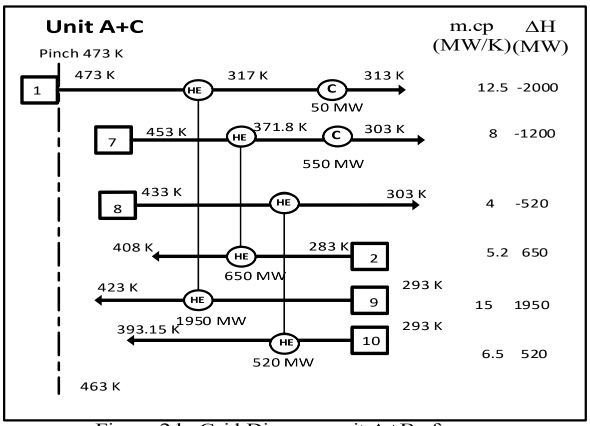

Figure 2.b. Grid Diagram unit A+B after simultaneous heat integration at ΔTmin = 10 K

Figure 2.b. is a grid diagram for units A and C after simultaneous heat integration. Figure 2.b. can also show hot and cold streams between unit A and unit B. The location of the process streams is all below the Pinch Temp. In sequential heat integration performed on unit A, all process flow is also below Pinch Temp (Figure 1.a), while for unit C, all process flow is above Pinch Temp (Figure 1.c). However, after simultaneous heat integration between units A and C, all the flow of the process is below the Pinch Temp. This is influenced by the temperature of the Pinch Temperature.

As with the simultaneous heat integration of units A and unit B (Fig. 2.a), the simultaneous heat integration between units A and C results in the requirement of heat utility (QCmin) = 0. Therefore, this simultaneous heat integration is more advantageous than sequential.

From Figure 2.a. until Figure 2.b. indicates that if all process streams are below the pinch temperature, it does not require a heat utility. Therefore, for target energy, it is preferred in the determination of heat integration techniques. Reduced hot utility requirement will reduce operational cost, therefore heat integration technique is more recommended to be done on Unit A + B, A + C, A + D, A + E, A + F.

Grid diagrams of the streams of unit's B and C, in which all cold and hot streams are in the area above the pinch temperature. All hot and cold streams can be paired, but for no hot stream. But is not maximal in heat matched because there is 80 MW remaining. As a result, cooler is to be installed, in this case the cooler is not allowed to be installed in the area above the pinch temperature. So that heat integration is simultaneously less than optimal.

Comparison between sequential and simultaneous integration is presented in Table 2. The percentage value of energy saving is obtained from the difference between the minimum heat requirement value after sequential heat regression with heat requirement after simultaneous heat integration divided by sequential heat integration requirement

Table 2. Comparison of heating duties resulting from sequential and simultaneous heat integration in various cases

No.	Unit Process	Non-Integration (1) Heating Duties Q_H MW	Sequensial (2) Heating Duties Q_{Hmin} MW	Simultaneous (3) Heating Duties Q_{Hmin} MW	(1)-(2) / (1) x 100 %	ES' (2)-(3) / (2) x 100 %	Recommendation
1	A, B	1506	70	0	95.4	100	Simultaneous
2	A, C	3148	750	0	76.2	100	Simultaneous
3	A, D	1211.6	130	0	89.3	100	Simultaneous
4	A, E	3996	75	0	98.1	100	Simultaneous
5	A, F	1256	232.5	0	81.5	100	Simultaneous
6	B, C	3566	820	250	77.0	70	Simultaneous
7	B, E	4410	145	142	96.7	2	Simultaneous
8	B, F	2670	302.5	95	88.7	69	Simultaneous
9	C, D	3271.6	880	880	73.1	0	Sequential
10	C, E	6056	825	777.5	86.4	6	Simultaneous
11	C, F	3316	982.5	952.5	70.4	3	Simultaneous
12	D, E	4115.6	205	72	95.0	65	Simultaneous
13	E, F	4160	307.5	300	92.6	2	Simultaneous

Table 2. shows the heating duties of the hot utility, which between the non-integration process unit and the heat integration-processing process unit indicates significant energy savings. On energy target, in most cases when combined heat integration between two units, the recommendations are simultaneous heat integration. Because when combined between two or more units will result in a minimum heat requirement equal to or greater than sequential heat integration. Thus, the recommended heat integration technique is simultaneously for target energy. All process units in the above case if integrated simultaneously would be more advantageous than sequential although the percentage of sequential between sequential and non-sequential differences. While C-D will be more advantageous if sequential heat integration is done simultaneously, this is because after heat integration is sequential or simultaneous, the utility needs are the same minimum. With the same result between sequential and simultaneous heat integration more potential is chosen sequentially, because if the cost of capital is taken into account sequentially the result will be more profitable. Thus, in this condition it is found that the simultaneous

heat integration is no better than sequential. In the heat integration of the E-F process unit it is seen that the cooling duty of the utility after heat integration either sequentially or simultaneously yields the same value, so that CS '= 0. But under such conditions it is not recommended sequential heat integration, due to simultaneous saving energy (ES') to the sequential obtained is 2%, so for hot integration recommendations more emphasis on heating duty utility derivation. From Figure 1. until Figure .2. shows that if all streams are below Pinch Temperature, then the minimum utility requirement (QHmin) = 0, can be expressed ΔH = mCp multiplied ΔTP > than when all the stream is above the pinch temperature. So to assume the same can be derived mathematical model to know the potential of heat integration of a process unit to be able to integrate with other units. The mathematical model is as follows:

(1) $H'_{sq}=\sum_{i=1}^{n} mh.Cph.\Delta TPhsq + \sum_{j=1}^{n} mc.Cpc.\Delta TPcsq$

(2) $H'_{sm}=\sum_{i=1}^{n} mh.Cph.\Delta TPhsm + \sum_{j=1}^{n} mc.Cpc.\Delta TPcsm$

Whereas , ΔTPh = (TPh –Tref)

ΔTPc = (TPc – Tref)

H'_{sq} = Potential of sequential heat integration

H'_{sm} = Potential of simultaneous heat integration

If $H'_{sq} < H'_{sm}$, then the selected is simultaneous heat integration,

$H'_{sq} > H'_{sm}$, then the selected is sequential heat integration

Further, equations (1) and (2) are applied to the above case and to find out whether equations (7) and (8) solve these problems are presented in Table 3.

Table 3. Comparison between the recommended calculation of potential heat integration with the calculation of target energy in various hypothetical cases

Units	Energy Target	Potential of heat integration
A, B	Simultaneous	Simultaneous
A, C	Simultaneous	Simultaneous
A, D	Simultaneous	Simultaneous
A, E	Simultaneous	Simultaneous
A, F	Simultaneous	Simultaneous
B, C	Simultaneous	Sequential
B, E	Simultaneous	Sequential
B, F	Simultaneous	Sequential
C, D	Sequential	Sequential
C, E	Simultaneous	Sequential
C, F	Simultaneous	Sequential
D, E	Simultaneous	Sequential
E, F	Simultaneous	Sequential

Table 3 shows that hypothetical process units A, B, C, D, E, F when heat integration is accomplished with objective function of target energy, then the result is that not all heat integration recommendations are simultaneous, but (C-D) sequential results. From the calculation of potential heat integration with equations (1) and (2), it shows that A-B, A-C, A-D, A-E, A-F are recommended simultaneous heat integration. While B-C, B-E, B-F, C-D, C-E, C-F, D-E and E-F are recommended sequentially. There are differences and similarities between the results of calculations using conventional PDM measures of target energy with the calculation of potential heat integration. From the existing equation it can be concluded that equations (1) and (2) apply only to units A-B, A-C, A-D, A-E, A-F and C-D.

From Table 2. until Table 3, the data presented are interconnected and there is correspondence, so the equations can be used in the determination of the technique to be applied to the preparation of the network structure of the heat of the process units in a plant / industry. So, the alternative steps before starting the design of an energy usage system that is on the preparation of the structure of the heat exchanger network (HEN) is as follows:

1. Identification of the flows involved in the process units of the heat exchange process. In this case is the capacity of flowrate, target temperature and supply temperature.
2. Determine the pinch temperature. Use the obtained pinch temperature to calculate the potential of heat integration H'sq and H'sm .
3. Subtract the potential heat integration value for the simultaneous H'sm with the potential of H'sq sequential heat integration.

If H'sq < H'sm , then choose a simultaneous heat integration technique, on the contrary. If H'sq < H'sm , it is advisable to choose sequential heat integration.

4. Conclusion

In this paper has been proposed a heuristic to determine the choice of heat integration techniques to be used (sequential or simultaneous) by using the concept of potential heat integration. The mathematical model of heat integration potential applies only to energy targets under conditions when all process streams are below Pinch Temperature. In this study found one case where simultaneous heat integration is no better than sequential heat integration (case of C-D process unit), so not always simultaneous heat integration better than sequential.

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