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Application of Energy Optimization Techniques for Heat Exchanger Networks Retrofitting

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Abstract

Energy optimization has become a priority for industry because of energy high cost as well as environmental concerns. This paper presents a systematic approach for heat exchanger network retrofitting to maximize energy recovery in chemical plants. Additionally, it introduces unconventional solutions through energy and utility optimization for some equipment, such as steam generation, Organic Rankine Cycle (ORC) and absorption chillers. The introduced methodology focuses on practical energy reduction that can be achieved in process plants; complex modifications are excluded unless the resulting energy reduction required it. The reliability of the considered approach is examined individually at each proposed modification. The proposed methodology begins with identifying maximum possible energy reduction using pinch analysis to decide either to proceed with retrofit or not. There are two main steps in this approach; the first is to perform the heat exchanger network suggested modification, while the second is to apply waste heat recovery techniques. Many energy reduction alternatives are presented to select the best one, based on the nature of each plant, which can need for chilling or electricity. The preheat train of an Egyptian crude distillation unit (CDU) is used as a case study to demonstrate the effectiveness of the proposed approach. The present approach results show a reduction in energy consumption with minimum changes in topology compared with energy consumption estimated by using pinch technology.

Keywords: *Pinch analysis; Retrofit; WHR; LGHR; Process integration; Sustainability; Grid diagram; ORC; Absorption chillers.*

1. Introduction

Interest in energy optimization arose in the 1970's due to the energy crisis. Since then, energy cost is in continual increase as well as environmental concerns. In the last few years, the world started replacing the conventional energy sources with clean renewable energy sources, but this will need more time to be economically applicable from the viewpoint of industrial scale. Therefore, providing methods and technologies to reduce energy consumption and relative environmental problems is essential to the investors. One method for energy conservation is heat exchanger network (HEN) optimization. Now, most new plants are designed based on the best energy optimization technologies such as pinch technology [1], but the old existing plants have problems of traditional design that mandates design retrofitting.

The problem with HEN retrofitting is the major structural changes should be applied on some cases to reach minimum consumption. So many methods have been introduced to reach the optimum changes to the existing HEN as well as make retrofit more systematic and easier to apply. Retrofit using pinch has been introduced, but the problem was the major changes accompanied [2]. To overcome the drawbacks of most conventional retrofit techniques, many researches have introduced other solution techniques such as mathematical optimization and problem automation [3–8], cross pinch heat exchangers elimination [9], utility pass and heat transfer enhancement techniques [10–12].

Many methods that combined between different approaches were applied [13–15]. Many researchers used Refinery crude distillation unit to apply their retrofit methods [16–19].

This paper introduces a systematic approach for HEN retrofitting that focuses on achieving maximum energy reduction with minimum changes as well as application of waste heat recovery technologies on some equipment such as steam generation, absorption chillers and Organic Rankine Cycle (ORC) that contribute greatly in energy reduction. The introduced methodology has been applied on a crude preheat train of CDU. The results show major decrease in energy consumption by the HEN retrofit as well as waste heat recovery (WHR) techniques (absorption chillers and steam generation).

2. Methodology

The proposed methodology depends on heat exchanger network retrofitting as well as waste heat recovery techniques. The following steps are supposed to be followed to get the best solution for a heat exchanger network retrofitting problem:

1. *Targeting;* Thermodynamic targeting for best economic scenario is important for retrofit evaluation from the beginning; that is why pinch technology is used for targeting. The target from pinch is the maximum energy recovery that could be reached, so a new target is set based on the required modifications. If the changes will be major, then evaluate minimum changes to get reasonable energy reduction and start evaluating WHR techniques.
2. *Grid diagram*; plotting a temperature scale grid diagram of the network to easily identify thermodynamically applicable initiatives. For example, process streams that use utility can be easily matched together if available without much effort. Addition of a new HX is the best practice when there are hot and cold streams that can be matched together instead of utilities are being used. Additionally, streams that have low grade heat can be identified and evaluated as energy saving techniques.
3. *Identify cross-pinching heat exchangers (HX) and evaluate their elimination*; if it is complex, ignore this step, otherwise compare the results with the specified target; if reached stop, otherwise proceed to the next step.
4. *Identifying the pinching HX* and increase UA to reach the minimum temperature approach (in this case 10°C).
5. *Utility pass HX;* if the pinching HX is constrained with stream duty, another HX in utility pass is processed. If utility pass HX does not exist, evaluate insertion of a new HX for heat recovery between utility consumption streams.
6. *Intensification;* Increasing existing heat exchanger heat transfer coefficients through tube-side enhancements (i.e. enhanced surface tubes, internal tube fins, coatings, fluid additives, mechanical mixing devices, twisted-tape inserts, coiled-wire inserts, etc.) and shell-side enhancements (i.e. externally enhanced surface tubes, external tube fins, coatings, fluid additives, helical baffles, etc.). After intensification, if the target is not accomplished, debottlenecking (stream split, relocation, re-piping) will be considered. Relocation or re-piping must be justified by satisfying savings because of the accompanied restructure in piping, installation, maintenance, etc. This may result in some complexity in the operation as well as high cost. Limit of HEN retrofit will basically depend on savings compared with complexity, so there could be a potential of saving but the solution is not preferable from the viewpoint of operability.
7. *Waste heat recovery (WHR);* In the cases where heat source is available but there is no heat sink, boiler feed water (BFW) that could be used as a cooling utility for steam generation, other options such as low grad heat recovery (LGHR) techniques like absorption chillers or organic Rankine cycle are considered. Choosing between those techniques depends on many factors such as the need and the economic evaluation for each one of them. For example, steam generation could be the easiest option but there no need for the steam

while absorption chillers could make cost reduction if the process already need chilling. Figure 1 shows the methodology for HEN retrofitting which is described by a logic tree

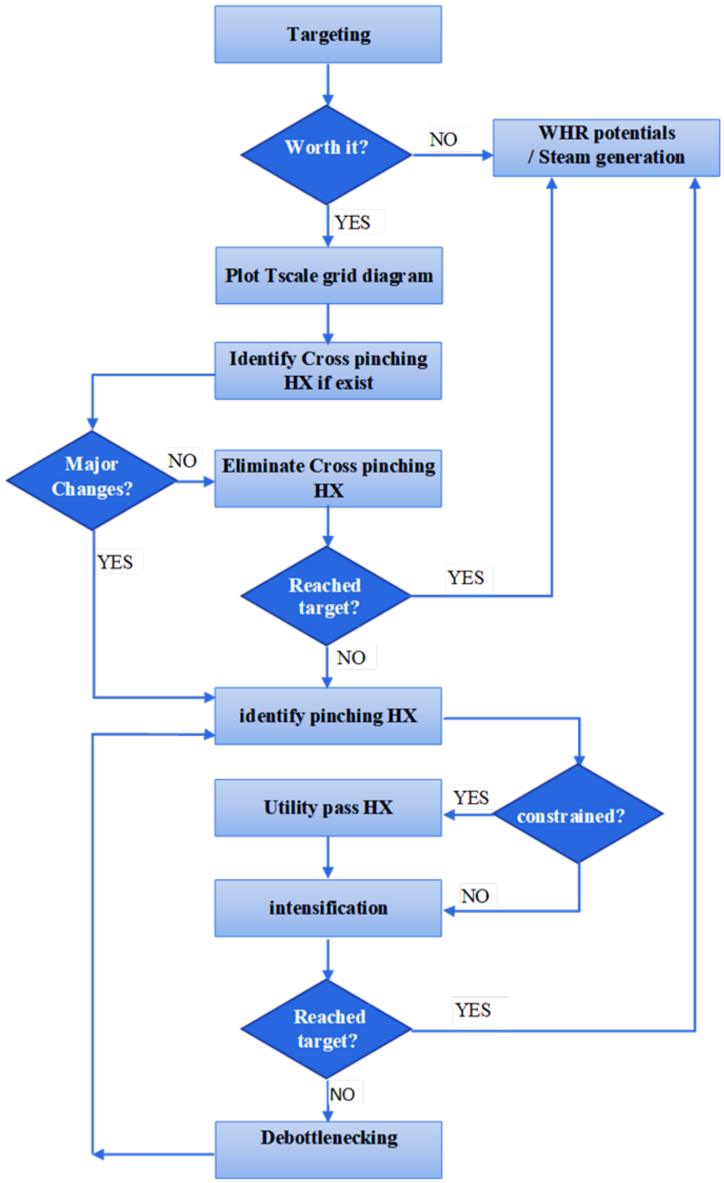

Figure 1. Logic tree for HEN retrofitting

3. Case study

The present work is applied on an Egyptian CDU preheat train used to preheat the crude oil feed to the plant. The grid diagram of the considered unit is shown in Figure 2. This figure represents the HEN in more simple way and make it easier to find the initiatives as explained in the methodology. The original HEN for the investigated plant composed of 13 hot streams and 4 cold streams. The desalter splits the crude stream (C3) into two streams as inlet temperature to the desalter is considered a constrain. The crude oil feed stream (C3) is heated in two sections by heat exchange with the hot fractions returning from the distillation tower as well as some streams from vacuum distillation unit (VDU). The first section is initiated from storage to a desalter inlet, while the second section represents the desalter outlet stream that passes through a fired heater to the crude atmospheric distillation tower. The remaining required heat is obtained from this fired heater. C1 represents the kerosene stream while C2 represents wash water for the desalters. Table 1 shows process data for cold and hot supplies and targets as well as the required heat duties for the studied heat exchanger network.

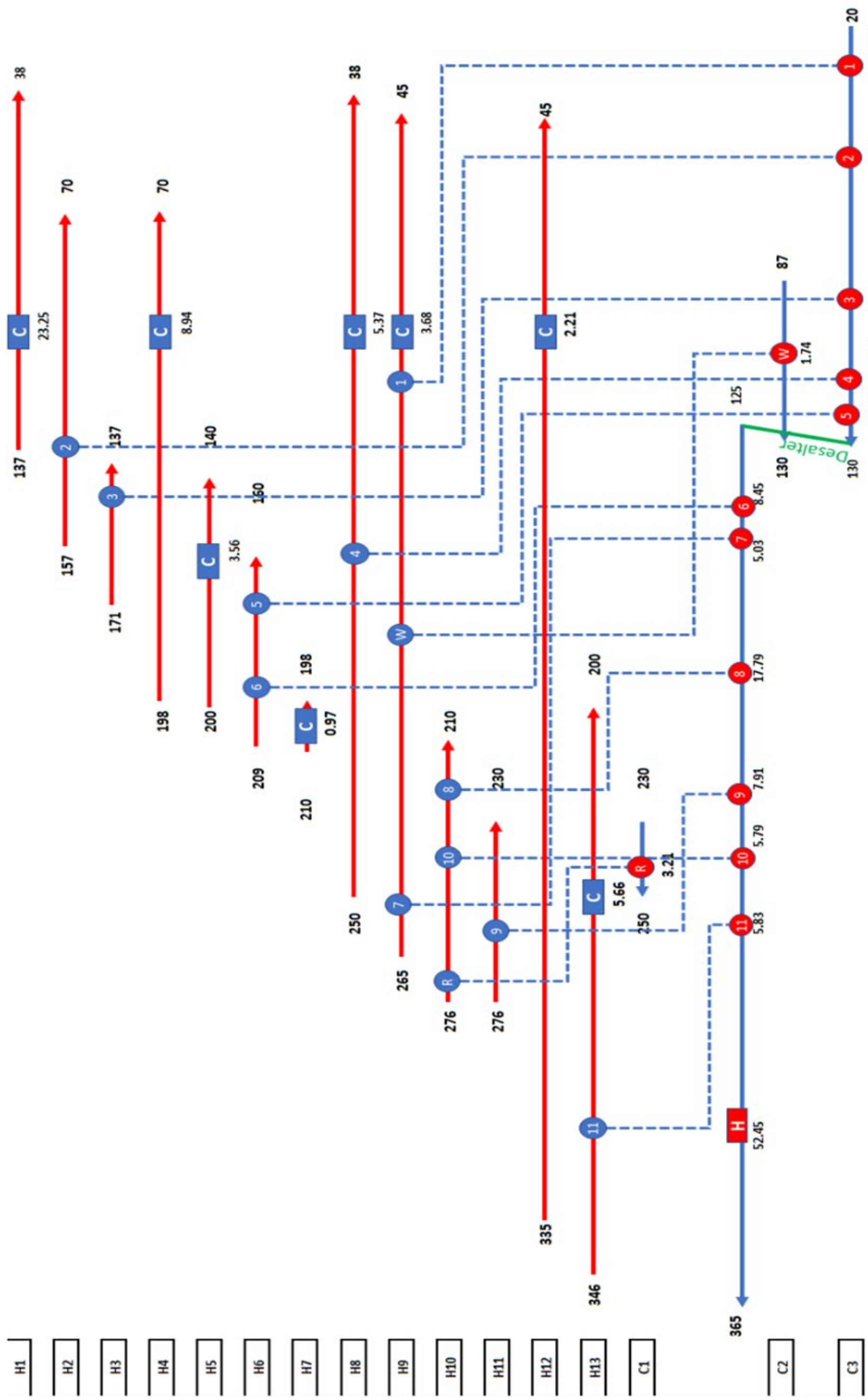

Figure 2. Grid diagram for the considered CDU preheat train

Table 1. Cold and hot streams as well as heat duties data of the original HEN

Stream	Temperature, °C				Duty, MM kcal/hr
	Hot supply	Hot target	Cold supply	Cold target	
1	176	106	20	38	4.8
2	157	70	38	60	6.2
3	171	137	60	110	15
4	250	205	110	116	1.7
5	178	160	116	130	4.6
6	209	178	125	151	8.5
7	265	200	151	166	5
8	254	210	166	217	17.8
9	276	229	217	238	7.9
10	268	254	238	253	5.8
11	346	276	253	269	5.8
W	200	176	87	130	1.7
R	276	268	230	250	3.2

4. Results and discussion

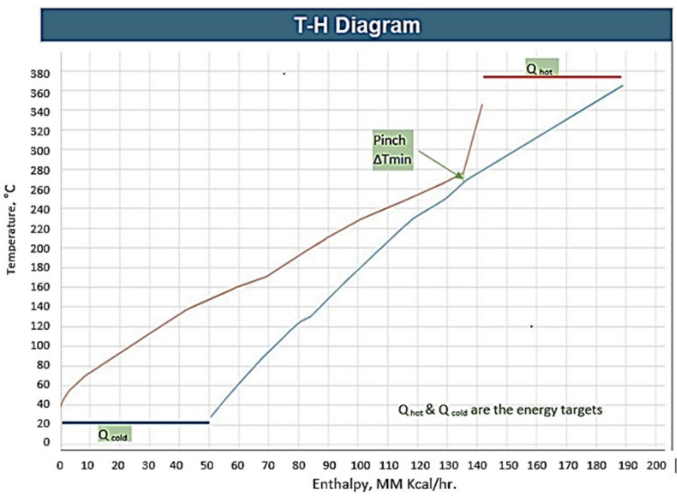

Figure 3. Composite curves for the original CDU preheat train

As displayed by Figure 1, Logic Tree for HEN retrofitting is started by targeting step. The energy targets are achieved by using composite curves. Therefore, in order to know if there is possibility of improvement for the original HEN, the composite curves are used to indicate optimum energy consumption as shown in Figure 3. Similarly, the pinch analysis shown in Table 2 for the considered CDU indicates that a potential improvement can be achieved to reduce the hot utility consumption by about 10% and reduce the cold utility consumption by about 10 %.

Table 2. Pinch analysis results

Pinch temperature, °C	271
Hot pinch, °C	276
Cold pinch, °C	266
Optimum hot duty (Q hot), MM kcal/hr	47.2
Optimum cold duty (Q cold), MM kcal/hr	48.4
Minimum approach temperature, °C	10

Composite curves can provide overall minimum energy consumption regardless of the utility type and consumption rate. As known, the composite curves are a complicated tool for setting loads for the multiple utility levels. Thus, for multiple utility levels, the Grand Composite Curve (GCC) is used. Figure 4 addresses the grand composite curve of the investigated preheat train. This curve is used to optimize the usage of different utility levels. For example, the GCC is used to maximize the usage of low-pressure steam (LPS) and to minimize the usage of high-pressure steam (HPS) as a hot utility and maximize using of air-cooling system (cold utility) instead of water-cooling system. GCC is considered a part of the targeting step but it focuses on utilities usage optimisation.

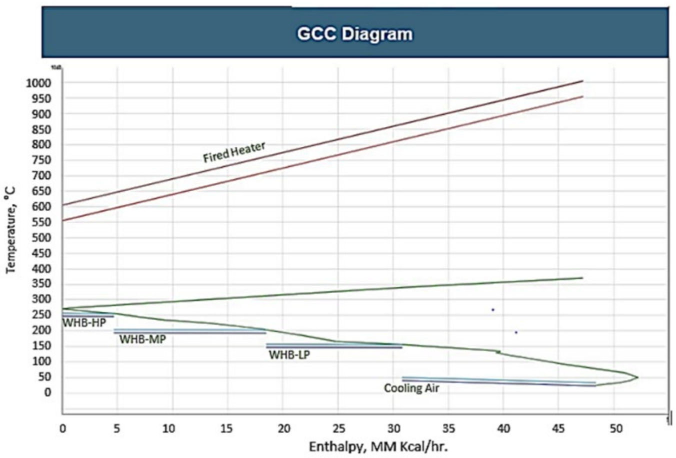

Figure 4. Grand composite curve (GCC) the original CDU preheat train

The pinch analysis presented in Table 2 shows the potential decrease in the overall utility consumption. However, Table 3 displays different utility types with current and optimum consumptions based on the optimum utility matching. The achieved percentage of optimum consumption of certain utility depends on the degree of complexity and cost of the required modifications compared to energy saving according to this optimization. As presented in Table 3, the WHR from HP and MP steam was created for the optimized HEN with heat duties of 4.67 and 13.82 MMKcal/hr respectively. On the other hand, water cooler is not used in the optimized HEN and the air cooler heat duty is reduced as well by more than 50% compared with that of the current investigated HEN. Thus, it is clear that the optimized HEN maximizes the dependency of WHB (HP, MP, and LP) for steam generation and minimized the dependency on water and air coolers as equipment for heat recovery.

Table 3. Comparing of utilities consumptions for current and optimized HEN

Utility name	Current duty (MM kcal/hr)	Optimum duty (MM kcal/hr)
Fired Heater	52.45	47.22
WHB - HP	0	4.67
WHB - MP	0	13.82
WHB - LP	7.85	12.33
Air Cooler	39.82	17.59
Water Cooler	5.97	0.00

According to the proposed methodology for HEN retrofitting, the grid diagram of the first stage of retrofitting is drawn. The retrofitting first stage with the proposed modifications for the considered CDU preheat system is depicted in Figure 5. As shown in this figure, reboiler HX R was relocated to overcome the HX 10 pinch and its duty was increased by HX R value. In the same way, the intensification step (step 6) was applied to HX 6 to overcome pinch for HX 11 stream split and a new HX were applied. These modifications to the HEN reduce hot utility consumption by about 10 % and cold utility by about 10 % as shown in Figure 5. According to pinch analysis, no more heat exchange can be achieved between hot and cold streams. However, by applying the last step of the proposed methodology (application of WHR techniques for steam generation and absorption chillers), the cold utility consumption can be reduced by about 60 % as presented in Figure 5.

As shown in Figure 5, stream splitting and addition of new HX (HX N) can recover a small duty of 0.45 MM kcal/hr and this is not practical because of the complexity of the solution compared to the small duty recovered. Therefore, this suggestion is not taken into consideration and the final retrofitted grid for the considered HEN is presented in Figure 6. The results of this retrofitting are summarized in Table 4.

Actual savings for the retrofitted HEN can be appeared in the form of reduction of natural gas amount used as fuel for the fired heater, reduction in power consumption for air coolers, producing of tons of refrigeration when using absorption chillers or producing power in case of using ORC, as well as producing of LP steam. Exact savings from applying absorption chillers or ORC can’t be determined without vendor quotations and data sheets.

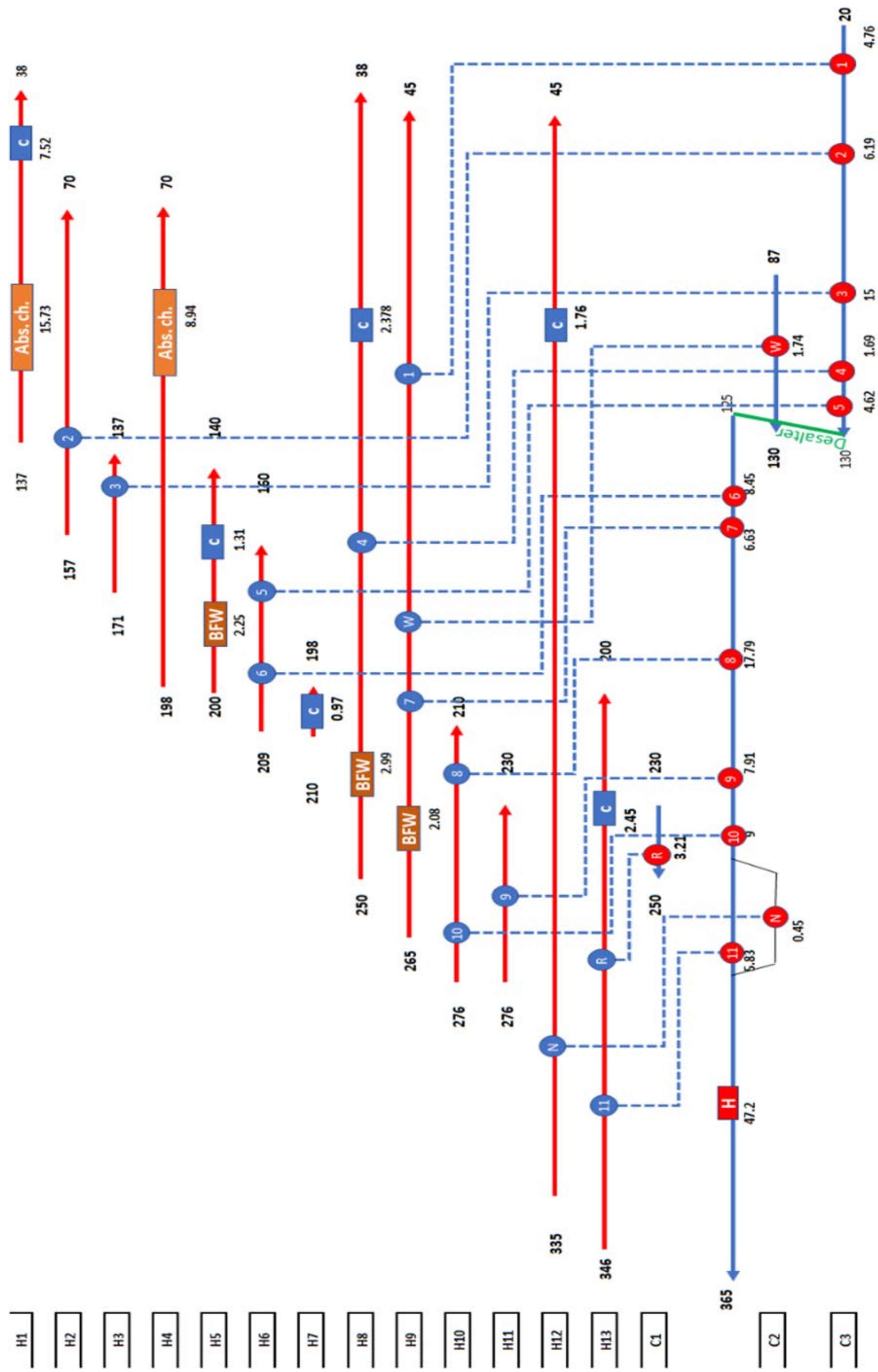

Figure 5. HEN Retrofitting first stage for maximum energy

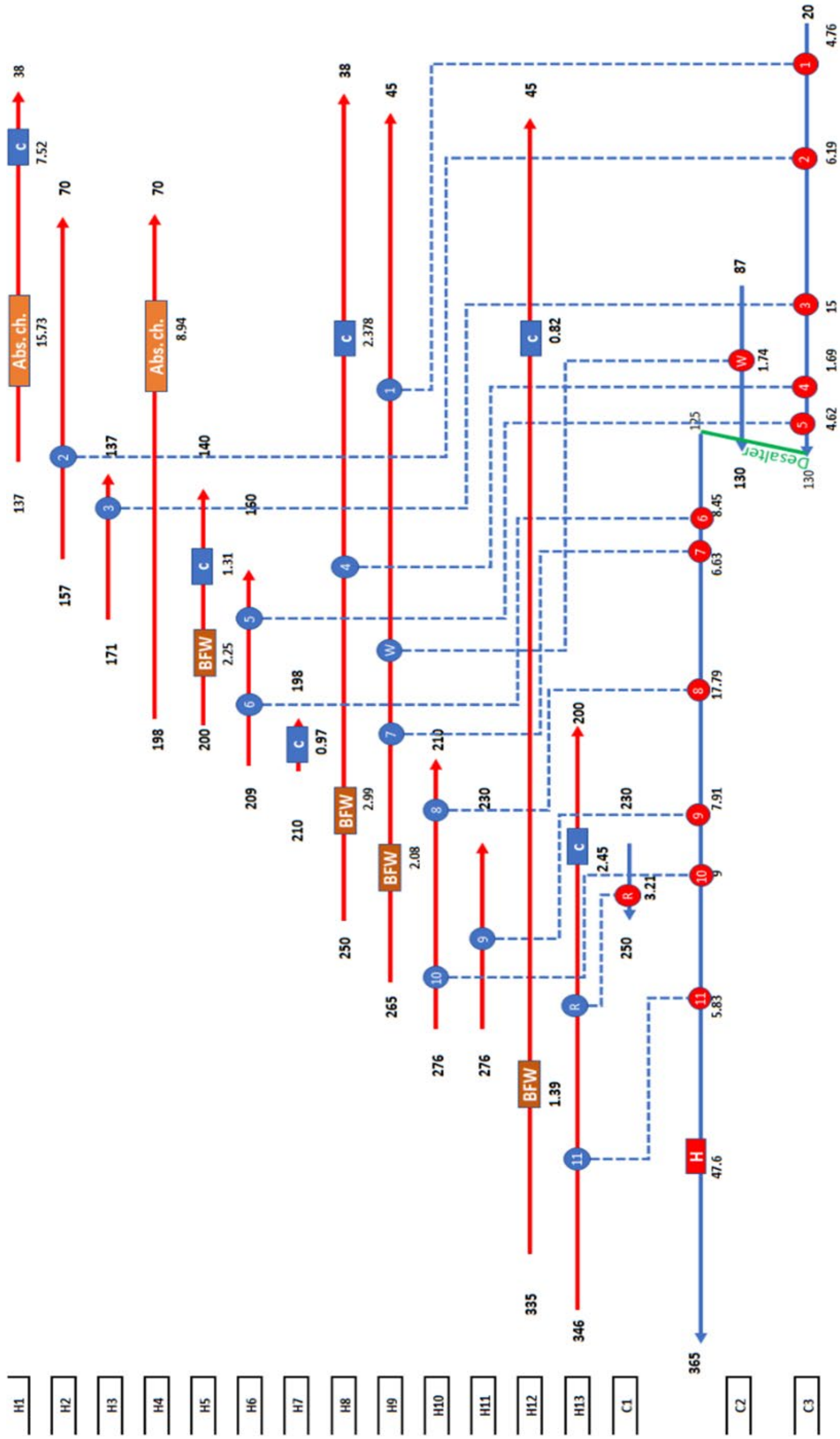

Figure 6. Final stage of retrofitting for the HEH

Table 4. Results summary for the last stage retrofitted HEN

Utility	Original equipment heat duty (MM kcal/hr)	Equipment heat duty after retrofitting (MM kcal/hr)
Fired heater	52.45	47.6
WHB - LP	7.85	12.07
Air cooler	39.82	7.55
Water cooler	5.97	2.29

5. Conclusion

This main objective of the present work is to introduce a systematic technique for heat exchanger network retrofitting in order to maximize recovery of energy. This technique depends mainly on practicality. According to the present approach, insignificant savings with unconvincing changes to operation and economic evaluation are neglected. In other words, this method takes into consideration the economics and complexity of individual HEN changes and not only the total savings with total capital expenses (capex). This approach composed of two main steps; the first step is to perform the heat exchanger network suggested modifications, while the second step is directed to apply waste heat recovery techniques. The results of the retrofitted HEN show that there is an energy reduction by 4.8 MM kcal/hr and 4.8 MM kcal/hr for hot and cold utilities respectively. By applying the WHR techniques, another energy reduction of 33.4 MM kcal/hr in the cold utility can be achieved. Selection between WHR different techniques depends on process requirements and economic consideration. Regarding the present case study, steam generation and absorption chillers were used as a representation for WHR techniques. The results show that the duties of fired heater, air coolers and water coolers are deceased by 4.8 MM kcal/hr, 32.27 MM kcal/hr, and 3.68 MM kcal/hr respectively. Moreover, LP steam generation is increased by 4.22 MM kcal/hr.

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