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Optimization of Heat Exchanger Network in the Steam Assisted Gravity Drainage Process Integration

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Abstract

The Steam Assisted Gravity Drainage (SAGD) process is an enhanced method to extract oil from bitumen which involves surface and central process facilities. This paper describes the Central Process Facilities (CPF) of SAGD and proposes several retrofit plans to the Heat Exchanger Network (HEN). In this approach, the process integration scheme is applied to estimate the energy saving in HENs, and various cases are modeled in favor of a commercial simulator. Throughout this work, a minimum approach temperature of 10℃ is assumed. The results reveal that, due to the HEN optimization using process integration, the heating and cooling duties can be reduced to 29.68MW and 1.886MW, respectively. Compared with the Husky case, all cases considered in this study indicate a potential reduction of at least 6% in total cost, including investment and operation costs.

Keywords: *HEN, Optimizing, CFP, SAGD, Energy analyzer, Process Integration*

1. INTRODUCTION

Due to the continuously increasing demand for oil, there has been growing interest in exploring the use of oil from unconventional reservoirs. Oil sands, which consist of sand, clay, water, and bitumen, make up one of the potential resources [1]. Bitumen is viscous and immobile at room temperature, which makes it impracticable to extract oil from via conventional production recovery methods.

The non-mining recovery of bitumen from oil sand deposits is an advanced technology compared to mining techniques, which lead to environmental problems. One of the widely used non-mining approaches is the Steam Assisted Gravity Drainage (SAGD) process. The SAGD process is a thermally enhanced method for continuously extracting oil from bitumen using paired wells horizontally drilled into an underground bitumen reservoir. Steam is injected into the upper well to heat the oil, and reduces its viscosity to a point at which the oil will flow. Then, the mixture of bitumen and water flows to the lower well, where it is pumped to the surface [2-4]. Bitumen emulsions from the field facilities are then delivered to the Central Process Facilities (CPF). The Central Process Facilities consist of four steps: oil treating, de-oiling, water treating, and steam generation. Oil is separated from water in the first step, then the produced water is sent to the de-oiling step to remove large oil droplets before being mixed with raw water. Next, the mixing of de-oiled and make-up water is

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softened and sent to boilers to produce steam that is used for injection. In the extracting process of oil, a considerable amount of energy is consumed mostly because of a large amount of required steam. In order to save energy and operation costs, Process Integration (PI) is applied to CPF of the SAGD process.

Since it was first reported in 1965, PI has been rapidly developed. It allows for the consideration of a process as a whole and improving it by analyzing the interactions between different parts as opposed to only optimizing an individual plant. On the other hand, the pinch analysis, one of the most mature tools in the field of PI, is widely used for industrial process designs and retrofits to minimize investment costs, increase energy saving, and reduce greenhouse gas. A study on the direct synthesis of adipic acid published by Iris et al. [5] described a retrofitting of a heat exchanger network using pinch analysis. In this study, the upgraded design can potentially save 70% operating cost with increasing capital cost which requires eight months to pay back [6]. Bao-Hong Li et al. [7] also investigated the modification of heat exchanger networks by eliminating cross-pinch loads in terms of pinch technology. Although the acceptance of the pinch analysis is increasing, it has attracted little attention in the oil sands industry. Nadella [8] appears to be the first study that applied pinch analysis to the oil sands extraction process. From the SAGD CPF flowsheet prepared in favor of the pinch method, the results indicate minimum energy savings of 6% [8,9] and a 5% reduction in Green House Gas (GHG) emissions through modifications to the heat exchanger networks [10].

This paper aims to retrofit an existing SAGD CPF to estimate the saving potential of investment and operating costs as well as energy saving capacity by using pinch analysis. Comparisons between the pinch and cross-pinch designs are also presented to demonstrate the effects of pinch breaking.

2. METHODS

By ensuring the proper networking of hot and cold streams in an industrial process, energy saving can be efficiently achieved to a considerable level. Pinch technology is commonly used to optimize heat exchanger networks because of its simplicity and functionality. In general, pinch technology used for the determination of minimum utility target assumes the following rules.

1. No heat transfer across the pinch.
2. Add heat utilities only above the pinch.
3. Add cold utilities only below the pinch.

2.1 Case study

Data provided from the Husky Corporation were applied to the original CPF design. In this case, six streams are to be cooled while one is to be heated. Table 1 shows the heat duties, mass flows, and input and output temperatures as well as heat capacities of the process streams. Fired heat is used as heating utility while glycol water blend contributes to both the heating and cooling process. However, heat capacity loss is caused by glycol, and this is replaced in this work by middle pressure (MP) steam and air [11, 12]. Any effects resulting from such modification can be safely ignored, because the aim of this analysis is to optimize the system as a whole. Furthermore, the consumption of MP steam and air can be converted into the demand for glycol water mixture at the final calculation stage. Figure 1 presents a simplified flowsheet diagram of the initial CPF.

Table 1. Process streams data for the Husky SAGD CPF.

Stream	T(℃)	T^t(℃)	Mass Heat Capacity(KJ/kg℃)	Mass Flow(kg/h)	Q(MW)
Produced Gas	127.6	50	1.747	2542.3	0.096
Sales Oil 1	145.2	70	2.203	25790.2	1.187
Sales Oil 2	145.2	70	2.203	25790.2	1.187
Produced Water	152.4	80	4.568	218591.9	20.082
Disposal Water	77.9	60	4.352	230725.9	4.993
Blowdown	305.6	65	5.944	42663.9	16.949
Boiled Feed Water	14.1	305.6	4.185	213319.3	-72.287

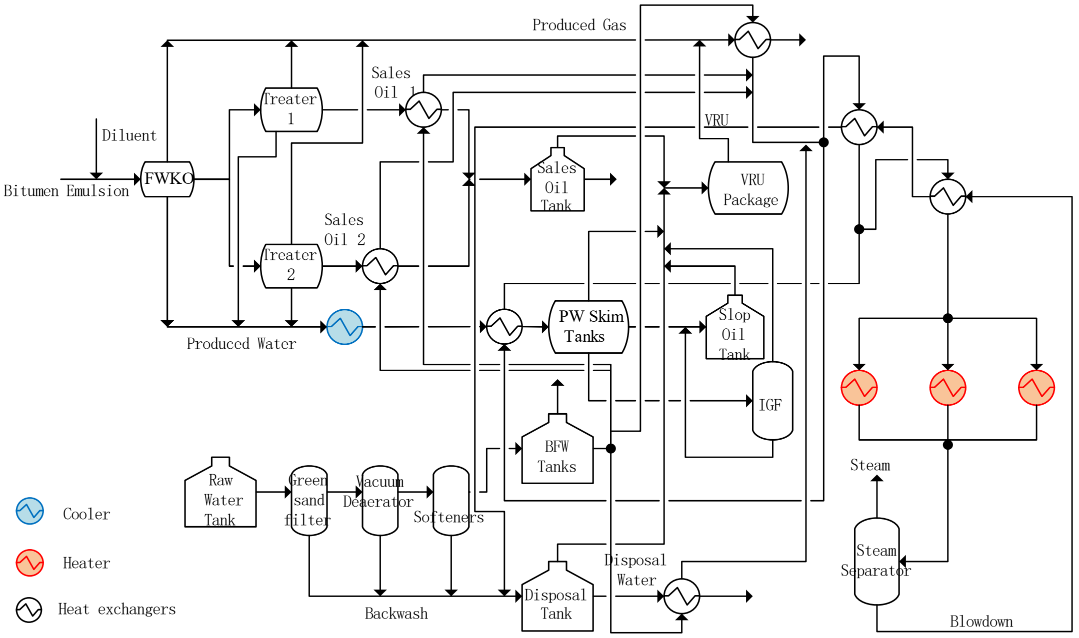

Figure 1. Simplified flowsheet diagram for initial SAGD CPF

Figure 2 shows the corresponding modeling of Husky CPF. In order to apply the pinch analysis to this process, a procedure is proposed as follows.

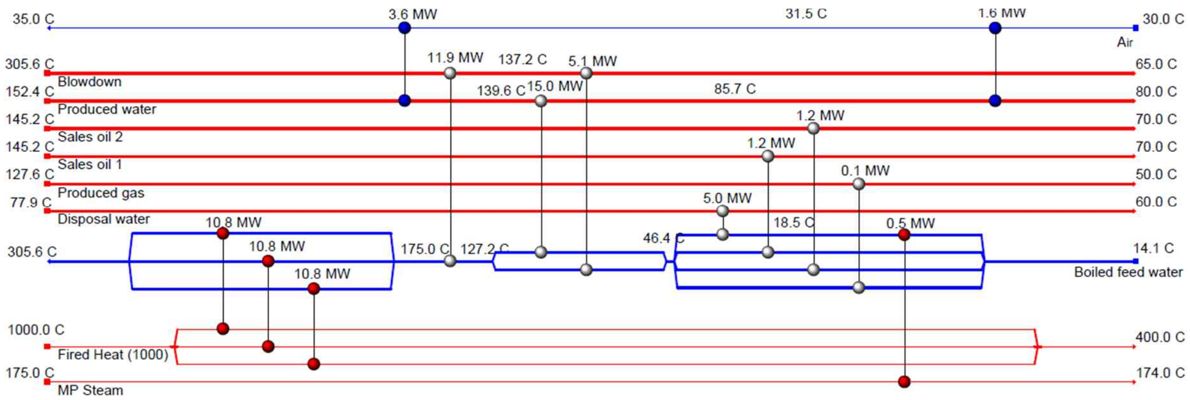

Figure 2. Corresponding modeling of heat exchanger network

Step 1: Select a proper $\triangle T_{min}$.
Step 2: Determine pinch temperatures and energy targets from a composite curve.
Step 3: Modify the initial HEN design.
Step 4: Estimate saving opportunities and select design.

The minimum approach interval (△Tmin) has a substantial influence on energy recovery and capital tradeoff. According to various experiments, in systems where the temperature is low, typical △Tmin values are below 5℃; by contrast, where the temperature is high, say, above 30℃ as is the case in chemical processes, △Tmin is suggested to be in the range of 10 to 20℃ [13]. In this study, we selected a △Tmin value of 10℃. With the known data and △Tmin, a composite curve is generated by using the Aspen Energy Analyzer, which is presented in Fig. 3. The composite curves include composite heating and cooling curves. When the two curves approach most closely, the pinch temperatures of hot and cold streams are 152.4℃ and 142.4℃, respectively. Moreover, the minimum external utility targets are 1.886MW and 29.68MW, respectively.

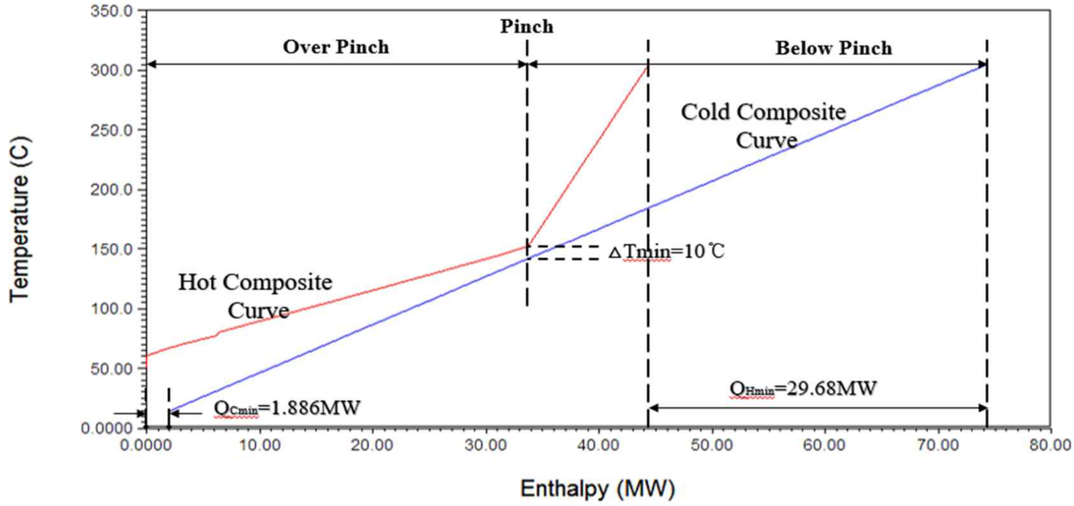

Figure 3. Composite curve of CPF process with $\triangle T_{min}$ = 10℃.

2.1.1 Pinch design cases

The initial HEN is divided into the hot end and the cold end designs on applying the pinch to the process. In the hot end, it only allows to add heaters while in the cold end, only coolers are admitted. A design procedure starts at the pinch and towards to both sides where free choice of matches is carried out in term of our knowledge of the process. In the retrofit designs, fired heat and air are used as heating and cooling utilities, respectively. Figure 4 presents a pinch design case which benefits on capital and energy saving. In the hot end, heat transfers from blowdown to boiled feed water provided by fired heat. In the cold end, hot streams individually give out heat to the split boiled feed water and the remained heat is cooled by cold air. More pinch designs are given in Appendix.

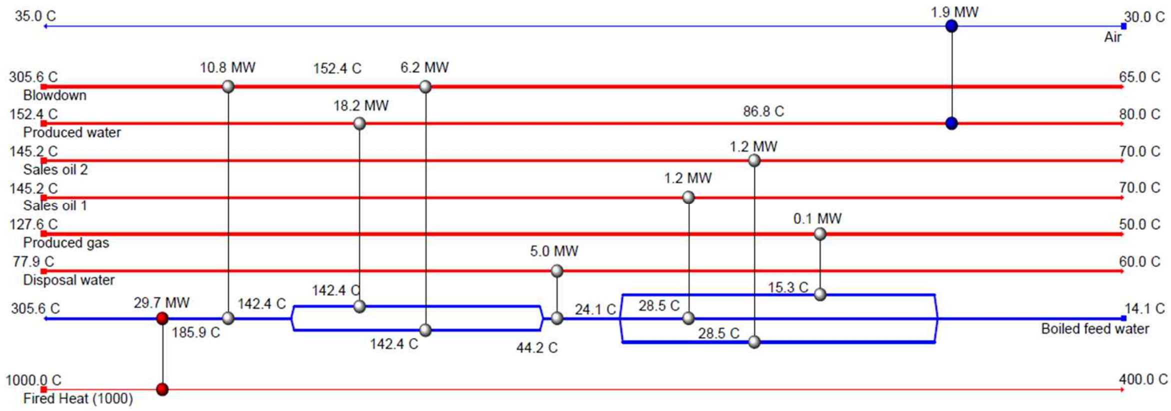

Figure 4. HEN for pinch design (case 10).

2.1.2 Cross-pinch design

Generally, the HEN processes without the pinch method are inefficient and more costly. However, it is also possible that the cross-pinch designs can lead to more benefits than pinch designs in some cases. Figure 5 shows a cross-pinch design to the CPF process. Heat from blowdown, produced water, and disposal water is recovered to heat the boiled feed water to a temperature of 183.6℃. Then, the boiled heat water is heated by fired heat to its target temperature, and the other three hot streams are individually cooled by cold air. This design decreases the number of units to eight (one heater and three coolers as well as four heat exchangers) with increasing 1.2MW external utilities.

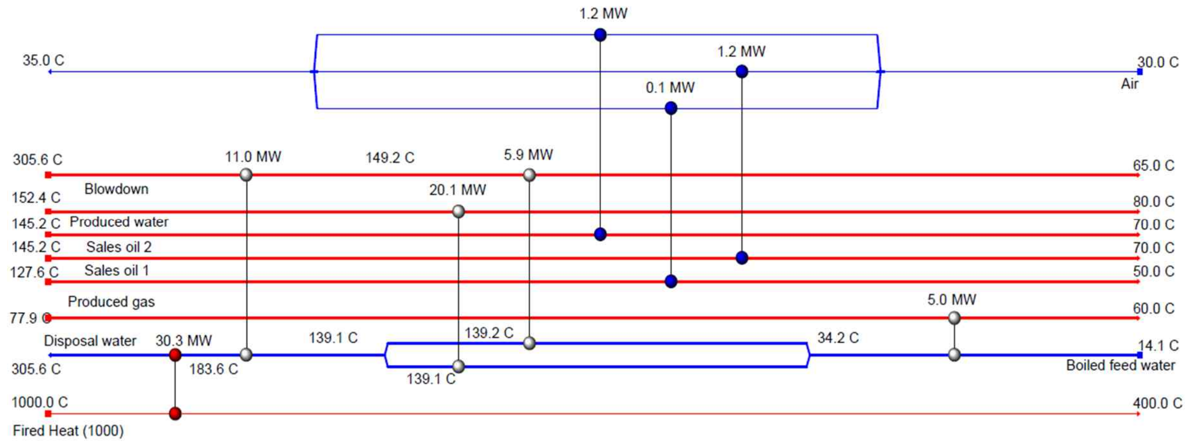

Figure 5. HEN for cross-pinch design (case 11).

3. RESULTS

Eleven potential energy-saving HEN designs, including ten pinch designs and one cross-pinch design, are generated with the help of Aspen Energy Analyzer. In pinch designs, there is no heat transfer across the pinch, which minimizes external utilities for the CPF process in order to save capital and operating trade-offs. Modified cross-pinch designs can also potentially reduce 2.6MW heating utility as well as 2.7MW cooling utility. In addition, the investment cost of a cross-pinch design is lower than that in the initial case and all other pinch designs. We assume 8765.76 operating hours per year and the calculated annual operating cost. Table 2 presents the capital and operating costs for all of the cases considered in this work. It is clear that pinch designs have the lowest operation cost compared to other cases. Figure 6 shows the annual cost saving opportunity for each case. Further, case 10 saves 10.6% of capital cost and 9.1% of operating cost per year. Moreover, the modified cross-pinch design saves 9.1% total cost per year, which reduces its cost down to even less than some of the pinch designs.

Table 2. Capital and annual operating cost.

		Capital cost (cost)	Operating cost (cost/year)
	Initial case	759200	4342207
Pinch designs	case 1	739100	3979304
	case 2	783900	
	case 3	749200	
	case 4	756600	
	case 5	733100	
	case 6	760500	
	case 7	734900	
	case 8	723400	
	case 9	714400	
	case 10	707900	
Cross-pinch design	case 11	674000	405819

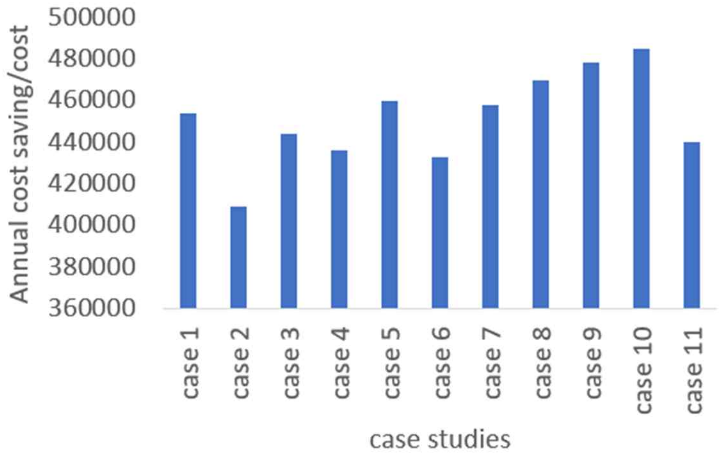

Figure 6. Annual cost saving.

4. CONCLUSIONS

In this study, eleven potential energy-saving HEN retrofit designs consisting of ten pinch designs and a cross-pinch design are presented. The pinch analysis is used to target minimum heat external utilities and total costs. Fired heat and air are used as heating and cooling utilities, respectively. The capital and operation costs are compared between the initial case and the retrofit cases. After improving HENs, the heating and cooling external utilities are reduced by up to 29.68MW and 1.886MW, respectively (pinch designs). In addition, the capital cost possibly decreases by 14.9% (Cross-pinch design). Case 10 is the plan that represents the best modification to the initial CPF HEN, considering both investment and operation trade-offs. Assuming a plan life of five years, if the initial HEN is replaced with case 10, a factory can achieve total savings of approximately 9.2% without considering fouling

ACKNOWLEDGMENT

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Appendix

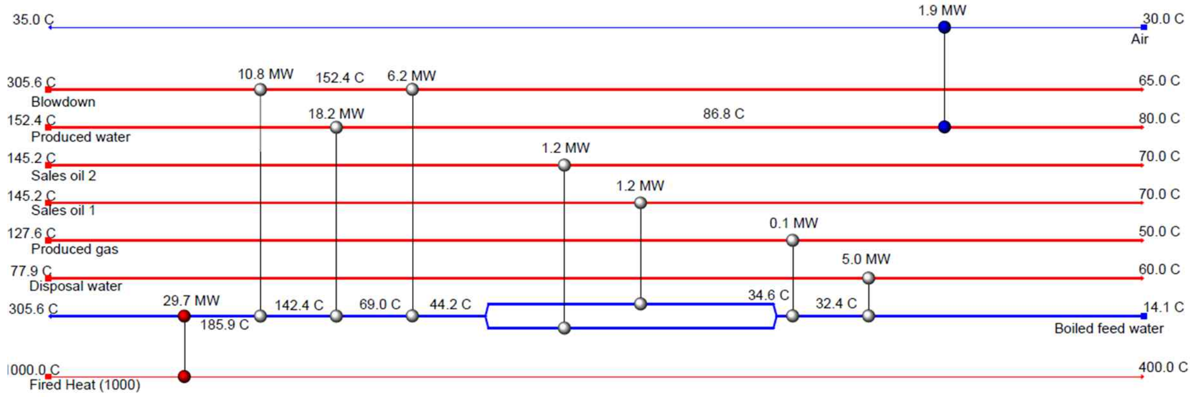

Figure 7. HEN for pinch design (case 1).

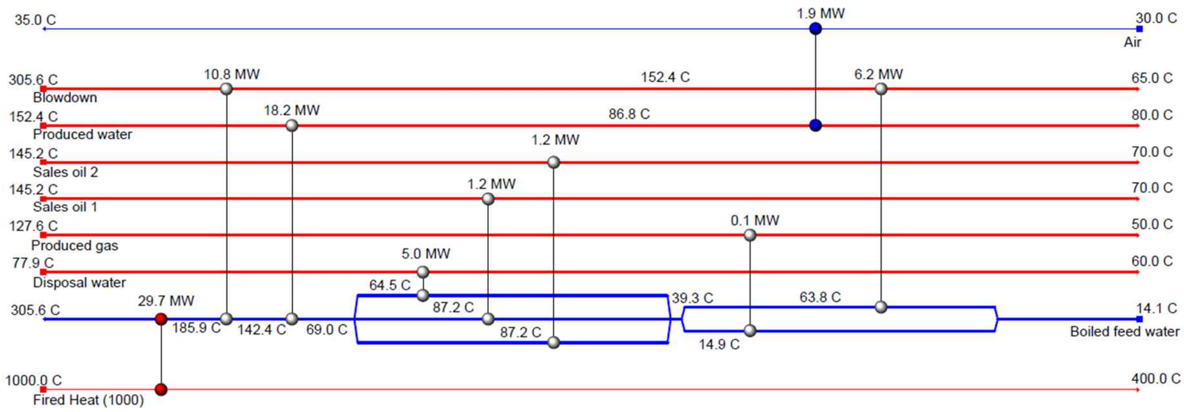

Figure 8. HEN for pinch design (case 2).

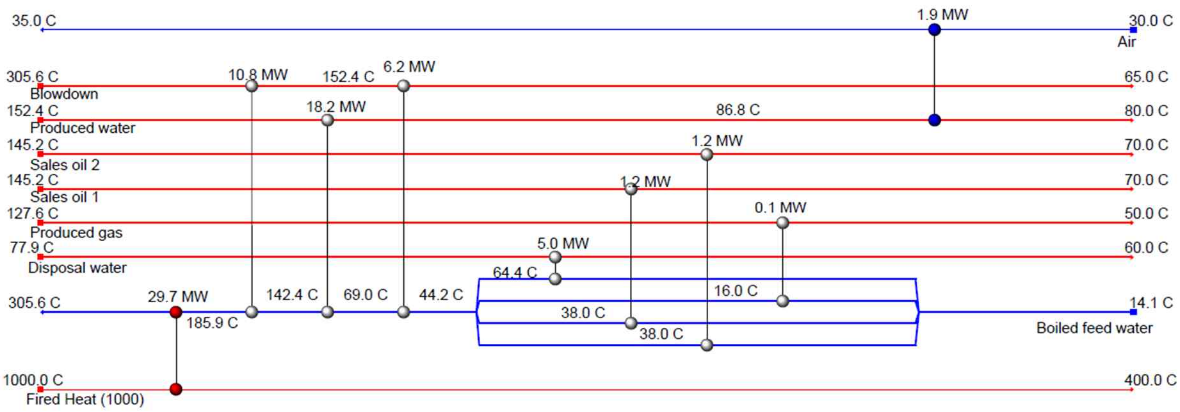

Figure 9. HEN for pinch design (case 3).

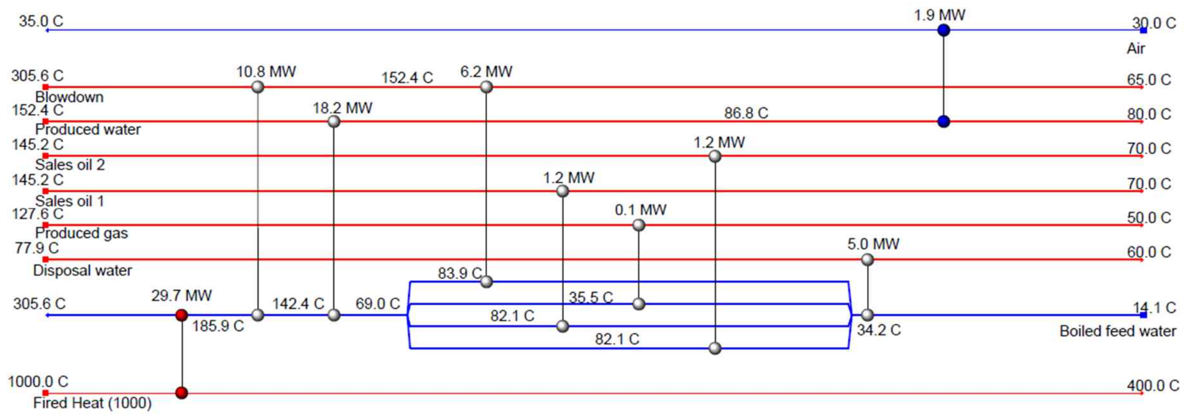

Figure 10. HEN for pinch design (case 4).

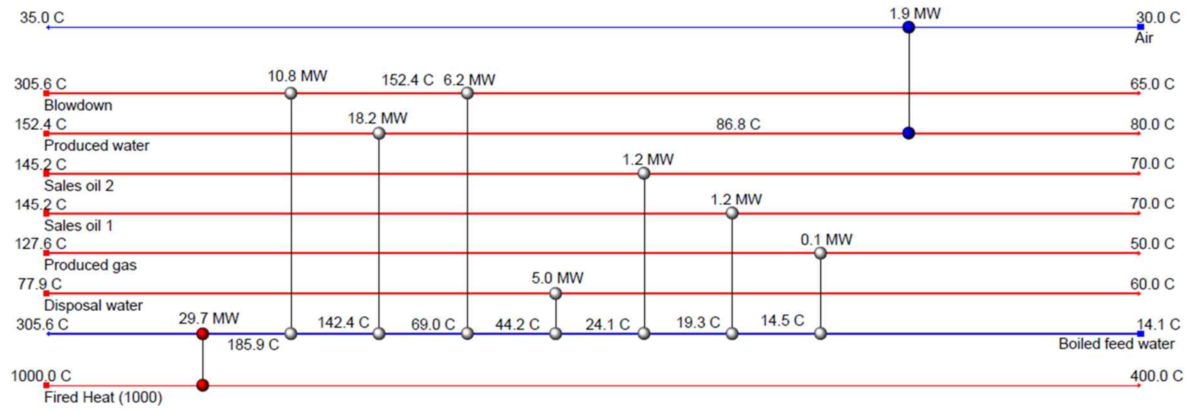

Figure 11. HEN for pinch design (case 5).

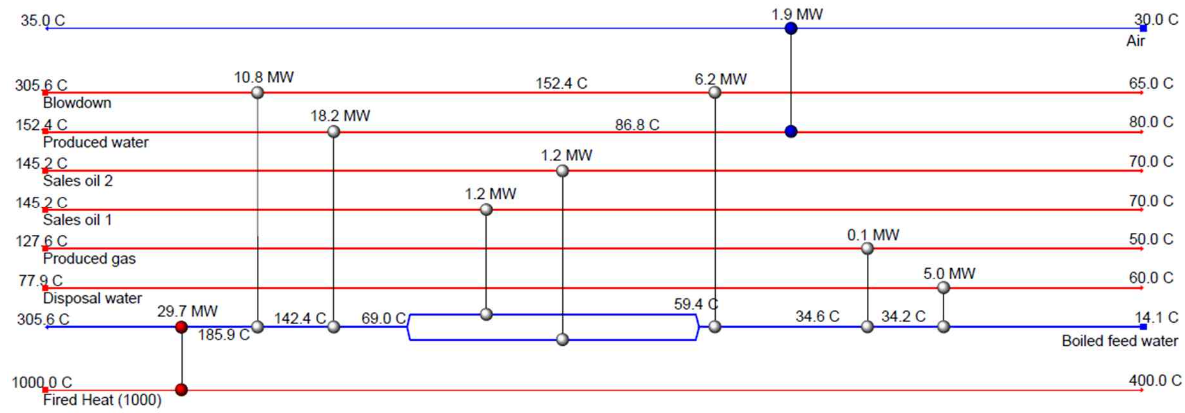

Figure 12. HEN for pinch design (case 6).

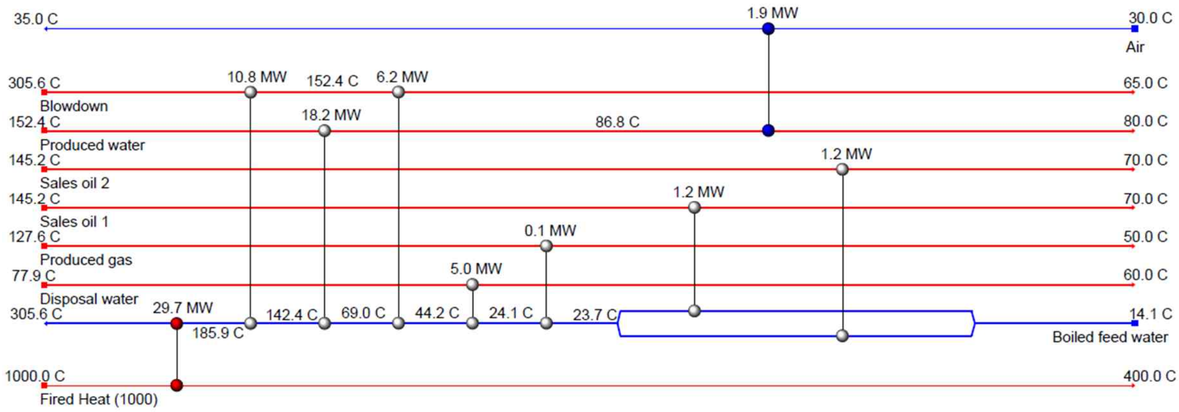

Figure 13. HEN for pinch design (case 7).

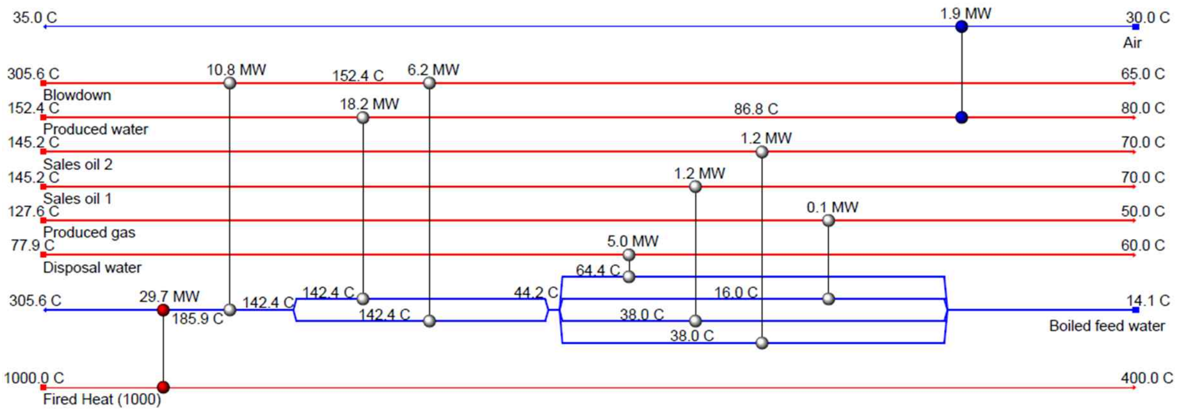

Figure 14. HEN for pinch design (case 8).

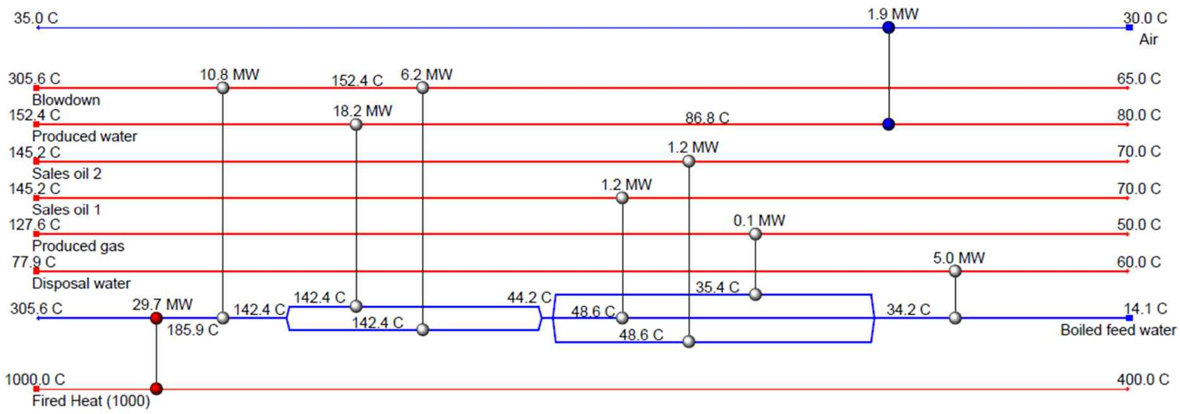

Figure 15. HEN for pinch design (case 9).