Development of a Model Efficiency Improvement for the Designing of Feedwater Heaters Network in Thermal Power Plants

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Abstract

Thermal power plants play a significant role in generating power, electricity, and energy consumption in the world, especially in developing countries. Therefore, the energy analysis of these power plants is very useful to increase the efficiency of systems and reduce energy consumption. One of the components of power plants that play a great role in energy consumption and recovery is the feedwater heater. In this study, a design method-based pinch technology for feedwater heaters of a coal power plant is presented. This method is used to reduce the irreversibility of heat transfer in feedwater heaters in this power plant. This study is performed on six feedwater heaters, which are similar in pairs. The results of this method show that this method is feasible for this system, and the results also show that the implementation of this method with a Pinch range of 10 °C indicated a deficit hot utility of about 48.54 MW. Also, the amount of power plant efficiency improvement is 12.12%, and according to the Pinch method, the energy price of the power plant can be reduced by about 125,489 $/year.

Keywords: energy analysis, pinch technology, thermal power plant, energy-efficient design, feedwater heater, energy systems analysis

1 Introduction

In today's world, energy is one of the important economic, social, and development elements. In today's world of modern technology, easy access to energy with high reliability and economic viability is essential for development [1]. Nowadays, optimizing feedwater heaters in thermal power plants is paid attention to minimize and reduce life cycle costs and maximize and increase additional energy savings for these systems [2,3]. Hence, the attention to Pinch analysis was extended, and this method stems from the systematic effort to improve and modify the recovery of excess heat in industries by process integration [4]. Valiani et al. studied a steam cycle in a 150 MW thermal power plant with bagasse fuel. They optimized the plant's process to decline energy waste and fuel flow by pinch analysis [5]. Ataei and Yoo simulated a 325-megawatt steam power plant in Cycle-Tempo 5.0 software and then used the concept of exergy with a pinch-based approach to optimize the Rankin cycle's operating parameters. It was shown that fuel consumption can be reduced by 5.3% [6]. Arriola-Medellín et al. examined exergy and pinch analysis of a custom steam power station.

The results showed that this method could enhance cycle efficiency by 0.81% and decrease the required water of cooling by 2.4% [7]. Sojitra and Dwivedi studied an oil and gas plant to study the pinch analysis. Graphical and algebraic methods are used to recognize the optimal pinch spot and determine the needs of external tools [8]. Jin et al. studied pinch point models and the achievement of an ORC control strategy for pinch point compliance. The results showed that the temperature difference between the evaporator and condenser at the pinch point is influenced by the cold and heat source parameters [9]. Deng et al. presented a typical process an ammonia plant coal slurry gasification section. They showed that the added converter had a little effect on the existing heat exchange subnet [10]. Asl et al. used pinch concepts thermal power station to introduce a mathematical-conceptual model for the one-way measurement. Their proposed models were confirmed by using data from other existing power stations and indicated sufficient accuracy in the given objectives [11]. Harkin et al. studied heat integration and pinch to decrease overall energy penalties, which indicated that considering effective heat integration could decrease the energy penalty by up to 50% [12]. Safder et al. analyzed the pinch using the concept of chemical exergy. 11.30 MW of net power with an energy balance cost of 0.038$/kWh is recovered by analyzing the complicated chemical exergy current with experimental chemical pinch analysis in the case study [13]. Rozali et al. investigated the probability-power pinch for the integration of diesel/biodiesel power plants into hybrid power systems. The results showed that it could save 19% of diesel fuel consumption [14]. Han et al. presented a new simple model to describe a combined system. Moreover, it was observed that the optimized system's power generation capacity was increased by a mean of 4.96% [15]. Ghorbani et al. studied a combination power generation system. They concluded that if the combustion chamber's inlet air steam was reduced to 250.0 kg/s, the total system's thermal efficiency will reach 56.15% [16–18]. Su et al. studied and identified the possible consequences of increasing clean energy production in key EU countries. Using pinch analysis in these countries showed possible ways to enhance the penetration of certain kinds of renewable energy in these countries that may reduce greenhouse gas emissions [19]. Saharkhiz et al. explored a new hybrid system for energy storage and freshwater production. They proposed combining the refrigeration cycle with the processor core in the form of hot and cold composite curves and pinch analysis [20]. Zhao et al. investigated a 600-MW chemical coal-fired power plant. They also created the heat exchange network using the combined pinch and exergy analyses method to adopt different degrees of energy from the flue gases and heat dissipated steam to the plant and to maximize energy efficiency [21].

Yong et al. developed a new energy targeting framework for analyzing an urban-industrial symbiosis system. They reported that the framework could operate several heating and cooling networks with different temperatures [22].

Jankowski et al. proposed a method for determining the optimal pinch point temperature difference. They showed that the proposed method should be considered as an initial assessment of the pinch point temperature difference distance, by which the designer could determine the optimal range [23]. Ebrahimi et al. analyzed an integrated power generation system. The results of the exergy and pinch analyses showed that the exergy efficiency of the nitrogen liquefaction unit and the power generation unit was higher than the other units [24,25]. Dehghani and Yoo studied Kalina electric cooling under a three-step method. They optimized the geometry of heat exchangers with nonlinear programming to minimize system purchase costs [26]. Wang et al. examined a hybrid energy system used for residential and industrial purposes. They combined heat and power curves to represent the total energy and heat and isolated power required of a hybrid energy system [27]. Farhad et al. investigated a design method based on the pinch technology for reducing heat transfer irreversibility and exergy analysis in steam power plants for feedwater heaters. Their result showed that applying the pinch method could reduce the fuel consumption in the power plant and the condenser load, and it also enhances the exergetic efficiency of the part of the power plant [28]. Espatolero et al. optimized the feedwater heaters network for improving the power plant efficiency. Hence, they simulated the process of the power plant with aspen software, and the results showed that the efficiency of the power plant could increase 0.7 in comparison with the primary state [29].

In this article, the pinch method is applied to optimize energy consumption in the feedwater heaters of a coal power plant. The number of feedwater heaters studied is 6, similar in pairs. This study is performed to better position the feedwater heaters relative to each other to reduce energy loss in these systems as much as possible. Also, the composite curve and problem table solution have been done for the pinch analysis. Finally, the efficiency improvement of the power plant and saving money during a year after applying the Pinch technology can be seen.

2 Design Method

Three analyses (energy, exergy, and environmental) of this coal-fired power plant have been done by Hoseinzadeh and Stephan Heyns [30]. As shown in Fig. 1. there are eight close feedwater heaters in this power plant, and in this study, six of them have been studied because these close feedwater heaters have the conditions of applying the pinch technology, They are numbered 1, 2, 3, 5, 6, and 7 in Fig 1. The streams number 6 and 11 that exit from pump 2 has been chosen as a cold stream, which needs to be hot and the streams that exit from the turbine has been chosen as a hot stream, which needs to be cold. Also, in this study, some golden rules of pinch have been considered [31]:

- Transferring heat across the pinch is prohibited.
- Using cold utilities above and hot utilities below the pinch is prohibited.

In this study two methods are chosen for solving the pinch analysis:

- Composite curves
- Problem table

Although curves of the composite can be used to indicate and determine energy targets in the pinch analysis, they are not very accurate because they are created based on the graphical structure. To achieve more accurate results, we use the table algorithm; this method solves the problem of the graphical structure.

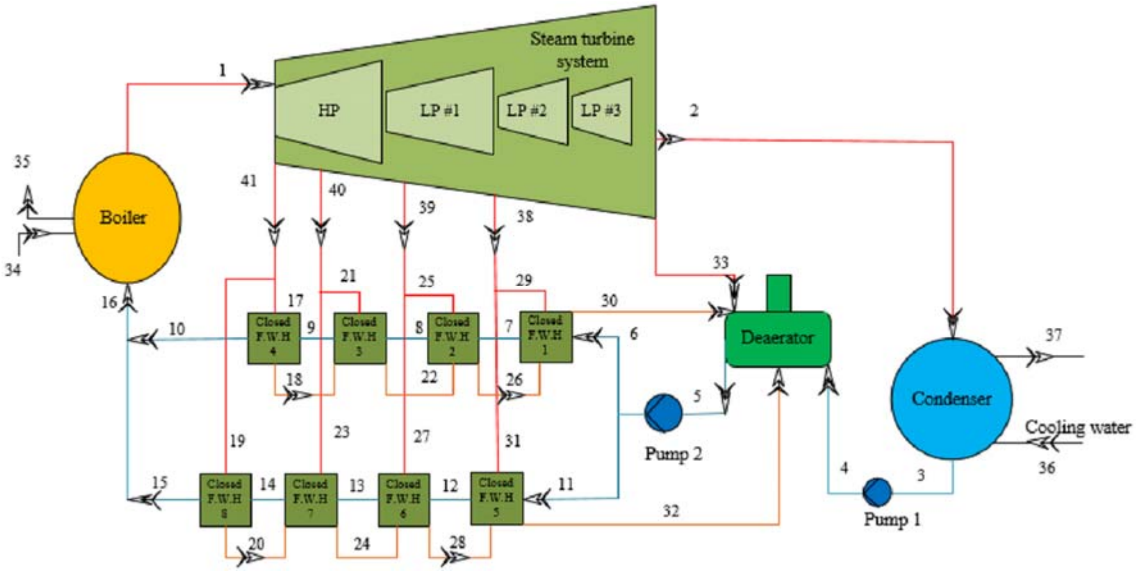


Fig. 1. Schematic of power plant

In this study, to construct composite curves, the temperature process is divided into specific intervals. Since temperature driving forces are not possible in every temperature range, it is not possible to recover all the heat in every temperature range. A combination of hot streams has been used to create a hybrid hot stream within each temperature range. The composite hot stream can be considered as a single stream, which is equivalent to any single hot stream in terms of temperature and enthalpy. A combination of cold streams has been used to create a hybrid cold stream within the same temperature ranges. The composite cold stream can be considered as a single stream, which is equivalent to any single cold stream in terms of temperature and enthalpy as the close feedwater heaters are the same. In this study, the pinch analysis has been done just for feedwater heaters numbers (1, 2, 3, and 4).

The stream date is presented in Table 1. The numbers of the stream are given from the numbers shown in Fig. 1.

Table 1. The stream data

Streams	Type	Supply temperature (°C)	Target temperature (°C)	Δ*H* (MW)	Heat capacity flowrate (MW/K)
6	Cold	123	246	0.53	0.74
17	Hot	322	150	2.69	0.13
21	Hot	420	212	3.29	0.05
25	Hot	186	144	2.78	0.04
29	Hot	242	150	2.8	0.04

To create shifted temperature intervals, subtract $\Delta T_{\min}/2$ from hot currents and add $\Delta T_{\min}/2$ to cold currents. A simple energy balance for each interval is calculated. If hot streams dominate the cold streams, the interval has a net surplus of heat and ΔH is negative. If cold streams dominate the hot streams, the interval has a net deficit of heat and ΔH is positive. The amount of ΔH is given from Eq. 1:

$$\Delta H_i = [\sum CP_C - \sum CP_H] \times \Delta T_i \tag{1}$$

where CP_C and CP_H are heat capacities for cold streams and hot streams, respectively. The shifted temperature for stream data is presented in Table 2.

Table 2. The shifted temperature for streams

Streams	Type	Supply temperature (°C)	Target temperature (°C)	Shifted supply temperature (°C)	Shifted target temperature (°C)
6	Cold	123	246	128	251
17	Hot	322	150	317	145
21	Hot	420	212	415	207
25	Hot	186	144	181	139
29	Hot	242	150	237	145

3 Results

By using data from Table 1, the composite curve of the system has been drawn. Figure 2 shows the diagrams for hot and cold streams of close feedwater heaters separately.

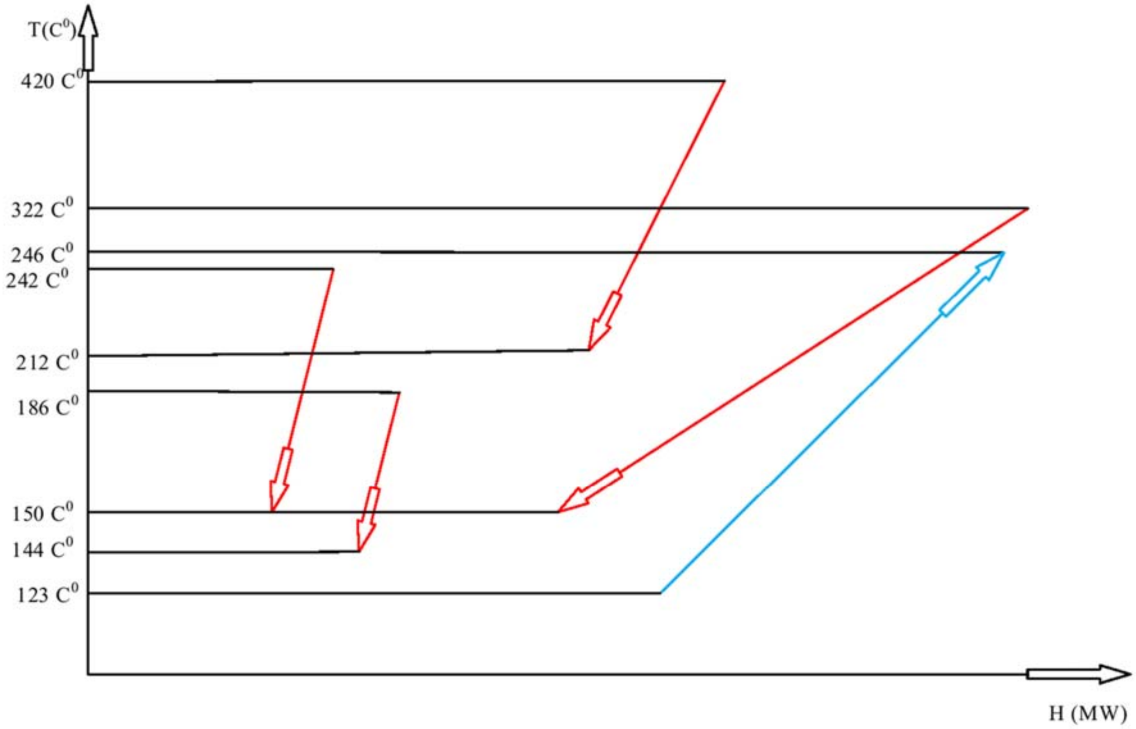


Fig. 2. The diagrams for hot and cold streams of close feedwater heaters separately

Figure 2 illustrates the points: different slopes of the hot and cold composite curves in each interval mean that lower slopes of any of the composite curves mean more enthalpy of the stream in that interval. The amount of heat slopes of the two curves in the recovery depends on the relative temperature interval. By combining the diagrams of hot and cold streams, the composite curves have been published. Figure 3 shows the composite curves of the streams.

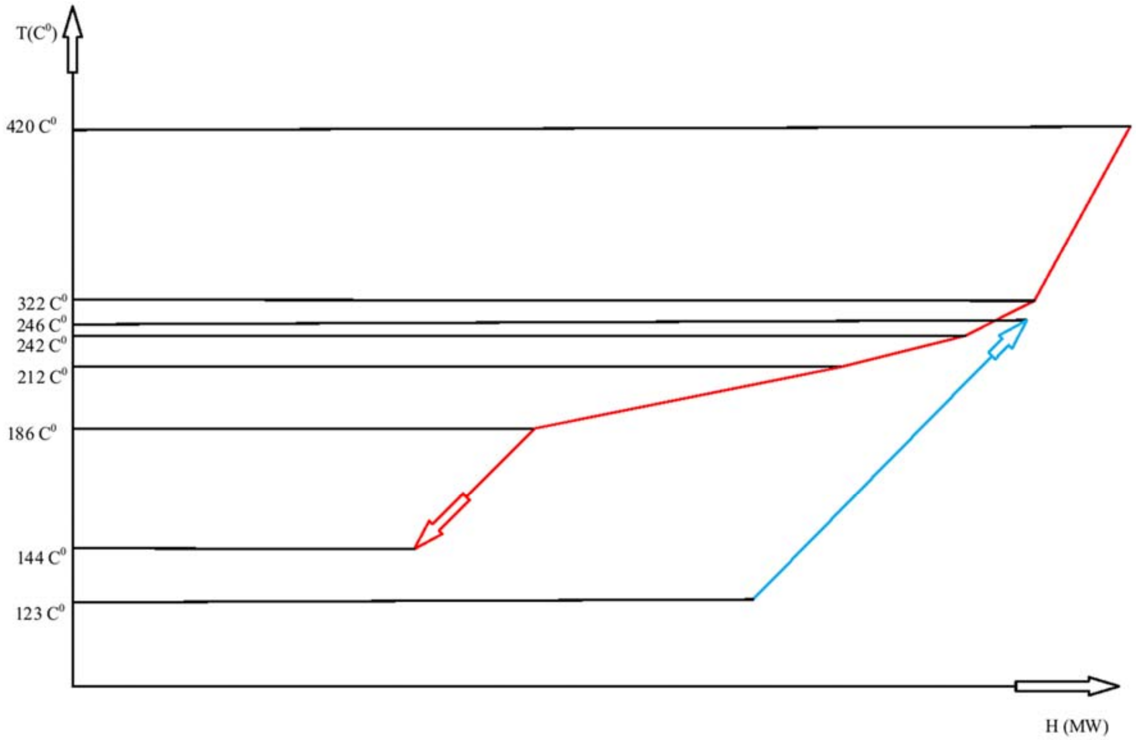
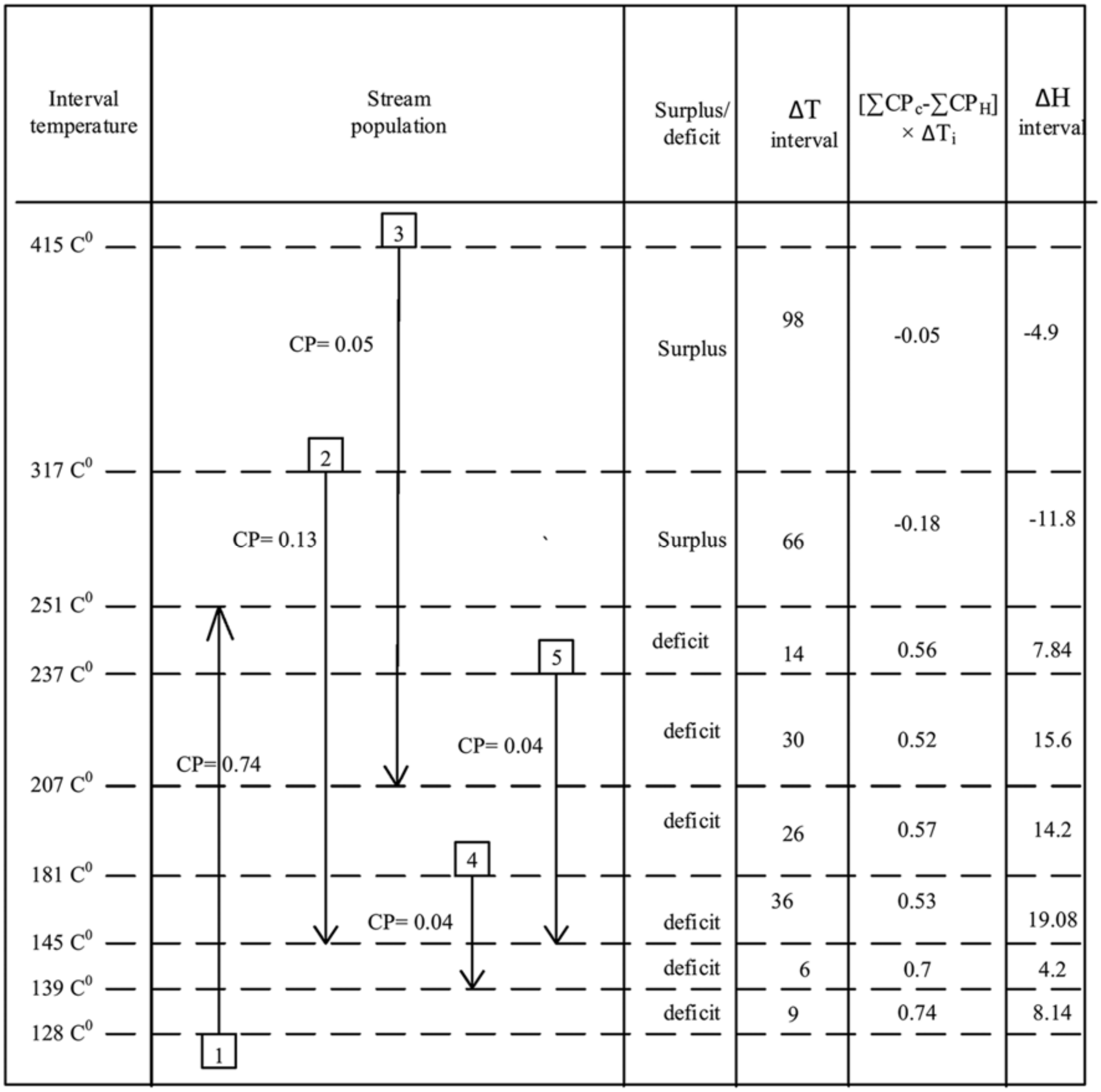


Fig. 3. The composite curves of the streams

It is shown in Fig. 3 that this is the relative position of the two curves relative to their degree-of-freedom. The relative position of two curves can be reduced or increased by moving them horizontally relative to each other. The whole of the cold stream can be warmed with hot streams, but on the other hand, the hot streams need a utility for cooling.

$\Delta T_{\min}$ in this study is 10 °C.

The problem table solution and result extracted from it are shown in Fig. 4.



Interval temperature	Stream population	Surplus/ deficit	ΔT interval	$[\sum CP_c - \sum CP_H] \times \Delta T_i$	ΔH interval
$415\ C^0$					
		Surplus	98	-0.05	-4.9
$317\ C^0$					
		Surplus	66	-0.18	-11.8
$251\ C^0$					
		deficit	14	0.56	7.84
$237\ C^0$					
		deficit	30	0.52	15.6
$207\ C^0$					
		deficit	26	0.57	14.2
$181\ C^0$					
		deficit	36	0.53	19.08
$145\ C^0$					
		deficit	6	0.7	4.2
$139\ C^0$					
		deficit	9	0.74	8.14
$128\ C^0$					

Fig. 4. The problem table solution and result

Cascade surplus heat from high temperature to low temperature (Fig. 5(a)) and the added extra heat from hot utility to make all heat stream zero or positive (Fig. 5(b)) are shown in Fig. 5.

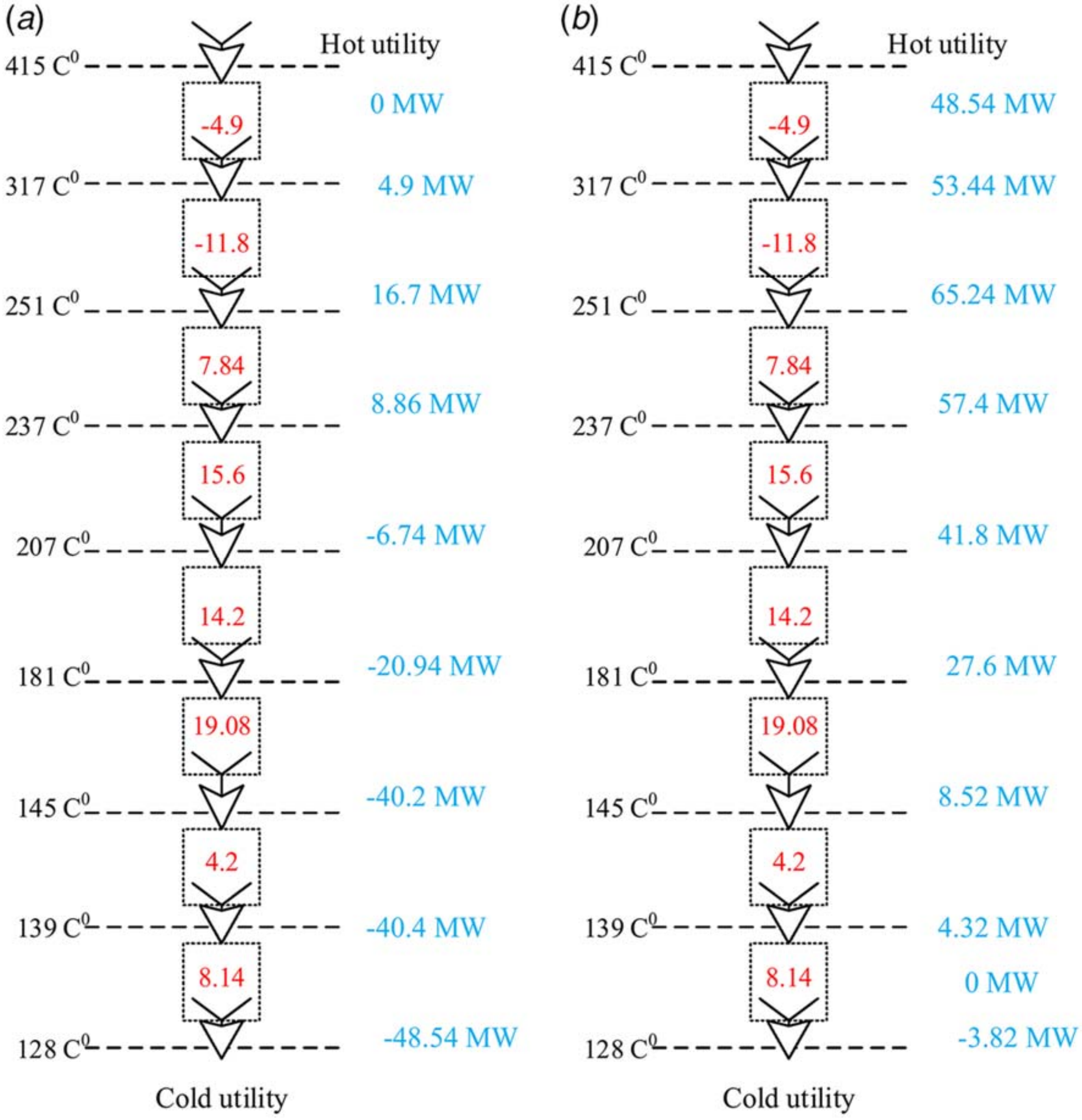


Fig. 5. (*a*) Cascade surplus heat from high temperature to low temperature and (*b*) the added extra heat from the hot utility to make all heat streams zero or positive

As shown in Fig. 5, the cascade diagram shows a deficit of hot duty of 48.54 MW, and in the corrected cascade diagram, the result shows that applying this system is feasible, and in the end, the needing cold utility is zero and the relative pinch temperature is about 132 °C.

The energy consumption of this power plant is 400 MW [30]. By implementing the pinch method, 48.54 MW will be saved, and the efficiency of the power plant will be improved by 12.12%.

According to Valev's data from the global economy and south Africa economy websites, the price of energy in South Africa is 0.17 $/ kWh [32,33]. Pinch analysis shows that by using this method, the amount of 48.54 MW of energy can be saved. Therefore, it can be concluded that the amount of economic savings after the implementation of this method is about 125,489 $/year.

4 Conclusion

In this study, the pinch analysis for six close feedwater heaters of a coal power plant has been done. These close feedwater heaters are the same as each other. The considered pinch temperature is 10 °C for the pinch analysis. Also, the composite curves of stream and problem tables and cascade diagrams have been plotted, and the result shows that approximately 48.54 MW hot utility need for applying pinch technology, and there are no needs for cold utility. This amount of extra heat can be used to recover the temperature in other units of the power plant, and by recovering the temperature, the efficiency of the system can be increased and energy wasted in the system can be prevented. In addition, the amount of power plant efficiency and economic savings after applying the pinch method is 12.12% and 125,489 $/year, respectively.

Conflict of Interest

There are no conflicts of interest.

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