East Journal of Human Science
ISSN: 3079-9384
Volume 1, Issue 5
Publisher: East Publication & Technology
DOI: https://doi.org/10.63496/ejhs.Vol1.Iss5.173

Economic Feasibility Study of Feedwater Heater System Integration in a 15 MW Thermal Power Plant

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This article is part of a special issue dedicated to the International Conference on Emerging Technologies in Multidisciplinary Fields (ICETMF25), 8–9 July 2025, organized by Mazoon College, Muscat, Oman.

Received: 28/07/2025, **Revised**: 05/08/2025, **Accepted**: 03/09/2025, **Published**: 03/09/2025

Abstract

This study presents a comprehensive economic analysis and optimization of the feedwater heater system in a 15 MW thermal power plant. Feedwater heaters play a critical role in improving thermal efficiency and ensuring operational sustainability of power generation. The analysis focuses on evaluating the operational costs associated with feedwater heating and circulation systems. One of the key economic indicator, the payback period is used to assess the viability and cost-effectiveness of various feedwater heater integration strategies. Comparative scenarios are developed to evaluate plant performance with and without feedwater heating systems. The results demonstrate that effective feedwater heater management can significantly reduce fuel consumption, improve the heat rate, and enhance overall plant performance. Without a feedwater heating system, the plant consumes 13.27 tons per hour (TPH) of fuel. Integrating a low-pressure feedwater heater (LPH) reduces fuel consumption by 1.2%, while the addition of a high-pressure heater (HPH) improves fuel savings to 1.7%. The study concludes that strategic investment in feedwater heater systems can enhance operational reliability and efficiency in medium scale thermal power plants.

***Keywords*: Economic Analysis, Payback Period, Thermal Power Plant, Feedwater Heater, Thermal Efficiency.**

1. Introduction

Improving the thermal efficiency of power generation systems remains a critical objective in the global transition toward sustainable energy. Among various strategies, the integration of regenerative feedwater heaters has emerged as an effective method to enhance the performance of Rankine cycle-based thermal power plants. By utilizing extraction steam to preheat the feedwater entering the boiler, these heaters reduce fuel consumption, improve cycle efficiency, and lower greenhouse gas emissions.

While such systems are widely adopted in large-scale power plants, their economic viability in small to mid-sized facilities, such as 15 MW units, is still under deliberation. These smaller plants often operate under financial constraints and face challenges in justifying capital-intensive upgrades without a clearly favorable return on investment. However, recent advancements in compact feedwater heater designs, coupled with rising fuel costs and stricter environmental regulations, necessitate a reevaluation of their feasibility in smaller scale applications.

Recent studies have highlighted the potential advantages of feedwater heater integration. For instance, Siamak Hoseinzadeh, & Stephan Heyns (2022) employed pinch analysis to design an optimized feedwater heater network, achieving a 12.12% improvement in plant efficiency and annual energy cost savings of approximately $125,489. Similarly, Khaleel et al. (2022) investigated the thermal performance of coal-fired power plants based on the number of feedwater heaters, concluding that an optimal configuration can significantly improve efficiency while minimizing exergy destruction.

Wijaya and Widodo (2018) evaluated twelve operation schemes for feedwater heaters and found that taking a heater out of service feedwater increased the net plant heat rate by 1.37%. These findings underscore the importance of a tailored approach when considering feedwater heater integration, particularly in smaller plants where the investment recovery margins are minimal.

Despite these encouraging results, there remains a gap in research specifically focused on economic feasibility of feedwater heater systems in small-scale thermal plants. This study aims to address that gap by evaluating the cost-effectiveness of implementing a feedwater heater system in a 15 MW thermal power plant, using key economic indicators such as capital investment, payback period and operational savings.

1.1 System Description

A schematic of a 15 MW thermal power plant incorporating a feedwater heater is shown in Figure 1. The plant utilizes superheated steam at a pressure of 66 bars and a temperature of 485 °C, which is directed into a high-speed steam turbine. The steam mass flow rate is 63.75 TPH. Operating at 7000 rpm, the turbine is connected to an electrical generator via a reduction gearbox that adjusts the rotational speed to 1500 rpm, aligning with standard generator operation requirements.

Following an expansion in the turbine, exhaust steam at a pressure of 0.1 bar and a temperature of 45.45 °C is directed to the surface condenser. Cooling water, supplied at 32 °C from a dedicated cooling tower facilitates the condensation of wet steam back into condensate.

To improve boiler feedwater quality and prevent corrosion, a deaerator is employed to remove dissolved gases (Sifat Abdul Bari et al., 2024). In this process, low-pressure steam extracted from the turbine at 3.17 bar (a) and 160 °C is introduced into the deaerator for effective gas stripping. Additionally, a portion of steam is extracted from the main steam line, pressure-reduced, and utilized in auxiliary systems such as the ejector and gland steam condenser (Rashidi et al.2014)

Table I provides a comprehensive overview of the technical specifications of the 15 MW thermal power plant, including configurations with low pressure and high-pressure feedwater heaters.

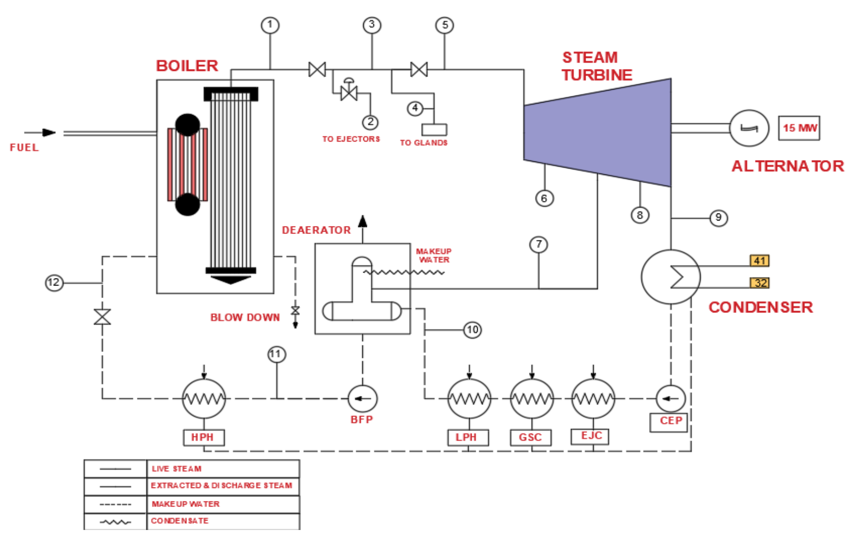

Figure 1: Thermal power plant with feedwater heaters

Table 1: Design parameters of 15 MW Thermal power plant

Point Number	Parameters	Description
1	Pressure (P) = 66 bar; Temperature (T) = 485 ºC; Flow rate (m) = 63.75 TPH	Main superheated steam line
2	P = 16 bar; T= 275 ºC; m = 0.3 TPH	Steam supply to ejector
3	P = 64 bar; T = 480 ºC; m = 62.85 TPH	Steam parameters after ejector
4	P = 64 bar; T = 480 ºC; m = 0.14 TPH	Steam supply to glands
5	P = 64 bar; T = 480 ºC; m = 63.31 TPH	Main steam supply to steam turbine
6	P = 14.36 bar; T = 307 ºC; m = 7.04 TPH	Steam supply to high pressure heater
7	P = 3.17 bar; T = 160 ºC; m = 3.56 TPH	Steam supply to deaerator
8	P = 0.98 bar; T = 98 ºC; m = 4.22 TPH	Steam supply to low pressure heater
9	P = 0.1 bar; T = 45.45 ºC; m = 48.49 TPH	Steam from turbine exit
10	P = 2.5 bar; T = 94.91 ºC; m = 48.93 TPH	Steam from low pressure heater to deaerator
11	P = 90 bar; T = 133.19 ºC; m = 65.25 TPH	Steam from deaerator to high pressure heater
12	P = 90 bar; T = 190.03 ºC; m = 65.25 TPH	Steam from high pressure heater to boiler

1.2 Feedwater heater

Figure 2 illustrates a key feedwater component used in a 15 MW thermal power plant to enhance the thermal efficiency of the Rankine cycle through a regenerative process. This system utilizes steam extracted from intermediate turbine stages to preheat the feedwater before it enters the boiler, thereby reducing the required heat input and improving overall cycle efficiency. A shell-and-tube heat exchanger facilitates thermal energy transfer from condensing steam on the shell side to feedwater flowing through the tubes. High-pressure feedwater heater is positioned downstream of the high-pressure boiler feedwater pump, while low-pressure heaters are located downstream of condensate pump (Sergio Espatolero 2014). In plants of this scale, low-pressure feedwater heaters are commonly used, although high-pressure units may be incorporated depending on specific performance and design objectives. Beyond improving efficiency, feedwater heating also reduces thermal shock to boiler components and assists in the removal of dissolved gases, thereby enhancing system reliability, reduced corrosion, and extending equipment lifespan (Oyedepo et.al., 2020).

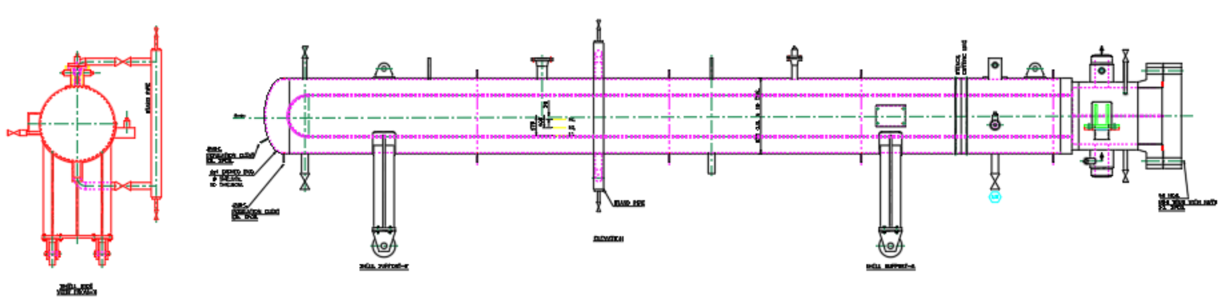

Figure 2: General arrangement of feedwater heater

2. Related Work

Jamshid Naeimi et al., (2023) demonstrated that the performance of both low and high-pressure feedwater heaters significantly improved with the substitution of new heat exchangers. As a result, the power output of the steam unit and the energy and exergy efficiencies of the repowered cycle increased by 15.7%, 49.3%, 5.93%, and 2.17%, respectively. Despite a 19 millibar rise in condenser pressure, the heat rate improved by 0.63%, leading to an overall enhancement of 4.62% in the repowered cycle's heat rate.

Romy and Muhammad Rizki (2021) modified the steam cycle by incorporating both closed and open feedwater heaters (FWHs). Their study reported an increase in steam cycle efficiency increased by 2.53% with the closed FWH and 2.78% with the open FWH, compared to the initial efficiency of 36.74%.

Mohammed Kamil Mohammed (2019) applied mass balance, energy balance, and entropy generation equations to evaluate a steam power plant equipped with varying numbers of feedwater heaters. By introducing nine heaters, the study achieved reduced fuel consumption and increased boiler feedwater temperature. The thermal efficiency of this power plant reached 40.1 % following the integration of feedwater heaters.

3. Methodology

3.1 Steam power plant of 15 MW without feedwater heater

Figure 3 illustrates the steam requirements across various components of the steam power plant operating without feedwater heater. In this study, operational process data were utilized to model the system. The plant components were organized into functional modules, and the input and output streams for each module were identified and recorded using Thermoflex software (Siamak Hoseinzadeh & Stephan Heyns 2020). Thermodynamic property values for super-heated steam, condensate, and water were entered into the software, and the simulation were validated through manual calculations. The requirement for superheated steam is 59.26 TPH at 66 bar(a) and a temperature of 485 ºC.

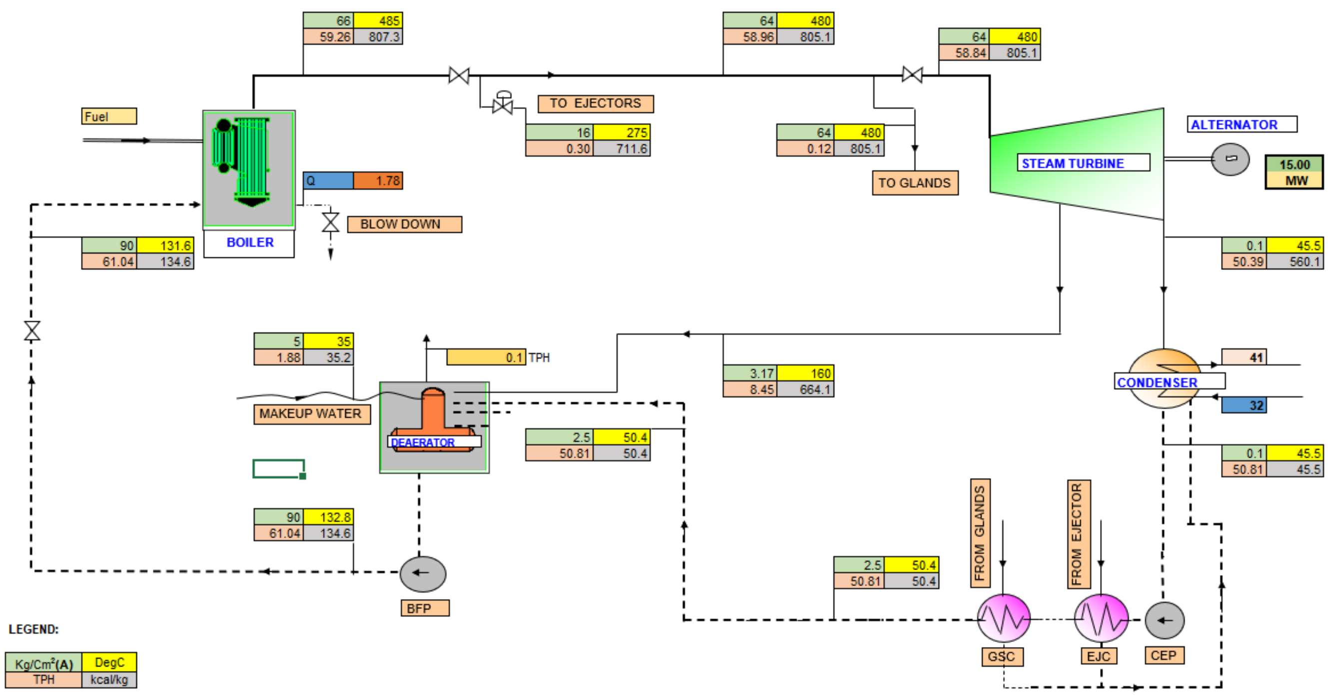

Figure 3: Steam power plant without feedwater heater

3.2 Steam power plant of 15 MW with low pressure feedwater heater

A low-pressure feedwater heater has been integrated into the regenerative Rankine cycle of a steam power plant to improve overall thermal efficiency (Rozita Kaviani and Amir Arezi 2023). As a result, the main steam flow rate is reduced from 59.26 TPH to 58.6 TPH. This adjustment ensures that adequate steam is available for both power generation and feedwater heating. To supply the low-pressure heater, steam is extracted from an intermediate stage of the steam turbine at a pressure of 0.97 bar (a) and a temperature of 98°C. The steam demands for various components of a steam power plant are illustrated in Figure 4. The extracted steam transfers part of its thermal energy to the feedwater, raising its temperature before it enters the boiler (Vedran Mrzljak and Igor Poljak 2017). The new configuration and thermodynamic interactions introduced by the feedwater heater were analyzed using Thermoflex software.

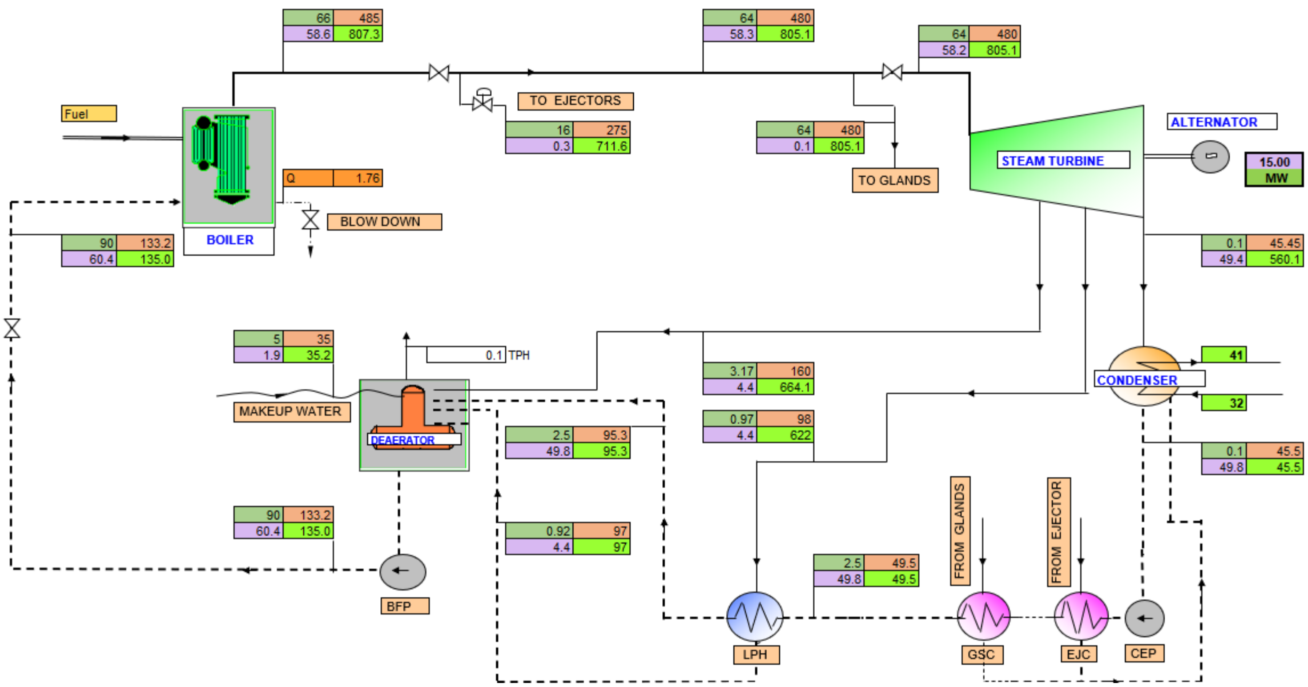

Figure 4: Steam power plant with low pressure feedwater heater

3.3 Steam power plant of 15 MW with high pressure feedwater heater

To improve the overall thermal efficiency of the steam power plant, a high-pressure feedwater heater has been incorporated into its regenerative Rankine cycle. This enhancement increases the main steam flow rate from 59.26 TPH to 63.75 TPH, ensuring sufficient steam is available to meet both power generation and feedwater heating requirements. In this modified configuration, steam is extracted from an intermediate stage of the steam turbine at a pressure of 14.36 bar (a) and a temperature of 307°C to supply the high-pressure heater (Alp Erdogan and M. Zeki Yilmazoglu 2021). The extracted superheated steam, with a mass flow rate of 7.12 TPH, transfers part of its thermal energy to the feedwater, raising its temperature before it enters the boiler. This preheating process reduces fuel consumption and increases the cycle's thermal efficiency (Răzvan Beniugă et al., 2021). The integration of the feedwater heater introduces additional thermodynamic interactions within the cycle, all of which were analyzed and validated through simulations performed using Thermoflex software. The steam demands for for various components of a steam power plant are illustrated in Figure 5.

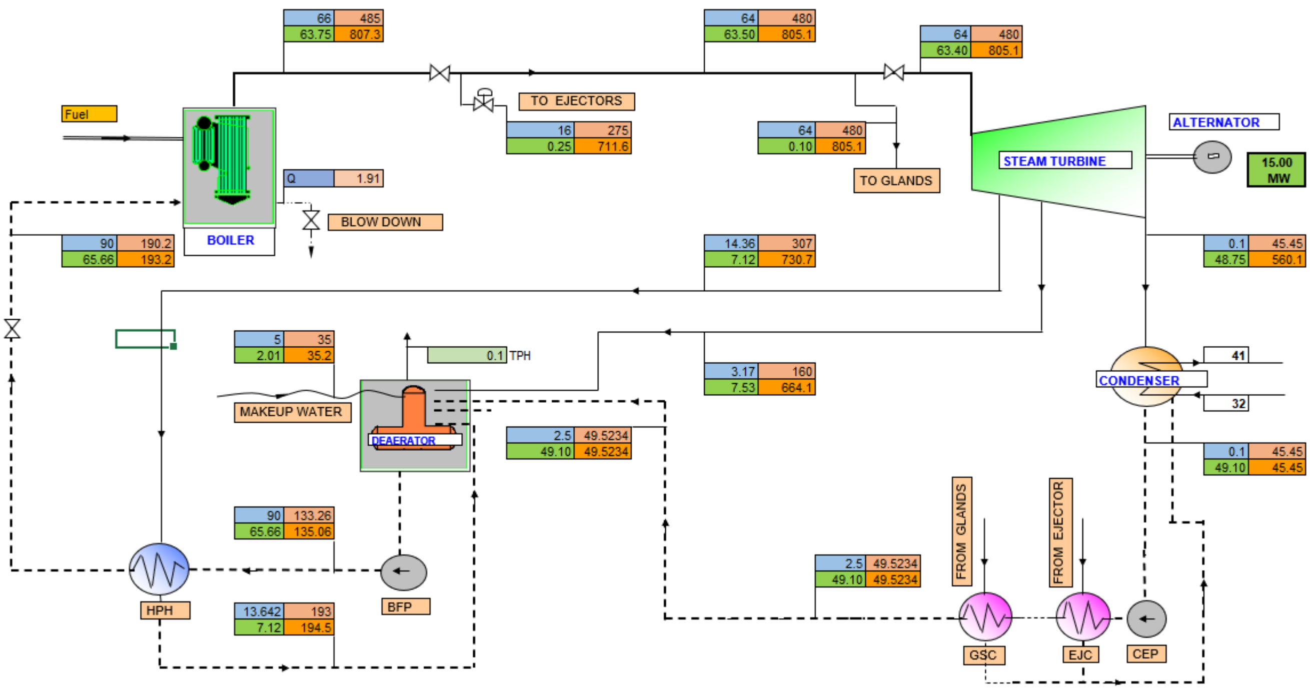

Figure 5: Steam power plant with high pressure feedwater heater

3.4 Cost Analysis

A set of standard engineering and economic equations is employed to analyze the cost implications of integrating a feedwater heater, accounting for capital investment, operational expenses, and maintenance costs. These equations also incorporate the energy savings achieved through improved thermal efficiency, which directly contributes to cost recovery.

The key equations used in the analysis are as follows:

- **Feedwater Heater Cost**

$$\text{Feedwater cost} = \text{Bare cost} \times \text{Material factor} \times \text{Index factor} \times \text{Pressure factor}$$

- **Plant Heat Rate**

$$\text{Plant heat rate} = \frac{Turbine\ heat\ rate}{Boiler\ efficiency}$$

(Boiler efficiency of 85 % is obtained from the manufacturer.)

- **Specific Steam Consumption**

$$\text{Specific steam consumption} = \frac{Steam\ output\ from\ the\ boiler}{Plant\ capacity}$$

- **Payback Period**

$$\text{Payback period} = \frac{Fixed\ capital\ cost}{Cost\ saving}$$

- **Fuel Requirement for the Plant**

$$\text{Fuel requirement} = \frac{Plant\ Heat\ Rate\ X\ Plant\ Capacity}{Gross\ Calorific\ Value\ of\ Fuel}$$

- **Percentage of Fuel Saving**

$$\text{Fuel saving (\%)} = \frac{Existing\ \ Fuel\ Consumption\ Rate - Modified\ Fuel\ ConsumptionRate}{Existing\ \ Fuel\ Consumption\ Rate} \times 100$$

4. Result Discussion

4.1 Plant performance without feedwater heater

The 15 MW power plant operating without a feedwater heater exhibits specific performance characteristics related to steam generation and energy efficiency. The steam requirement for this plant is 59.26 TPH. The deaerator raises the feedwater temperature to 132.8°C, contributing to improved boiler efficiency by removing dissolved gases and preheating the water. Steam for the deaerator is extracted from the turbine at 3.17 bar (a) and 160°C. A total of 50.39 TPH of steam is directed to the condenser. This configuration results in a turbine heat rate of 2631 kcal/kWh and an overall plant heat rate of 3095 kcal/kWh, indicating a 1.76% increase in heat rate compared to the configuration with a high-pressure feedwater heater. Consequently, the specific steam consumption rises to 3.95 kg/kWh. The fuel requirement for the plant is 13.27 TPH, based on a gross calorific value of 3500 kcal/kg and a boiler efficiency of 85%. With coal priced at USD 56 per ton, the annual fuel cost for operating the plant without a feedwater heater amounts to approximately USD 5.37 million

4.2 Plant performance with low pressure feedwater heater

A steam power plant equipped with low-pressure feedwater heater requires 58.6 TPH of superheated steam. The low-pressure feedwater raises the condensate temperature from 49.52°C to 95.3°C, while the deaerator further raises the feedwater temperature to 133.3°C. This configuration results in a turbine heat rate of 2601 kcal/kWh and an overall plant heat rate of 3060 kcal/kWh, indicating a 0.59% increase in heat rate with respect to high-pressure feedwater configuration. As a result, the specific steam consumption decreases to 3.9 kg/kWh. The fuel requirement for the plant is 13.11 TPH, based on a gross calorific value of 3500 kcal/kg and a boiler efficiency of 85%. The annual fuel cost for operating the plant with low-pressure feedwater heater is approximately USD 5.31 million.

4.3 Plant performance with high pressure feedwater heater

A steam power plant equipped with a high-pressure feedwater heater requires 63.75 TPH of superheated steam. The deaerator raises the feedwater temperature to 133.26°C, while the high-pressure feedwater heater further increases the boiler feedwater temperature to 190.2°C. This configuration results in a turbine heat rate of 2586 kcal/kWh and an overall plant heat rate of 3042 kcal/kWh. Consequently, the specific steam consumption rises to 4.2 kg/kWh. The fuel requirement for the plant is 13.04 TPH, based on a gross calorific value of fuel 3500 kcal/kg and a boiler efficiency of 85%. The annual fuel cost for operating the plant with a high-pressure feedwater heater is approximately USD 5.27 million. Table 2 presents a detailed comparison of all configurations.

Table 2: 15 MW Steam power plant with feedwater heater analysis

Description	Without feedwater heater (Deaerator only)	Low-pressure feedwater heater	High-pressure feedwater heater
Steam output from boiler (TPH)	59.26	58.6	63.75
Steam exhaust to condenser (TPH)	50.31	49.43	48.75
Turbine heat rate (kcal/kWh)	2631	2601	2586
Plant heat rate (kcal/kWh)	3095	3060	3042
Feedwater temperature (°C)	133	133	190
Specific steam consumption (kg/kWh)	3.95	3.9	4.25
Fuel requirement (TPH)	13.27	13.11	13.04
Fuel cost per annum (Million USD)	5.37	5.31	5.27

Figure 6 illustrates the effectiveness of feedwater heater integration in improving thermal efficiency. The plant operates without feedwater heater exhibits the highest heat rate of 3095 kcal/kWh. Incorporating a low-pressure heater reduces the heat rate by approximately 1.13%, while a high-pressure heater achieves a further improvement with a 1.71% reduction. Figure 7 highlights the influence on specific steam consumption. The integration of a low-pressure feedwater heater slightly reduces the steam required per unit of electricity, lowering it from 3.95 to 3.9 kg/kWh, which is approximately a 1.27% reduction. In contrast, the high-pressure feedwater heater configuration increases specific steam consumption by 7.05% . This rise is attributed to the greater amount of steam required for feedwater heating at elevated pressures. Although this increases steam consumption per unit of electricity generated, it contributes to improved thermal efficiency and a reduced overall plant heat rate. Figure 8 presents fuel consumption across different configurations. The low-pressure feedwater plant reduces fuel consumption by 1.11%, while the high-pressure feedwater heater plant achieves a reduction of 1.86%.

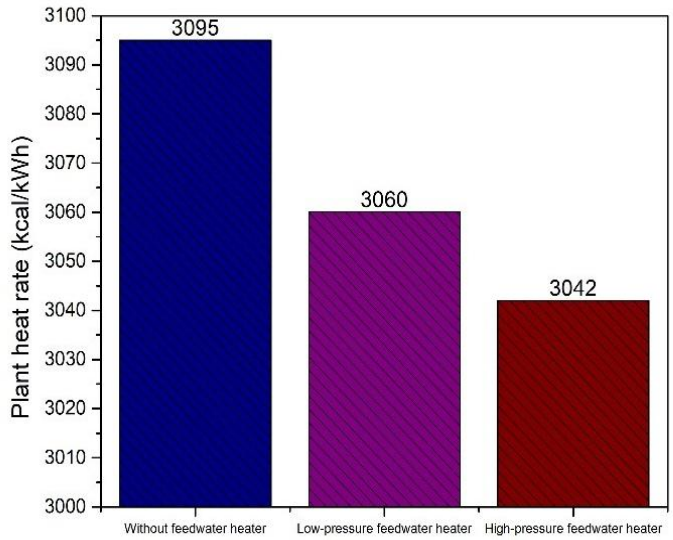

Figure 6: Plant heat rate for different configuration

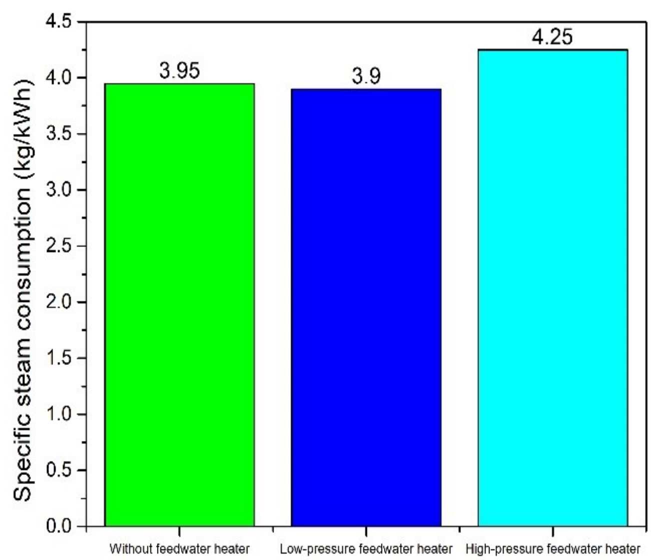

Figure 7: Specific steam consumption for different configuration

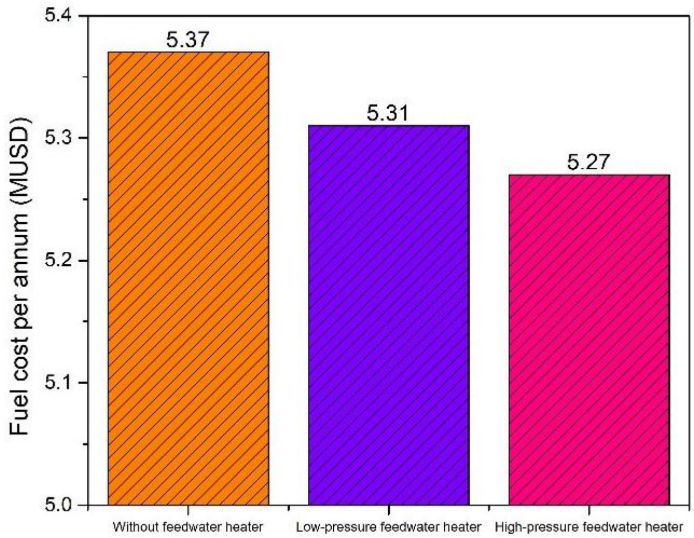

Figure 8: Fuel cost per annum for different configuration

5. Conclusion

Based on the analysis presented, it can be concluded that the integration of feedwater heaters significantly enhances both the thermal performance and economic efficiency of the 15 MW power plant. The plant heat rate improves notably—from 3095 kcal/kWh without a feedwater heater to 3060 kcal/kWh with a low-pressure heater, and further to 3042 kcal/kWh with a high-pressure heater—indicating a clear gain in thermal efficiency. Although specific steam consumption increases slightly from 3.95 kg/kWh to 4.25 kg/kWh with the high-pressure heater due to steam extraction for preheating, this trade-off results in fuel savings. Most importantly, the annual fuel cost decreases from USD 5.37 million (without a feedwater heater) to USD 5.31 million (with a low-pressure feedwater heater), and further to USD 5.27 million (with a high-pressure feedwater heater). The investment cost for a high-pressure feedwater heater, including stainless steel tubes and instrumentation, is approximately USD 20,000, yielding a payback period of just one year. These findings demonstrate that integrating a high-pressure feedwater heater offers the best balance between efficiency improvement and cost reduction, making it a highly beneficial option for optimizing plant performance. However, practical implementation may face challenges due to plant-specific constraints such as turbine extraction limits, boiler compatibility, and physical space limitations—particularly in older facilities with conventional layouts. Despite these challenges, the study underscores that even modest efficiency gains can lead to meaningful cost savings and emissions reductions over the plant's operational life. In small-scale power plants, payback periods may vary, and lifecycle evaluations considering risk and long-term reliability are essential. Additionally, policy-driven incentives such as carbon credits could further enhance the attractiveness of feedwater heater adoption. Future work will include a comprehensive economic analysis incorporating Net Present Value (NPV), Internal Rate of Return (IRR), and sensitivity analysis to strengthen the investment case for similar capacity power plants.

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