International Journal of Engineering Research

Sirte University
Faculty of Engineering

Journal homepage: Scientific Journals (su.edu.ly)

The Effect of inlet Steam Pressure and Its Flow Rate on The Performance of Steam Turbine Power Plant Based on Exergy Analysis

Mahdi Algool[1] *Awad Alshebani*[2]

1 Mechanical Engineering Department, Faculty of Engineering, Sirte University, Sirte, Libya

2 Chemical Engineering Department, Faculty of Engineering, Sirte University, Sirte, Libya

Corresponding Author: mahdi.alg@su.edu.ly

ARTICLE INFOR

Article history:

Received 31 July 2026

Revised day Month Year

Accepted 03 August 2026
Available online

01 November 2026

ABSTRACT

An energy analysis of the Elkalije Steam Turbine Power Plant (KSTPP) has previously been conducted. Because energy analysis alone cannot reveal the true locations and magnitudes of thermodynamic losses, this paper presents an exergy analysis of the same plant to provide a more complete performance assessment. The analysis is based on two practical operating cases: a 170 MW load with an inlet steam pressure of 136 bar, and a 250 MW load with an inlet steam pressure of 161 bar. These cases were selected to examine the effect of inlet steam pressure on plant performance, as well as the influence of steam flow rate variation on exergy losses within each case.

The results show that increasing the inlet steam pressure improves the exergy performance of several major components and slightly reduces exergy destruction in the boiler, the plant's dominant source of irreversibility. However, increasing the steam flow rate and plant loading leads to a substantial increase in exergy losses across the system, particularly in the boiler. These findings highlight the boiler as the primary target for performance improvement and demonstrate that pressure and loading conditions must be considered together when optimizing the exergy performance of the plant.

2026 Sirte University, All rights are reserved

Keywords: *Exergy analysis, Exergy efficiency, inlet steam pressure, Exergy losses*

1. Introduction

Energy analysis is based on the first law of thermodynamics, which expresses the principle of energy conservation. It deals with the quantities of energy in various forms transferred between a system and its surroundings, as well as changes in the energy stored within the system. In energy analysis, heat and work interactions are treated as equivalent forms of energy transfer. However, the first law does not provide information about the quality or usefulness of energy or the degree of thermodynamic irreversibility associated with energy transformations. Therefore, exergy analysis, which is based on the second law of thermodynamics, is employed to evaluate the quality of energy, identify sources of irreversibility, and quantify the maximum useful work that can be obtained from a system. Consequently, there has been increasing interest in applying both energy and exergy analyses to provide a more comprehensive assessment of the thermodynamic performance of energy systems.Many studies have been conducted using energy and exergy analyses to investigate the performance of steam power and cogeneration systems. According to the thermodynamic characteristics of the system, including pressure, temperature, mass flow rate, and the type of working fluid such as saturated water, compressed liquid, and superheated steam the corresponding enthalpy and entropy values were determined. Subsequently, energy and exergy balance equations were applied to evaluate the energy losses, exergy destruction, and efficiencies of the various system components. The results of the energy and exergy analyses indicated that the highest energy losses occurred in the boiler, drum, and deaerator. Furthermore, owing to the utilization of steam extracted from the turbine in other operating units of the studied refinery, the condensers exhibited lower exergy destruction and energy losses than those typically observed in conventional power plants [1]. The performance of a 200 MW steam cycle power plant (SCPP) was investigated using energy and exergy analyses to evaluate the effect of employing different numbers of feed water heaters (FWHs) on the performance of the steam turbine cycle. Several simulation analyses were conducted to determine the exergy destruction in each system component and the overall exergy efficiency. The analysis focused on evaluating the irreversibility of the system and identifying potential opportunities for improving its thermodynamic performance. The results showed that the boiler accounted for the highest rate of

exergy destruction among the major components of the plant [2]. An energy and exergy analysis of a boiler and an extraction-condensing steam turbine cogeneration plant was also conducted. The results revealed that the maximum exergy destruction occurred in the boiler, particularly during the combustion process, which represents a major source of thermodynamic irreversibility in the system [3]. The steam and power generation plant of a chemical and fertilizer industry was analysed using an exergy-based approach. Selected components of the system were analysed individually to identify the locations and magnitudes of the major energy losses and exergy destruction. The results showed that the highest energy loss occurred in the condensers. In contrast, the highest exergy destruction was observed in the two boilers and the condenser. Furthermore, the exergy efficiencies of the power generation cycle were found to be higher than the corresponding energy efficiencies [4]. In order to optimize the thermodynamic performance of steam turbines and achieve higher exergy efficiency, exergy analysis has been widely recognized as an important criterion for evaluating and improving the performance of thermal power plants. In one study, the exergy efficiency of a steam power plant was initially optimized using an exergy-efficiency objective function. The results were subsequently compared with those obtained using genetic algorithm (GA) and particle swarm optimization (PSO) methods. The final results indicated that, by appropriately adjusting the decision variables and employing the firefly algorithm, the exergy efficiency of the thermal power plant could be increased by approximately 0.6% [5]. An exergy analysis of three cylindrical sections of a steam turbine, namely the high-pressure cylinder (HPC), intermediate-pressure cylinder (IPC), and low-pressure cylinder (LPC), was performed. The results indicated that the intermediate-pressure cylinder exhibited the lowest exergy loss and, simultaneously, the highest exergy efficiency. The high-pressure cylinder also demonstrated a relatively high exergy efficiency [6]. The performance of a steam power plant was evaluated using component-wise modelling, together with a detailed assessment of energy and exergy losses. The analysis was conducted under part-load operating conditions to identify the magnitude, location, and sources of thermodynamic inefficiencies within the plant. The results showed that the largest energy loss occurred in the condenser, whereas the lowest energy loss was observed in the boiler. In contrast, the highest exergy destruction occurred in the boiler, followed by the turbine and condenser. These findings demonstrate the importance of distinguishing between energy losses and exergy

destruction when evaluating the thermodynamic performance of steam power plants [7

2. . TS diagram of thermodynamic processes of Elkhalij steam turbine power plant

The working fluid undergoes a series of thermodynamic processes that constitute the power plant cycle. Initially, the feed water is supplied to the boiler, where it receives heat until it is converted into superheated steam at state 3. The high-temperature steam is subsequently admitted to the High-Pressure Turbine (HPT), where it undergoes an expansion process accompanied by the first steam extraction at state 5. Following partial expansion, the steam is directed to the reheating at state 4, where its temperature is increased before entering the Intermediate-Pressure Turbine (IPT) at state 6. As the steam expands through the IPT, two extraction streams are withdrawn at states 7 and 8 for use in the regenerative feed water-heating system. The remaining steam then enters the Low-Pressure Turbine (LPT) at state 9 and continues its expansion to a lower pressure. During the LPT expansion process, four additional steam extractions are made at states 10, 11, 12, and 13. The unextracted steam finally leaves the turbine at state 14 as a vapor–liquid mixture and enters the condenser, where it rejects heat to the cooling medium and is converted into liquid water at state 15. The condensate is then pressurized by the condensate pump to state 16 and supplied to the first stage of the regenerative feed water-heating system. In this stage, the feed water passes successively through Heaters 1–4, where its temperature and thermodynamic properties are progressively increased, reaching state 27. The heated feed water is subsequently introduced into the deaerator at state 28,1, where further heating and removal of dissolved gases take place. The water is then pressurized by the feed water pump to state 2 and directed toward the second stage of the regenerative preheating system. In the second preheating stage, the feed water passes through Heaters 6 and 7, resulting in a further increase in its temperature and reaching state 30. At this stage, the feed water has attained the required thermodynamic conditions for boiler entry. It is subsequently returned to the boiler, where the heating process begins again, thereby completing the Rankine cycle and establishing continuous operation of the power generation system.

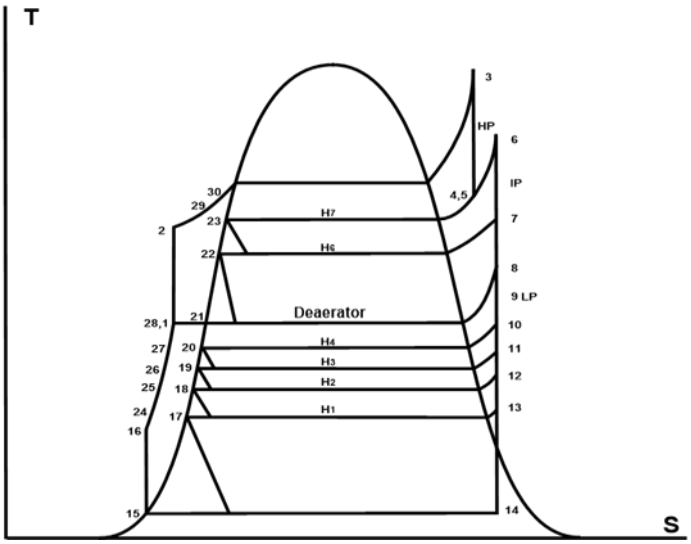


Figure1. TS diagram of thermodynamic processes of (KSTPP) [8].

3. Exergy analysis of KSTPP:

Exergy is defined as the maximum theoretical work that can be obtained from a system as it undergoes a reversible process and reaches thermodynamic equilibrium with its surrounding environment, which is taken as the reference state. Unlike energy, exergy provides a measure of the useful work potential of an energy stream and accounts for the irreversibility associated with real thermodynamic processes. The exergy of a flowing stream can generally be divided into four main components: physical, chemical, kinetic, and potential exergy. Physical exergy arises from the differences in temperature and pressure between the working fluid and the reference environment, whereas chemical exergy is associated with differences in chemical composition between the system and the environmental reference state. Chemical exergy is particularly significant in systems involving combustion, mixing, and chemical reactions. Kinetic and potential exergy are related to the velocity and elevation of the fluid, respectively.

For a control volume operating under steady-state conditions, and assuming that changes in kinetic and potential energies are negligible, the exergy balance can be established by applying the second law of thermodynamics. Accordingly, the exergy balance accounts for the exergy entering and leaving the control volume, the exergy associated with heat and work interactions, and the exergy

destruction resulting from thermodynamic irreversibility. Based on this balance, the exergy efficiency and loss can be determined to evaluate the effectiveness of the thermodynamic process in utilizing the available work potential. Therefore, the general exergy balance and exergy efficiency equations for the main thermodynamic processes in a steam-turbine power plant can be expressed as follows:

$$X^{ch} + \sum Xi^{in} - \sum Xi^{out} - W_T + W_P - X^L = 0 \quad (1)$$

$$Xi = (hi - h_o) - T_o(Si - S_o) \quad (2)$$

$$X^{ch} = m_f \times LHV \times \xi \quad (3)$$

$$\eta_{XT} = \frac{W_T}{\sum Xi^{in} - \sum Xi^{out}} \quad (4)$$

$$\eta_{XP} = \frac{X_{out}}{X_{in} + W_P} \quad (5)$$

$$\eta_{XB} = \frac{\sum Xi^{out}}{\sum Xi^{in} + X^{ch}} \quad (6)$$

$$\eta_{XC} = \frac{X_{SW}^{out} - X_{SW}^{in}}{\sum Xi^{in} - Xi^{out}} \quad (7)$$

4. Governing equation of thermodynamic processes of Exergy losses and efficiency of each component of KSTPP.

4.1. Boiler

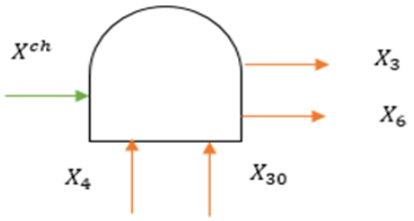


Figure 2. Exergy inlet and outlet of boiler

$$X^{ch} + \sum X^{in} - \sum X^{out} - X^L = 0 \quad (8)$$

$$X^{ch} = m_{fuel} \times LHV_{fuel} \times \xi \quad (9)$$

$$\sum X^{in} = X_4 + X_{30} \quad (10)$$

$$\sum X^{out} = X_6 + X_3 \quad (11)$$

$$\eta_{XB} = \frac{X_6 + X_3}{X_4 + X_{30} + X^{ch}} \quad (12)$$

4.2. High pressure turbine (HPT)

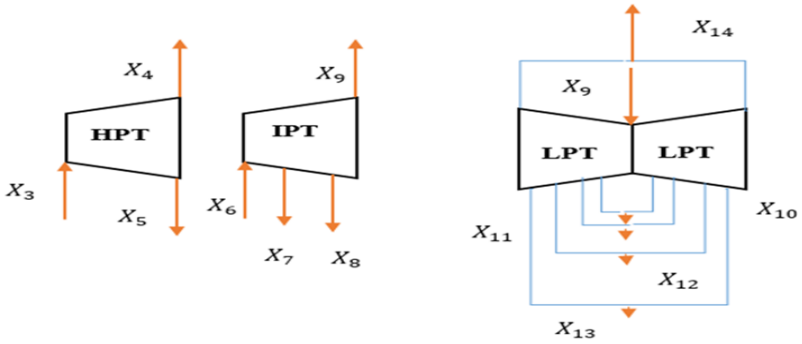


Figure 3. Exergy inlet and outlet of steam turbine, (HPT, IPT and LPT).

$$\sum X^{in} - \sum X^{out} - W_{HPT} - X^L = 0 \quad (13)$$

$$W_{HPT} = m_S\,(h_3 - h_4) \quad (14)$$

$$\sum X^{in} = X_3 \quad (15)$$

$$\sum X^{out} = X_4 + X_5 \quad (16)$$

$$\eta_{XHPT} = \frac{W_{HPT}}{X_3 - (X_4 + X_5)} \quad (17)$$

4.3. Intermediate pressure turbine exergy balance (IPT)

$$\sum X^{in} - \sum X^{out} - W_{IPT} - X^L = 0 \quad (18)$$

$$W_{IPT} = (m_s - m_{bs7})(h_6 - h_7) + (m_s - \sum_{i=6}^{7} mbsi)(h_7 - h_8) + (m_s - \sum_{i=5}^{7} mbsi)(h_8 - h_9) \quad (19)$$

$$\sum X^{in} = X_6 \quad (20)$$

$$\sum X^{out} = X_7 + X_8 + X_9 \quad (21)$$

$$\eta_{XIPT} = \frac{W_{IPT}}{X_6 - (X_7 + X_8 + X_9)} \quad (22)$$

4.4. Low pressure turbine (LPT)

$$\sum X^{in} - \sum X^{out} - W_{LPT} - X^{L} = 0 \quad (23)$$

$$W_{LPT} = (m_s - \sum_{i=5}^{7} mbsi)(h_9 - h_{10}) + (m_s - \sum_{i=4}^{7} mbsi)(h_{10} - h_{11}) + (m_s \sum_{i=3}^{7} mbsi)(h_{11} - h_{12}) + (m_s - \sum_{i=2}^{7} mbsi)(h_{12} - h_{13}) + (m_s - \sum_{i=1}^{7} mbsi)(h_{13} - h_{14}) \quad (24)$$

$$\sum X^{in} = X_9 \quad (25)$$

$$\sum X^{out} = X_{10} + X_{11} + X_{12} + X_{13} + X_{14} \quad (26)$$

$$\eta_{XLPT} = \frac{W_{LPT}}{X_9 - (X_{10} + X_{11} + X_{12} + X_{13} + X_{14})} \quad (27)$$

4.5 Condenser

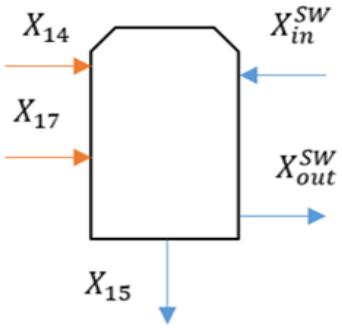


Figure 4. Exergy inlet and outlet of condenser.

$$\sum X^{in} - \sum X^{out} - X^{L} = 0 \quad (28)$$

$$\sum X^{in} = X_{14} + X_{17} + X_{in}^{SW} \quad (29)$$

$$\sum X^{out} = X_{15} + X_{out}^{SW} \quad (30)$$

$$\eta_{XC} = \frac{X_{SW}^{out} - X_{SW}^{in}}{X_{14} + X_{17} - X_{15}} \quad (31)$$

4.6 Extraction condenser pump

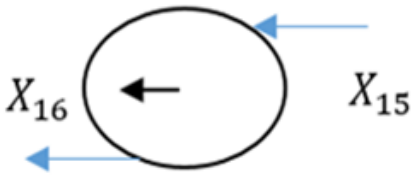


Figure 5. Exergy inlet and outlet of ECP.

$$X^{in} - X^{out} + W_{ECP} - X^{L} = 0 \quad (32)$$

$$W_{ECP} = (m_S - \sum_{i=5}^{7} mbsi)\,(h_{16} - h_{15}) \quad (33)$$

$$X^{in} = X_{15} \quad (34)$$

$$X^{out} = X_{16} \quad (35)$$

$$\eta_{XP} = \frac{X_{16}}{X_{15} + W_{ECP}} \quad (36)$$

4.7 Feed water pump

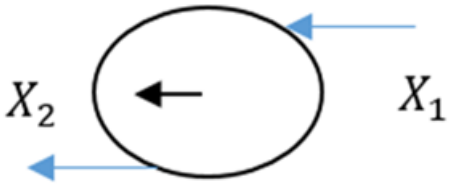


Figure 6. Exergy inlet and outlet of FWP.

$$X^{in} - X^{out} + W_{FWP} - X^{L} = 0 \quad (37)$$

$$W_{FWP} = m_S(h_2 - h_1) \quad (38)$$

$$X^{in} = X_1 \quad (39)$$

$$X^{out} = X_2 \quad (40)$$

$$\eta_{XP} = \frac{X_2}{X_1 + W_{FWP}} \quad (41)$$

5. Results and discussion

5.1 Exergy efficiency:

Figure 7 compares the exergy efficiencies of the KSTPP's main components at inlet steam pressures of 136 bar and 161 bar. Raising the inlet pressure from 136 to 161 bar improves exergy efficiency across most components, with the notable exception of the condenser and the extraction condenser pump, whose efficiency declines at the higher pressure. At 136 bar, the Intermediate-Pressure Turbine (IPT) records the highest exergy efficiency (~91.3%), while the condenser records the lowest (~49.55%). At 161 bar, the IPT's efficiency rises further to ~93.2%, whereas the condenser's efficiency falls to ~44.5%. The efficiency gains in the turbine stages stem from improved thermodynamic conditions of the steam at higher pressure, which enhances exergy utilization during expansion and increases the potential for energy conversion. The condenser's decline, however, shows that raising inlet pressure does not uniformly benefit all components heat-rejection equipment in particular responds differently. This underscores that inlet steam pressure has a system-wide effect on exergy distribution, improving turbine performance while penalizing the condenser.

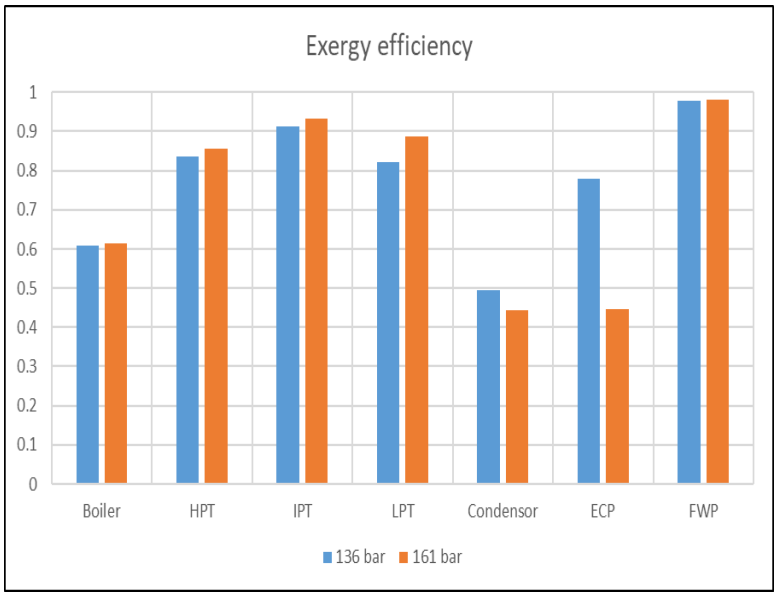


Figure 7. Comparison of Exergy efficiency of main components of KSTPP at 136 bar and 161 bar of steam inlet pressure.

5.2. Exergy Losses:

Figures 8–10 present exergy losses and loss ratios for the plant's main components at 136 bar and 161 bar, with a constant steam mass flow rate of 150 kg/s. The boiler is by far the largest source of exergy destruction under both conditions, though its loss decreases slightly at higher pressure from 268.5 MW (86.5% loss ratio) at 136 bar to 265.5 MW (85.9%) at 161 bar. This confirms the boiler as the dominant contributor to irreversibility in the EKSTPP, driven mainly by the large temperature gradients between combustion gases and the working fluid. At 161 bar, exergy losses are 9.5 MW (HPT), 4.0 MW (IPT), 10.4 MW (LPT), and 18.2 MW (condenser), with loss ratios of 0.031%, 0.013%, 0.034%, and 0.060% respectively, the condenser now the largest loss among these, followed by the LPT and HPT. At 136 bar, the corresponding losses are 11.2 MW (HPT), 5.2 MW (IPT), 15.8 MW (LPT), and 8.6 MW (condenser), with ratios of 0.036%, 0.017%, 0.052%, and 0.026%. Raising pressure from 136 to 161 bar therefore reduces losses in the HPT (11.2→9.5 MW), IPT (5.2→4.0 MW), and LPT (15.8→10.4 MW), but more than doubles the condenser's loss (8.6→18.2 MW), a shift traceable to how the changed turbine exit conditions alter the condenser's operating state. Losses in the extraction condenser pump and feed water pump remain negligible at both pressures.

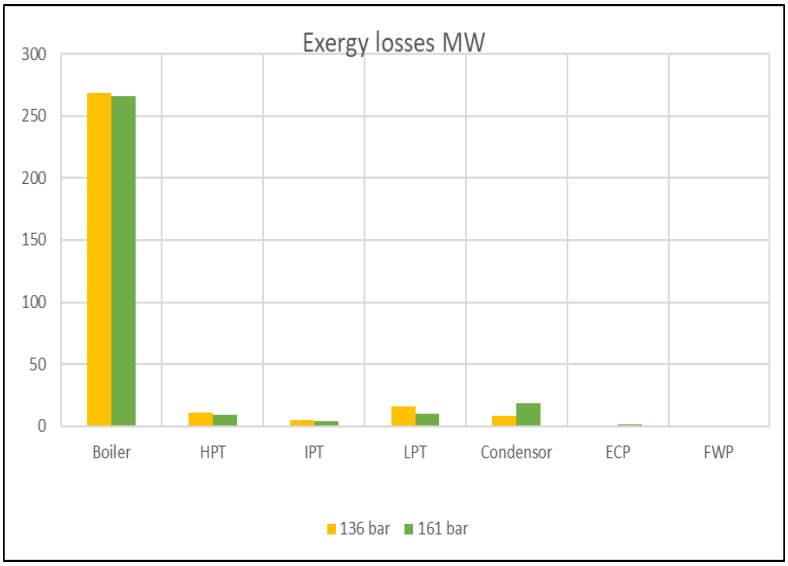


Figure 8. Comparison of Exergy losses of main components of KSTPP at 136 bar and 161 bar of steam inlet pressure at $m_s = 150\ kg/s$.

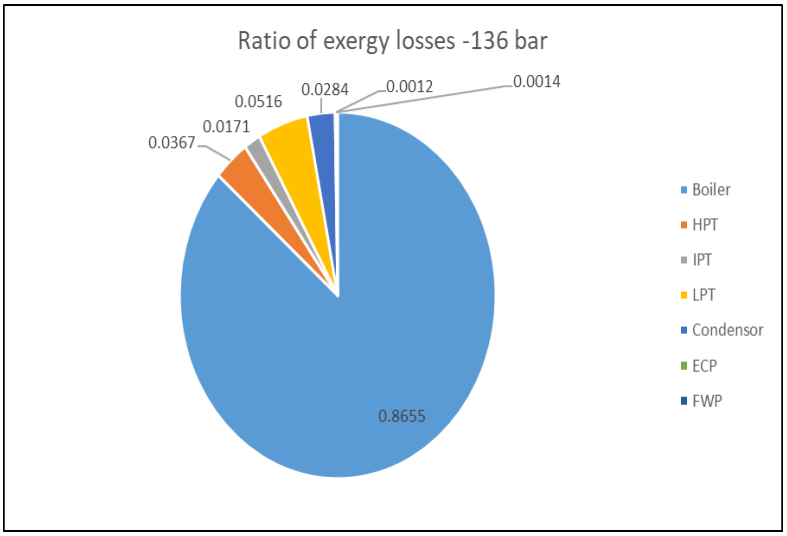


Figure 9. Exergy losses ratio of main components of KSTPP at 136 bar of inlet steam pressure.

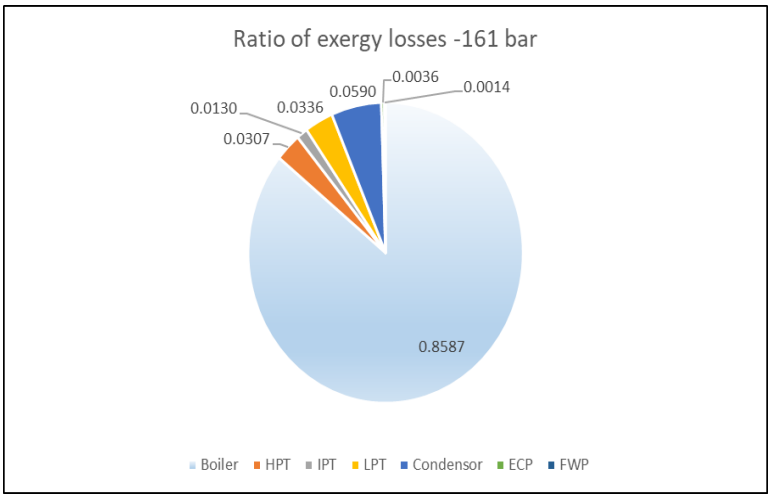


Figure 10. Exergy losses ratio of main components of KSTPP at 161 bar of inlet steam pressure.

5.3 *The effect of steam flow rate on the exergy loss of KSTPP:*

Figure 11 shows that increasing steam flow rate and hence plant load raises exergy losses across all components, since more working fluid passing through the system increases both energy and exergy transfer rates, and with them, irreversibility. At 136 bar, boiler exergy loss rises from ~148.6 MW at 102 MW load to ~506.8 MW at 347 MW load. At 161 bar, it rises from ~145.1 MW to ~493.8 MW over the same load range. In both cases the increase is nonlinear, steepening at higher loads indicating that irreversibility within the boiler grows disproportionately as flow rate increases. At every load point, boiler losses are marginally lower at 161 bar than at 136 bar (e.g., 493.8 MW vs. 506.8 MW at full load; 145.1 MW vs. 148.6 MW at minimum load),

confirming that higher inlet pressure offers a small but consistent efficiency benefit across the operating range.

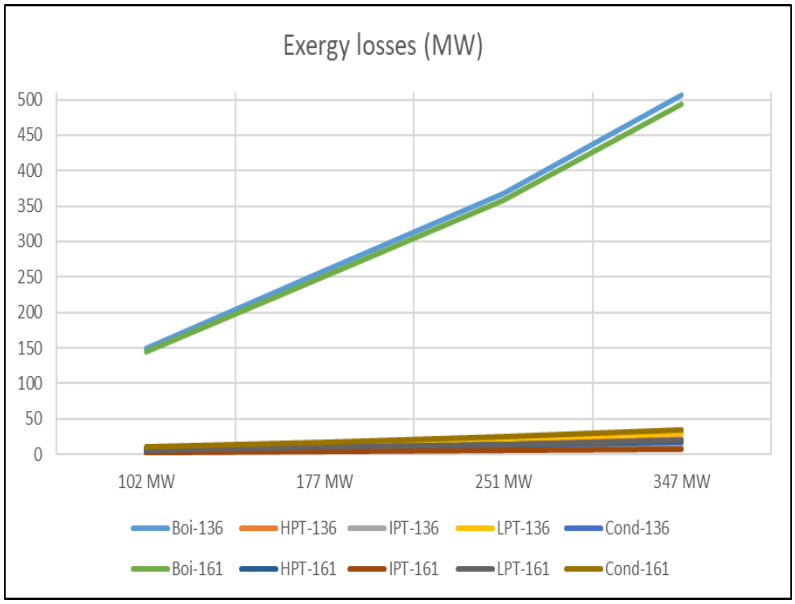


Figure 11. Comparison of Exergy losses of main components of KSTPP at 136 bar and 161 of inlet steam pressure

6. *Conclusion*

This analysis shows that inlet steam pressure and steam flow rate both strongly influence the thermodynamic performance and exergy destruction of the KSTPP. Raising inlet pressure from 136 to 161 bar improves exergy efficiency in the major turbine components most notably the IPT, which reaches ~93.2% but reduces condenser efficiency, illustrating that pressure optimization benefits are not uniform across the cycle. The boiler remains the dominant source of exergy destruction throughout: at 150 kg/s, its loss falls only modestly from 268.5 MW (86.5%) at 136 bar to 265.5 MW (85.9%) at 161 bar, indicating that boiler and heat-transfer improvements offer the greatest potential for overall gains. The condenser is the next most significant loss source, especially at higher pressure. Increasing steam flow rate substantially raises exergy losses system-wide, with boiler losses climbing from 148.6–506.8 MW (136 bar) and 145.1–493.8 MW (161 bar) across the 102–347 MW load range losses that grow more steeply as load increases, reflecting rising irreversibility at higher throughput. Overall, the boiler warrants the most attention for exergy-performance improvement, with the condenser as a secondary priority. While higher inlet pressure improves most components and modestly reduces boiler

losses, its adverse effect on the condenser shows that the plant must be optimized as an integrated system rather than component-by-component.

Nomenclature

X^{ch}	Chemical exergy, (w)
Xi	Flowing of exergy at state i (W)
X_{SW}	Exergy of sea water (W)
X^{L}	Exergy loss (W)
W_T, W_P	Power of turbine and pump (W)
hi, Si	Static enthalpy (J/Kg) and Static entropy (J/Kg.K) at state i
h_o, S_o	Static enthalpy and entropy of environment at (T = 15 Cº. P=1.013 bar)
ξ	Coefficient of exergy of fuel (1.04-1.06)
LHV	Low heating value of fuel (J/Kg)
m_f	Mass flow rate of fuel (Kg/s)
m_s	Mass flow rate of steam (Kg/s)
m_{bsi}	Mass flow rate of bleeding steam (Kg/s)
$\eta_{XT}, \eta_{XP}, \eta_{XB}, \eta_{XC}$	Exergy efficiency of turbine, pump, boiler and condenser

References

[1] Mehrabi Gohari, E., Pishkar, I., & Omidian, E. (2025). Energy and exergy analysis of steam power plant cycle of the Ninth Refinery of South Pars Gas Complex. Iranica Journal of Energy and Environment, 16(1), 124–135. doi.org

[2] Mohammed, M. K., Al Doori, W. H., Jassim, A. H., Ibrahim, T. K., & Al-Sammarraie, A. T. (2019). Energy and exergy analysis of the steam power plant based on effect the numbers of feed water heater. Journal of Advanced Research in Fluid Mechanics and Thermal Sciences, 56(2), 211–222.

[3] Bhagat, V. H., Rehman, A. I., & Hatkar, D. N. (2018). Energy and exergy analysis of boiler and extraction cum condensing steam turbine in sugar

cogeneration plant. International Journal of Interdisciplinary Research and Innovations, 6(3), 672–683.

[4] Pilankar, K. D., & Kale, R. (2016). Energy and exergy analysis of steam and power generation plant. International Journal of Engineering Research & Technology (IJERT), 5(6), 415–420.

[5] Elahifar, S., Assareh, E., & Nedaei, M. (2018). Exergy analysis and optimization of the Rankine cycle in steam power plants using the firefly algorithm. Mechanics & Industry, 19(5), Article 505. doi.org

[6] Mrzljak, V., Marjanović, D., Prpić-Oršić, J., & Glažar, V. (2023). Exergy analysis of steam turbine from ultra-supercritical power plant. International Scientific Journal "Mechanics. Technologies. Materials", 17(3), 98–101.

[7] Elfeituri, I. A., & Almotalip, A. A. (2017). Energy and exergy analysis of a steam turbine power plant at part load conditions. Port Said Engineering Research Journal, 21(2), 181–192.

[8] Mahdi Algool, Awad Alshebani, Abdulhalim.A. Saaid, H.S. Bin Hamdin3 Ahmed Alsaadi, Evaluating of performance of Elkhalej steam turbine power plant (KSTPP) based on energy criteria, Sirte University Scientific Journal,Vol. 16, No. 1 (2026) 173-182