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# Energy and exergy assessment of the Coal-Fired power plant based on the effect of condenser pressure

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ABSTRACT

In this study, an analytical model has been developed to predict the performance of coal-fired thermal power plant based on effect of condenser pressure. The current model has been developed to anticipate the energy and exergy-based behavior of the coal-fired power plants. This study deals fundamentally with the coal-fired power plants based on exergy analysis. The objective of this study is to analyze the effect of condenser pressure that leads to the highest exergy destruction. The plant's thermal efficiency was determined to be 44% with a net efficiency of 31% for a gross power output of 594.25 MW. Increasing the condenser pressure lead to decreases energy and exergy efficiency. It was observed that operating the coal-fired power plant yields a positive response regarding exergy losses.

KEYWORDS

Energy, Exergy, Coal-Fired, Power plant, Condenser Pressure, Second law

INTRODUCTION

There has been a continuous demand for energy, especially the demand for electricity in recent decades. Today, fossil fuels remain the major source of energy for electricity generation but as per the International Agency of Energy, it has been predicted that gas-fueled combined cycle's power plants will contribute majorly to fuel sources by the year 2030 [1, 2]. One of the major indicators of development and improved standard of living among communities is the level of energy consumption as increases in population, industrialization, and urbanization results in increased energy utilization. Currently, more than 80% of global electricity production is contributed by thermal power plants (TPPs) while the remaining 20% comes from different energy sources such as wind, solar, hydraulic, nuclear, biomass, geothermal, etc. [3-7]. The growth of the economy of any nation is directly influenced by the cost and availability of electricity. These days, electricity remains a part of normal life; it is so important that electricity consumption per capita is considered today an economic development index and a measure of the standard of living of a country [8-11]. Therefore, it is evident that the level of prosperity of a country is directly dependent on the level of emphasis it places on the continuous development of electrical power, as well as energy and exergy efficiency analysis [12].

Currently, improvements in industrialization, global population, and quality of life have significantly increased the rate of fossil fuel consumption [13-20]. However, this increased consumption of fossil fuel has been suggested to cause adverse environmental problems that could impact negatively on the quality of life; it has also been suggested to cause global climate change and adverse depletion of natural fossil reserves [21-32]. Therefore, it is important to develop methods that can help reduce the over-dependence on fossil fuels for energy generation. Steam power plants (SPP) remain a major way of electricity generation, hence, it is necessary to focus on how to improve their efficiencies. One of the ways to minimize fossil fuel consumption in SPP is to minimize the heat transfer-related irreversibility in the feedwater heaters network. Furthermore, the second way to reduce fuel consumption is to optimise the ambient and operating conditions of the steam power plants [33-39]. A consideration of the energetic & exergy performance criteria during the analysis normally gives better plant assessment, thus providing the basic information needed for performance enhancement. It is necessary that, after exergy analysis, the basic differences between exergy and energy concepts should be presented as tabulated in Table 1.

**Table 1.** The basic differences between energy & exergy concepts [33, 40-42]

| No | Energy | Exergy |
|---|---|---|
| 1 | Energy analysis is based on the law of conservation (First Law of Thermodynamic). | Exergy analysis is exempted from the law of conservation. |
| 2 | Energy analysis is dependent on the condition of the matter under consideration. | Exergy analysis is dependent on both the condition of the considered matter and on the condition of the immediate environment. |
| 3 | Energy analysis can be calculated based on an assumed state of reference. | Exergy analysis is calculated based on the condition of the reference as imposed by the surrounding environment. |
| 4 | Energy and temperature increase proportionally. | For isobaric processes, minimum exergy is reached at the temperature of the surrounding; it increases with decreases in the temperature. |
| 5 | For ideal gases, energy is not dependent on the pressure. | Exergy of ideal gases depends on the pressure. |

Many researchers have studied the energy and exergy analysis of thermal power plants. A component-based exergy analysis that compared the exergetic performances of each component via the identification of their weaknesses was performed by Wu et al. [43]. The aim of process-based exergy analysis is the determination of the level of the inadequacy of the main processes in order to break the limitation of single component performance optimization (a sensitivity analysis) and enlighten process-level optimization by innovative flow design, as well as the consideration of the inter-component interaction. In this work, the exergy consumption and distribution profile of a large-scale coal-fired power plant were provided with component-based and process-based analysis; it serves as a guide for energy-efficiency measures [43]. The measures for improving the other components of plants using exergy analysis have been investigated. For instance, the improvement of compression & expansion processes using exergy analysis has been reported. Similarly, the use of exergy-based criteria for heat exchangers optimization has been performed in general, and for feedwater heaters specifically. This research attempts the development of an integrated strategy for the analysis and improvement of the overall performance of the coal-fired power plants based on the effect of condenser pressure.

## METHOD AND ANALYSIS

The energy and exergy analysis have been used as basis for the suggested methodology. Essentially, the performance of the Coal-Fired Power plant will be evaluated by examining the influence of various ambient temperatures and operation conditions. Integrated strategies developed from different enhancing elements are used for constructing major models in order to improve the performance of Coal-Fired Power plant [44-46]. These strategies included the effect of feed water heaters configurations on the performance of the Coal-Fired Power plant. Optimization of Coal-Fired Power plant performance and integrated simulation is provided by energy and exergy analysis [47].

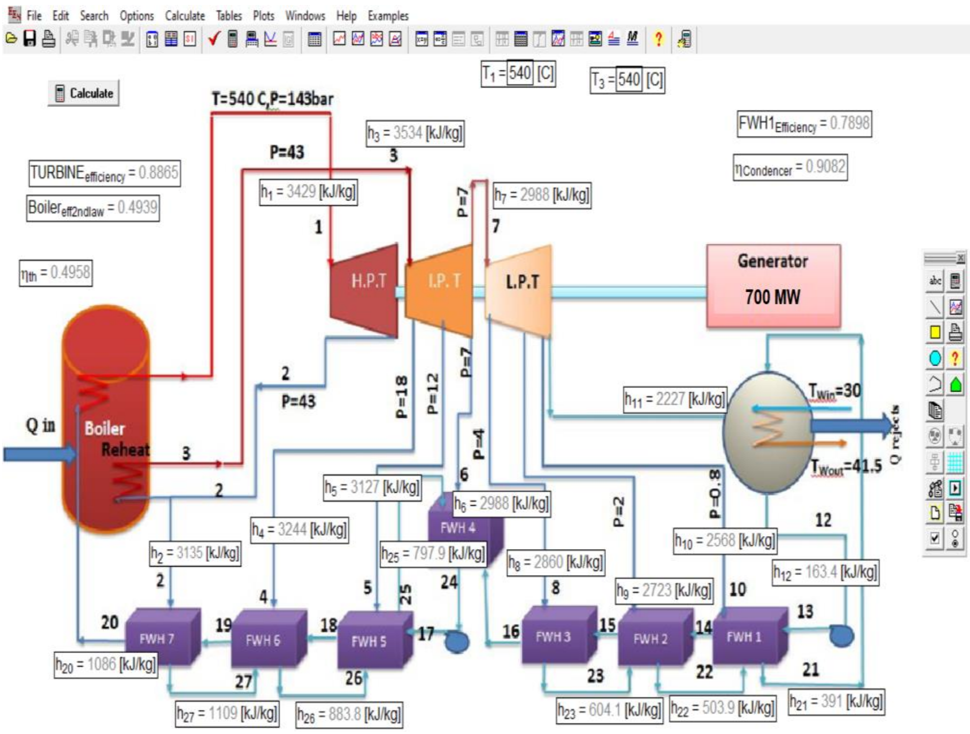


**Figure 1.** Process flow diagram of the considered power plant

In the present study, Unit 1 of Manjung Coal Fired power plant located in Malaysia is considered for investigation. The process flow diagram (PFD) of this power plant is illustrated in Figure 1. To analyze the complete cycle of the power plant, the continuity, energy and exergy equations governing various components of the cycle are developed and resolved using Engineering Equation Solver (EES) software. The continuity equations are invoked to find the distribution of feed water and steam throughout the cycle as shown in table 2. To examine the performance of the power plant, two modes are considered. In the first mode, the actual data of the power plant at several conditions are acquired and put into the computational code to generate the performance main data. These results are compared with the real data measured at the power plant to demonstrate the credibility of the method and computational code. In the second mode, a predictive model will be developed to reflect the impact of varying the conditions of different components of the cycle on the performance parameters of the power plant. This model will be capable of reckoning the efficacy of factors like the mass flow rate, pressure and temperature of the bled steam for different feed water heaters; pressure and temperature of the exit steam from the superheater and reheater; the mass flow rate of the main steam; the Approach of the boiler, and the pressure of the condenser.

**Table 2.** Model equations for different devices of the coal-fired power plant

| Components | Energy Balance | Exergy Balance | Energy Efficiency | Exergy Efficiency |
|---|---|---|---|---|
| Boiler | $\Sigma \dot{m}_{in}.h_{in} + \dot{Q}_{boiler} = \Sigma \dot{m}_e.h_e$ | $\dot{E}x_f + \Sigma \dot{E}x_{in,B} = \Sigma \dot{E}x_{e,B} + \dot{E}x_{D,B}$ | $\eta_{e,B} = \left(\frac{\dot{m}_e.h_e - \dot{m}_{in}.h_{in}}{\dot{Q}_{boiler}}\right)$ | $\eta_{ex,B} = \left(\frac{\dot{E}x_{e,B} - \dot{E}x_{in,B}}{\dot{E}x_f}\right)$ |
| Steam Turbine | $\Sigma \dot{m}_{in,T}.h_{in,T} = \Sigma \dot{m}_{e,T}.h_{e,T} + \dot{W}_{st}$ | $\Sigma \dot{E}x_{in,T} = \Sigma \dot{E}x_{e,T} + \dot{W}_{st} + \dot{E}x_{D,T}$ | $\eta_{e,T} = \left(\frac{W_{st}}{\dot{m}_{e,T}.h_{in,T} - \dot{m}_{e,T}.h_{e,T}}\right)$ | $\eta_{ex,T} = \left(\frac{\dot{W}_{st}}{\dot{E}x_{in,T} - \dot{E}x_{e,T}}\right)$ |
| Pump | $\dot{m}_{in,p}.h_{in,p} + \dot{W}_p \dot{m}_{e,p}.h_{e,p}$ | $\dot{E}x_{in,p} + \dot{W}_p = \dot{E}x_{e,p} + \dot{E}x_{D,p}$ | $\eta_{e,p} = \left(\frac{\dot{m}_{in,p}.h_{in,p} - \dot{m}_{e,p}.h_{e,p}}{\dot{W}_p}\right)$ | $\eta_{ex,p} = \left(\frac{\dot{E}x_{in,p} - \dot{E}x_{e,p}}{\dot{W}_p}\right)$ |
| Heater | $\Sigma \dot{m}_{in,H}.h_{in,H} = \Sigma \dot{m}_e.h_{e,H}.h_{e,H}$ | $\Sigma \dot{E}x_{in,H} = \Sigma \dot{E}x_{e,H} + \dot{E}x_{D,H}$ | $\eta_{e,H} = \frac{\dot{m}_{e,H}.h_{e,H}}{\dot{m}_{in,H}.h_{in,H}}$ | $\eta_{ex,H} = \frac{\dot{E}x_{e,H}}{\dot{E}x_{in,H}}$ |
| Condenser | $\Sigma\dot{m}_{incond}h_{incond} = \Sigma\dot{m}_{econd}h_{econd} + \dot{Q}_{rejecte}$ | $\Sigma \dot{E}x_{in,cond} = \Sigma \dot{E}x_{e,cond} + \dot{E}x_{D,cond}$ | $\eta_{e,cond} = \frac{\dot{m}_{e,cond}.h_{e,cond}}{\dot{m}_{in,cond}.h_{in,cond}}$ | $\eta_{ex,cond} = \frac{\dot{E}x_{e,cond}}{\dot{E}x_{in,cond}}$ |

RESULTS AND DISCUSSIONS

All calculations are carried out by using EES program. This program made the assignment easier; because all properties can be calculated without spend much time to get them from tables or books. By calculating the properties in all point the T_S diagram is showed in figure 2. As it is clear here in the figure there are some errors in T_S diagram and that because of accuracy in our calculation. Also figure does not show the work pump that because the pump's work very small comparing to rest energies.

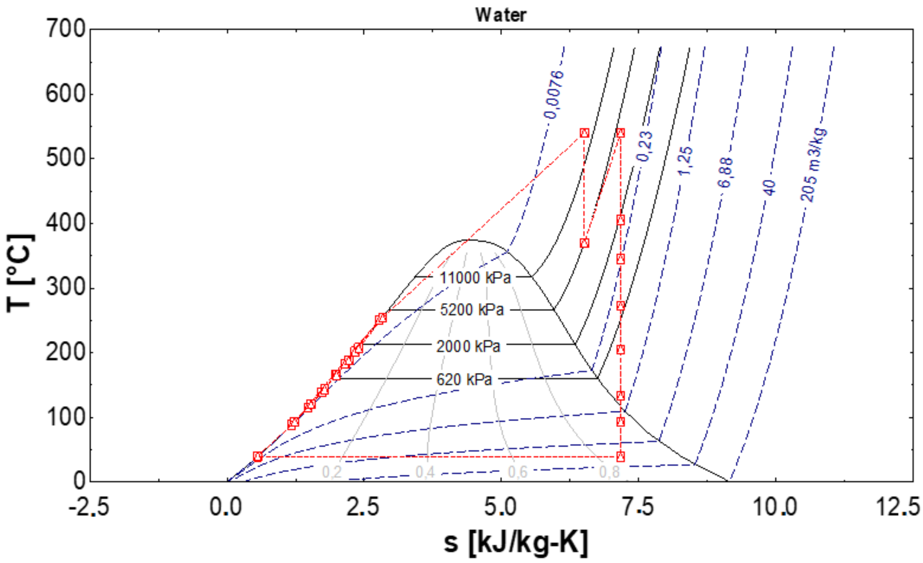


**Figure 2.** Temperatures and Entropies in T_S diagram of the Reheat Rankin cycle.

From the results of this power plant the results that are calculated by using EES program are very close to power plant design values. Hence this program can be used to make simulation for this power plant like study the effect of some parameters on the boiler efficiency or thermal power plant efficiency in order to determine the most factors that affect the efficiencies parts of power plant and try to improve them to make the power plant better. Some of these factors are TIT (Turbine inlet temperature) and ambient temperature. The following figures show the effects of these factors as example. Figure 3 shows the decreasing in thermal efficiency with decreasing of Turbine inlet temperature as it is clear in the figure when TIT reduce to 400ºC the thermal efficiency may be decrease to 34%.

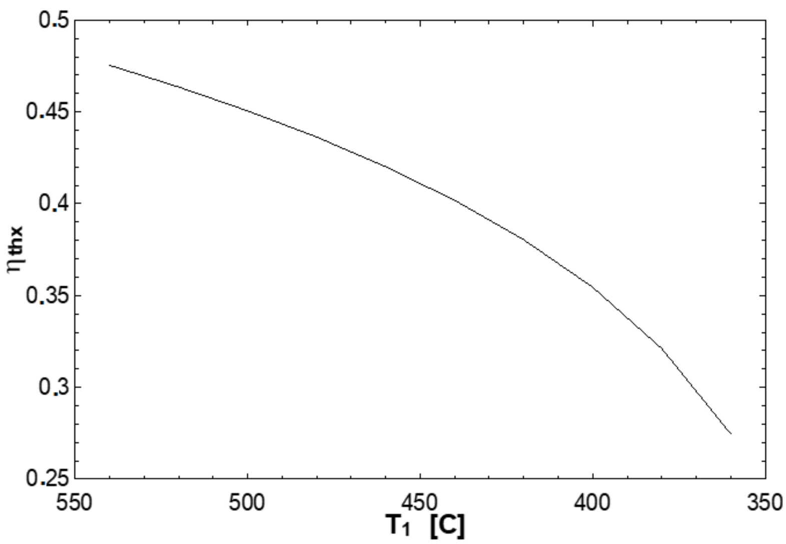


**Figure 3.** The effect of turbine inlet temperature on the thermal efficiency of the power plant.

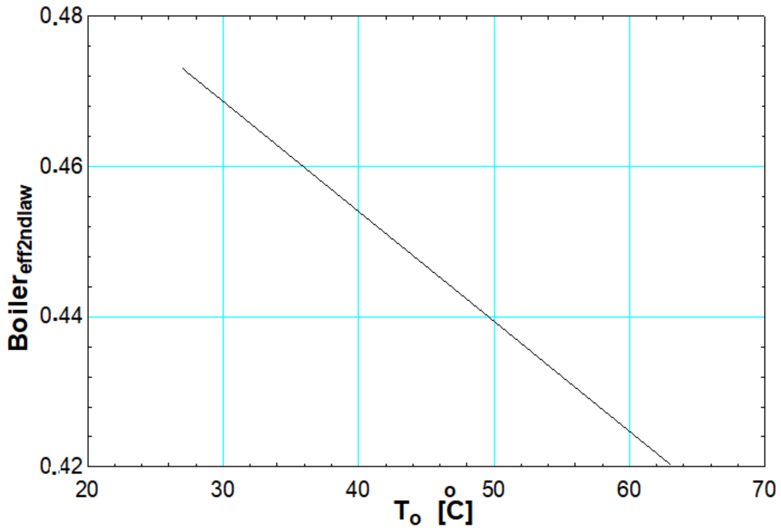


**Figure 4.** Shows the ambient temperature effect on the thermal Boiler's efficiency.

Figure 4 shows the decreasing in Boiler efficiency with increasing of ambient temperature as it is clear in the figure when ambient temperature increase to be equal to 50 ℃ the boiler efficiency may be decrease to less than 44%. Changing the pressure of the condenser affects neither the coal consumption rate nor the exergy efficiencies of high pressure turbine, intermediate pressure turbine and feed water heaters. The impact of changing the pressure of the condenser on the thermal and powerplant efficiencies are given in Figure 5. It is observed that increasing the condenser pressure reduces both efficiencies. Because, increasing the condenser pressure raises the back pressure of turbine, and hence, the power delivered by the turbine will decline.

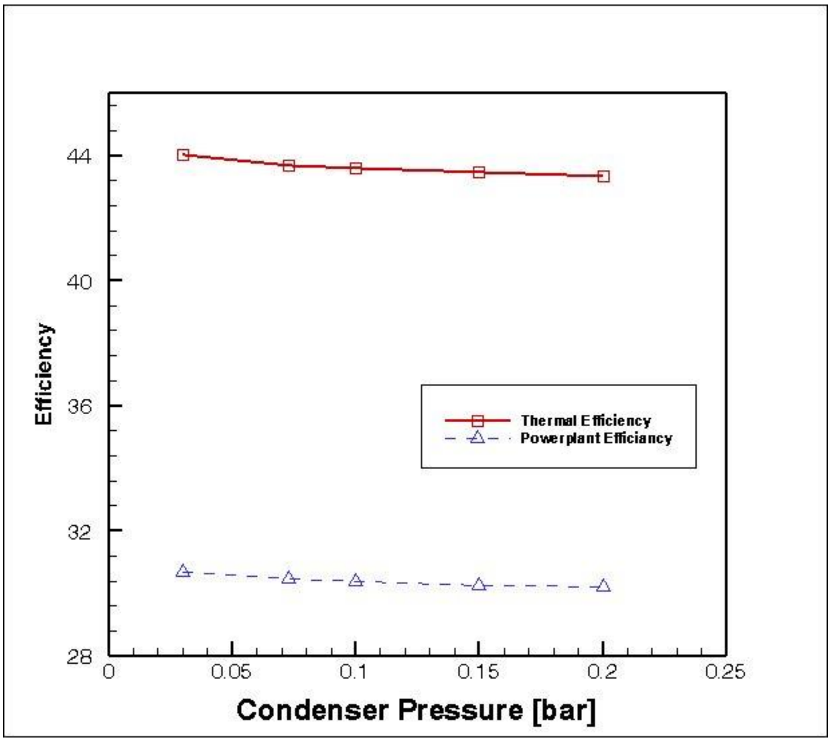


**Figure 5.** The effect of condenser pressure on thermal efficiencies of the cycle and powerplant

Figure 6 represents the variations of exergy efficiency of the cycle with the pressure of the condenser. Here again, it is seen that the higher the pressure of the condenser, the lower the exergy efficiency. Increasing the pressure of the condenser corresponds to the increase in its temperature. Thus, at higher condenser pressures, the temperature difference between the condensing steam and cooling water increases. This leads to higher entropy generation and irreversibility associated to heat transfer in the condenser. Hence, the exergy efficiency of the cycle will decline.

The variations of the heat rate of the cycle and the net power delivered by the cycle with the condenser pressure are given in Table 3. From this table, it is clear that increasing the condenser pressure decreases the net power generated by the power plant. Because, the power produced by turbines are reduced while the fuel consumption is fixed. By increasing the condenser pressure from 0.03 to 0.2 bar, the net power delivered by the cycle declines from 594.659 to 585.536 MW. From the heat rate of the cycle, it is perceived that increasing the condenser pressure in the mentioned range raises the heat rate of the cycle from 2.271 to 2.306.

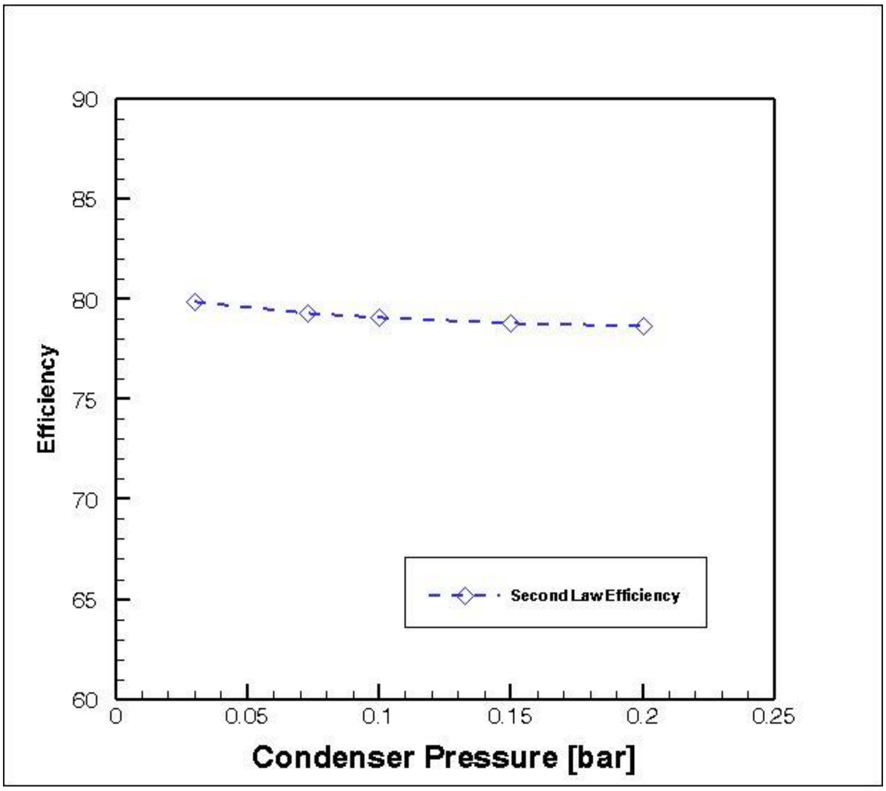


**Figure 6.** The effect of condenser pressure on the exergy efficiency of the cycle

**Table 3.** The effect of condenser pressure on the Heat Rate of the cycle and net power delivered by the cycle

| **Condenser Pressure [bar]** | **$HR_{cycle}$** | **$\dot{W}_{net}$ [MW]** |
|---|---|---|
| 0.03 | 2.270 | 594.799 |
| 0.073 | 2.288 | 590.234 |
| 0.10 | 2.294 | 588.725 |
| 0.15 | 2.301 | 586.890 |
| 0.20 | 2.306 | 585.676 |

## CONCLUSIONS

We can conclude from this study the following points:

- By increasing the condenser pressure, both the thermal efficiency and exergy efficiency will decrease.
- By increasing the condenser pressure from 0.03 to 0.2 bar, the net power delivered by the cycle declines from 616.269 to 553.341 MW.
- When the pressure of the condenser increases, the supplied exergy and destructed exergy to/at the LPT decline.

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