Influence of the Variation of Power Turbine Inlet Temperature on Overall Turbine Efficiency

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Abstract In this paper, the effect of variation of power turbine inlet temperature to the performance of a gas turbine was investigated. Data was collected from control room log sheets for a period of sixty weeks and analyzed. The parameters considered during the data collection were pressures, temperatures and power output. Parameters that could not be obtained directly from the log sheets were determined using appropriate thermodynamic relations. The results show that as the power turbine inlet temperature reduced from 843.44K to 799.05K, the power turbine efficiency increased from 94.65% to 94.76% and the power output from 13.28MW to 15.52MW. Furthermore, irreversibility reduced from 63.22% to 61.96% as the power turbine inlet temperature reduced from 732.46K to 710.26K. These show that operating a gas turbine power plant at lower power turbine entry temperatures as the system approaches its rated capacity gives better performance.

Keyword: Efficiency, Gas-Turbine, Inlet Temperature, Power Turbine.

I. INTRODUCTION

The gas turbine power plant which is a typical internal combustion engine that operates on the Bryton Cycle produces a great amount of energy for its size and weight. It has found increasing service over the years in the power industry, both among utilities and merchant plants as well as the petrochemical industry, and utilities throughout the world [1]. Its compactness, low weight, and multiple fuel application make it a natural power plant for offshore platforms. Today there are gas turbines, which run on natural gas, methane, low-Btu gases, vaporized fuel oils, and biomass gases [1]. They are generally designed to work at certain values of power and efficiencies. However, gas turbines are often required to work at conditions different from which they are designed [2]. It therefore become pertinent to study the performance of these plants in other to improve there efficiency and maximize power output. Due to power to weight ratio of gas turbines, they are used to drive air planes, military tanks, trains, naval gun boats, etc. Usually the rated capacities of turbines are based on ambient air and zero inlet and exhaust pressure drops [3]-[4]. It is also known that gas turbines produce less power when the ambient temperature is hotter [5]. According to Lebele-Alawa and Asuo [6]-[7] higher ambient temperature affect power turbine inlet temperature, hence the overall power produced and efficiency. As the ambient air temperature increases, less air can be compressed by the compressor [8]-[9]. Researchers over the years have worked on the area of cooling the air before the compression process and inter-cooling between compressors using various methods such as evaporative cooler, indirect mechanical refrigeration system, direct mechanical refrigeration system, mechanical refrigeration system with chilled water storage and absorption chiller inlet air cooling system [10]. This work investigates the effect of variation of the power turbine inlet temperature to the performance of the gas turbine power plant. A schematic diagram of the gas turbine plant is shown in fig 1.

II. MATERIALS AND METHODS

The data for the study was obtained from the Kolo-Creek gas turbine power station from actual control room log sheets for a period of six weeks. The variables considered during the data collection are the pressures, temperatures and power output. The analysis and treatment of the data involved computing weekly mean values of these variables using excel for the period the research was carried out. Variables that could not be obtained directly from the control room log sheets were simulated from appropriated thermodynamic equations [11]-[12]. The T-S diagram for the gas turbine processes is shown in fig 2. The ideal processes and actual are represented by broken and continuous lines respectively.
The temperature relationships for the actual and ideal processes are obtained from the following equations:

\[ T_{2S} = T \left( \frac{P_2}{P_1} \right)^{\frac{\gamma-1}{\gamma}} \]  
(1)

\[ T_2 = T_1 + \left( \frac{T_{2S} - T_1}{\eta_C} \right) \]  
(2)

Where \( \eta_C \) is the isentropic efficiency of the compressor

\[ W_C = C_{pg} (T_2 - T_1) \]  
(3)

\[ T_{SS} = \frac{T_4}{\left( \frac{P_4}{P_3} \right)^{\frac{\gamma-1}{\gamma}}} \]  
(4)

\[ T_5 = T_4 - \eta_{PT} (T_4 - T_{SS}) \]  
(5)

\[ T_{4S} = T_3 - \left( \frac{T_3 - T_4}{\eta_T} \right) \]  
(6)

Where: \( \eta_T \) is the isentropic efficiency of the turbine.

\[ P_4 = \frac{P_3}{\left( \frac{T_3}{T_{4S}} \right)^{\frac{\gamma-1}{\gamma}}} \]  
(8)

The work developed by the power turbine is given by,

\[ W_{PT} = C_{pg} (T_4 - T_5) \]  
(9)

III. RESULTS AND DISCUSSIONS

The results and analysis are shown in table 1 and figures 3 to 6.

### Table 1: Table showing Variation in Power Turbine Entry Temperature (PTET) with other parameters

<table>
<thead>
<tr>
<th>PTET (K)</th>
<th>Power Turbine Efficiency (%)</th>
<th>Exergetic Efficiency (%)</th>
<th>Exergy Destruction (%)</th>
<th>Work Output (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>887.83</td>
<td>90.30</td>
<td>16.33</td>
<td>73.0</td>
<td>9.66</td>
</tr>
</tbody>
</table>
Fig 3: Effect of Power Turbine Entry Temperature to Power Turbine Efficiency

Fig 3 shows the graphical presentation of the effect of variation in power turbine entry temperature to power turbine efficiency. As the power turbine inlet temperature is reduced, there is a remarkable increase in the power turbine efficiency. It is clear from fig.3 that lowering the power turbine entry temperature there is gain in power turbine efficiency because of reduction in exergy loss. Table 1 shows that as the power turbine entry temperature reduces from 843.44K to 799.05K, the power turbine efficiency increases from 94.61% to 94.76% and the power output increases from 13.28MW to 15.58MW. Fig 5 shows the variation of power turbine entry temperature to the overall exergetic efficiency and exergy destruction rate. As the power turbine entry temperature reduces from 732.46K to 710.26K, there is increase in overall exergetic efficiency from 31.86% to 33.55%; also there is a reduction of exergy destruction from 63.22% to 61.96% as shown in fig 6.

![Power Turbine Efficiency Graph](image1)

![Exergetic Efficiency Graph](image2)

<table>
<thead>
<tr>
<th>Power Turbine Entry Temp. (K)</th>
<th>94.10</th>
<th>94.61</th>
<th>94.76</th>
<th>94.95</th>
<th>95.31</th>
<th>95.34</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Efficiency</td>
<td>72.51</td>
<td>70.06</td>
<td>67.24</td>
<td>65.87</td>
<td>63.22</td>
<td>61.96</td>
</tr>
<tr>
<td>Power Output (MW)</td>
<td>20.25</td>
<td>22.45</td>
<td>26.23</td>
<td>28.18</td>
<td>31.86</td>
<td>33.55</td>
</tr>
</tbody>
</table>

Table 1: Power Turbine Efficiency and Power Output

![Power Output Graph](image3)

![Exergetic Efficiency Graph](image4)

Fig 4: Effect of Power Turbine Entry Temperature to Power Output

Fig 5: Effect of Power Turbine Entry Temperature to Exergetic Efficiency
The study shows that the power turbine entry efficiency is affected by variation in the power turbine entry temperature; that at lower power turbine entry temperature, there is increase in the in power turbine efficiency and power output. Also there is decrease in exergy loses in the power turbine and exhaust at lower power turbine inlet temperatures.

IV. CONCLUSION

The power turbine efficiency depends on the power turbine inlet temperature. As the gas turbine operates to its highest rated capacity there is improvement in the power turbine efficiency at lower temperatures. The power output and overall exergetic efficiency also increases with decrease in power turbine inlet temperature. The irreversibility rate in the power turbine and exhaust are reduced at lower power turbine entry temperatures. The results show that operating a gas turbine power plant at lower power turbine entry temperatures as the system approaches its rated capacity gives better performance.

REFERENCES


