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# Performance analysis of two combined cycle power plants with different steam injection system design

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ABSTRACT

A thermal analysis of two combined cycle power plants is performed. The steam injection system in the combustion chamber constitutes the main difference between the two designs. For the first power plant (design 1) the injected steam is generated in the HRSG. While for second power plant (design 2) this steam is provided using a heat recovery system installed at the compressor outlet. The steam turbine cycle engenders two pressure extraction levels connected to open feed-water heaters. The steam injection in the combustion chamber improves the overall combined cycle efficiency if this steam is generated outside the HRSG.

The increase of the ambient temperature affects the overall cycle efficiency.

The optimum thermal efficiency, for any temperature value during the year, may be obtained for suitable margin of steam injection ratio. The second design presents better overall efficiency then the first one. In winter season ($T_{am} = 15$ °C), the overall cycle efficiency is about 54.45% for a range of steam injection ratio within 11.8 and 14%. While in summer season ($T_{am} = 35$ °C) and for the same cycle efficiency, the required range of steam injection ratio is between 18.5 and 18.8%.



## Introduction

In our days the use of electrical energy around the world increases excessively and constitutes a key factor for the economy balance. To overcome this need, several research works are investigated in the purpose to optimize the existing power plant performances and to propose new cycle design more efficient and less pollutant.

Combined cycle power plant seems to be the most important way for electricity production using fossil fuel. In this context a national energy management program is conducted in Tunisia in the purpose to enhance the energy balance, improve the power plant efficiencies and reduce the costs of energy production.

In the frame of this program an optimization study is conducted in our research unit considering different combined cycle power plants. The main object of this study is to analyze the effect of the operating parameters on cycle performances.

Several research works are performed on the optimization of combined cycle performance. Among these works Basrawi

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**Nomenclature**

| | |
|---|---|
| ACSG | Air Cooling Steam Generator |
| Air | Humid air (kg/s) |
| f | Steam extracted flow(kg/s) |
| h | Enthalpy (kJ/kg) |
| HP | High pressure (bar) |
| HRSG | Heat Recovery Steam Generator |
| LHV | Lower Heating Value (kJ/kg) |
| LP | Low pressure (bar) |
| M | Mass flow (kg/s) |
| MP | Medium pressure (bar) |
| OFWH | Opened Feed Water Heater |
| P | Pressure (bar) |
| Q | Heat (kW) |
| R | Relative humidity (%) |
| Rapport | Compression ratio |
| Steam | Steam water (kg/s) |
| T | Temperature (K) |
| TIT | Turbine Inlet Temperature |
| W | Heat (kW) |

*Greek letters*

| | |
|---|---|
| $\eta$ | Efficiency (%) |

*Subscripts*

| | |
|---|---|
| air | air |
| amb | ambient |
| CC | combined cycle |
| comb | combustion |
| comp | compression |
| eco | economizer |
| evap | evaporator |
| excess | air excess |
| fuel | combustible |
| GC | gas cycle |
| GT | gas turbine |
| is | isentropic |
| pump | pump |
| sat | saturation |
| SC | steam cycle |
| sea | sea water |
| steam | steam |
| steam inj | steam for injection |
| ST | steam turbine |
| sup | superheated |
| 18 | first steam extraction |
| 19 | second steam extraction |

et al. [1] have conducted a study of the combined cycle performance improvement considering different variation ranges of the operating conditions.

AlRafea et al. [2] studied an 'Energy Hub' as one of the new ideas for connecting fossil and sustainable energy sources in a centralized unit. An energy hub is a system where multiple energy sources can be converted, conditioned, and stored in a synergistic fashion. It represents an interface between different energy infrastructures and/or loads. And it use wind, solar and fossil fuel in the same combined cycle power plant. Hydrogen production cost is found to be an average of \$4.10 per kg representing an extra cost while reducing $CO_2$ and NOx emissions by about 2%.

Sanchez et al. [3], presents a performance analysis of a combined cycles power plants burning a number of syngas fuels. The effect of gas composition on the rated performance of the plant gives two main conclusions. First, higher pressure ratio and lower firing temperature are found at turbine inlet. Second, the pressure at which fuel is supplied to the gas turbine plays an essential role in the power capacity of the engine.

Lee et al. [4] describes the gas turbine combustion characteristics of coal-derived synthetic gas (syngas), particularly for the syngases at the Taean IGCC plant in Korea and the Buggenum IGCC plant in the Netherlands. They evaluate the combustion performance of these syngases, by conducting a combustion tests with elevated temperature and ambient pressure in a GE7EA model combustor. As a result they observed flame stability, dynamic pressure characteristics, NOx and CO emissions, temperature in the combustion chamber, and flame structures while varying the heat input and diluents integration ratio. All the tested results and conclusions drawn are considered for optimal operation and trouble shooting at the Taean IGCC plant, which is scheduled to be complete toward the end of 2016.

Haseli et al. [5] examines the performance of a high-temperature solid oxide fuel cell combined with a conventional recuperative gas turbine (GT–SOFC) plant. Individual models are developed for each component. The overall system performance is then analyzed by employing individual models and further applying thermodynamic laws for the entire cycle, to evaluate the thermal efficiency and entropy production of the plant.

The results of an assessment of the cycle for certain operating conditions are compared against those available in the literature. The comparisons provide useful verification of the thermodynamic simulations in the present work. The thermal efficiency of the integrated cycle becomes as high as 60.6% at the optimum compression ratio.

Chi et al. [6] studied the thermodynamic performance of integrated gasification combined cycle (IGCC) systems with $Na_2CO_3$eMgO-based warm gas decarbonation (WGDC) and CaO based hot gas decarbonation (HGDC), evaluated and compared with that of an IGCC system with methyldiethanolamine (MDEA)-based cold gas decarbonation (CGDC). The net efficiency of the system is increased by improving the $CO_2$ capture capacity of the sorbent. The IGCC with $Na_2CO_3$ eMgO experiences more significant increase in efficiency than that with CaO along with the improvement of sorbent average $CO_2$ capture capacity. The efficiency of the IGCC systems reaches the same value when the average $CO_2$ capture capacities of both sorbents are 53% of their theoretical levels. The effects of gas turbine combustor fuel gas inlet temperature on IGCC system performance are analyzed. Results show that the efficiency of the IGCC systems with HGDC and WGDC increases by 0.74% and 0.53% respectively as the fuel gas inlet temperature increases from 250 °C to 650 °C.

De Paepe et al. [7] studied the effect of the steam injection in the combustion chamber on the overall cycle performance. A special attention is given to the blade cooling process. The obtained results show that the steam injection leads to higher efficiency and specific power.

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