Thermodynamic Analysis of Rankine and Brayton Power Cycles

1. Introduction

Thermodynamic power cycles play a crucial role in modern energy conversion systems. Among them, the Rankine cycle is widely used in steam power plants, while the Brayton cycle forms the basis of gas turbine engines. This report presents a computational analysis of both cycles using MATLAB, focusing on ideal and non-ideal performance, energy conversion characteristics, and the influence of operating parameters such as pressure ratio and component efficiencies.

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2. Rankine Cycle Analysis

2.1 Modeling Assumptions

The Rankine cycle was modeled under the following assumptions:

- Steady-state, steady-flow operation
- Negligible kinetic and potential energy effects
- Water–steam as the working fluid
- Saturated liquid at condenser outlet
- Superheated vapor at boiler exit
- Isentropic pump and turbine for the ideal cycle
- Realistic efficiencies applied for the non-ideal cycle

The condenser pressure was fixed at 10 kPa and the boiler pressure at 15 MPa.

2.2 Ideal Rankine Cycle Performance

Using thermodynamic property data, the ideal Rankine cycle produced the following results:

- Turbine work: **1110.00 kJ/kg**
- Pump work: **15.14 kJ/kg**
- Net work output: **1094.86 kJ/kg**
- Heat added: **3303.06 kJ/kg**
- Thermal efficiency: **0.331**
- Back work ratio: **0.0136**

The low back work ratio indicates that only a small fraction of turbine output is required to drive the pump, which is characteristic of vapor power cycles. The thermal efficiency lies within the expected range for a simple Rankine cycle without regeneration or reheating.

2.3 Real Rankine Cycle Performance

To account for irreversibilities, turbine and pump isentropic efficiencies of 0.85 and 0.80 were introduced, respectively. Under these conditions:

- Net work output reduced to **924.58 kJ/kg**
- Thermal efficiency decreased to **0.280**

The reduction in performance highlights the impact of frictional losses and irreversibility in real systems. This emphasizes the importance of accounting for non-ideal effects in practical power plant analysis.

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3. Brayton Cycle Analysis

3.1 Modeling Assumptions

The Brayton cycle was analyzed assuming:

- Ideal gas behavior for air
- Steady-state operation
- Constant and temperature-dependent specific heats
- No pressure losses in the combustion chamber

The turbine inlet temperature was set to 1400 K, and the compressor pressure ratio was selected as 10 for baseline analysis.

3.2 Brayton Cycle Performance

The computed results for the Brayton cycle are summarized below:

- Compressor work: **333,876 J/kg**
- Turbine work: **641,581 J/kg**
- Net work output: **307,705 J/kg**
- Heat added: **826,623 J/kg**
- Thermal efficiency: **0.372**

- Work ratio: **0.4796**

The work ratio indicates that approximately 48% of the turbine work is available as useful output, while the remaining portion is consumed by the compressor. This highlights the strong dependence of Brayton cycle performance on compressor efficiency.

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4. Effect of Pressure Ratio

A parametric study was performed by varying the compressor pressure ratio from 2 to 20. The results showed that:

- Net work output initially increases with pressure ratio due to improved turbine expansion.
- Beyond an optimal pressure ratio, the increasing compressor work reduces net output.
- Thermal efficiency increases with pressure ratio but approaches an asymptotic limit.

This behavior demonstrates the trade-off between work output and efficiency in gas turbine operation.

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5. Effect of Altitude on Brayton Cycle Performance

Altitude effects were modeled as a reduction in inlet pressure. Lower ambient pressure decreases air density and mass flow rate, resulting in reduced power output. Although thermal efficiency may remain relatively unchanged, the reduction in mass flow significantly impacts the available shaft power. This explains the performance degradation of gas turbines operating at high altitudes.

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6. Conclusion

This study successfully modeled both Rankine and Brayton power cycles under ideal and non-ideal conditions. The Rankine cycle exhibited high efficiency with minimal pump work, while the Brayton cycle demonstrated strong sensitivity to pressure ratio and component efficiencies. Incorporating realistic losses provided more accurate predictions of actual plant performance. The developed models serve as effective tools for analyzing and understanding thermodynamic power systems.
