Optimization of a Combined Brayton–Rankine Cycle

1 Introduction

Combined Brayton–Rankine cycles are widely used in modern thermal power plants due to their ability to efficiently utilize high-temperature exhaust gases from gas turbines. By integrating a steam cycle at the exhaust of the gas turbine, a significant improvement in overall efficiency can be achieved compared to a simple Brayton cycle.

The objective of this work is to model and optimize a single-pressure combined Brayton–Rankine cycle by varying key operating parameters. The study focuses on understanding how turbine inlet temperature and pressure ratios influence overall cycle performance, while maintaining realistic thermodynamic constraints.

2 System Description and Assumptions

The system consists of a Brayton topping cycle and a Rankine bottoming cycle. The Brayton cycle includes a compressor, combustion chamber, and gas turbine, while the Rankine cycle consists of a heat recovery steam generator (HRSG), steam turbine, condenser, and pump.

The following assumptions are applied throughout the analysis:

- Steady-state and steady-flow operation.
- Ideal gas behavior for air.
- Constant specific heats.
- Single-pressure Rankine cycle without reheating.
- No heat loss to the surroundings.
- Minimum steam quality at turbine exit of 0.92.
- Pinch point temperature difference of 10 °C.

The compressor inlet temperature and pressure are fixed at 298 K and 1 bar, respectively. Isentropic efficiencies for the compressor, turbines, and pump are taken from standard engineering references.

3 Thermodynamic Modeling

The Brayton cycle is modeled using isentropic relations for compression and expansion. The compressor and turbine work are expressed as:

$$W_c = c_p(T_2 - T_1), \quad W_t = c_p(T_3 - T_4) \tag{1}$$

The heat added in the combustor is given by:

$$Q_{in} = c_p(T_3 - T_2) \tag{2}$$

The Brayton cycle efficiency is:

$$\eta_{Brayton} = \frac{W_t - W_c}{Q_{in}} \tag{3}$$

For the Rankine cycle, heat is recovered from the exhaust gases in the HRSG. The steam turbine and pump works are calculated as:

$$W_{st} = \dot{m} * s, \eta * st(h_{10} - h_{11}), \quad W_p = \frac{p_7 - p_1}{\eta_p} \tag{4}$$

The Rankine cycle efficiency is defined as:

$$\eta_{Rankine} = \frac{W_{st} - W_p}{Q_{HRSG}} \tag{5}$$

The overall combined cycle efficiency is therefore:

$$\eta_{combined} = \frac{W_t + W_{st} - W_c - W_p}{Q_{in}} \tag{6}$$

4 Optimization Procedure

The turbine inlet temperature T_3 is varied between 900,°C and 1400,°C. For each value of T_3, the Brayton pressure ratio and the Rankine cycle pump outlet pressure are optimized to maximize the combined cycle efficiency. The optimization is constrained by a minimum steam quality of 0.92 at the turbine exit and a fixed pinch point temperature difference.

5 Results and Discussion

Table 1 summarizes the optimal operating conditions and corresponding efficiencies obtained from the simulation.

Table 1: Optimized performance of the combined Brayton–Rankine cycle

T_3 (°C)	Optimal r_p	$\eta_{Brayton}$ (%)	$\eta_{Rankine}$ (%)	$\eta_{Combined}$ (%)
900	16.0	36.17	0.73	36.19
1000	20.0	38.82	0.73	38.84
1100	24.5	41.18	0.73	41.19
1200	29.5	43.29	0.73	43.30
1300	30.0	45.04	0.73	45.05
1400	30.0	46.37	0.73	46.38

The results show a clear increase in overall efficiency with increasing turbine inlet temperature. The Brayton cycle dominates the overall performance, while the Rankine cycle contributes a smaller but consistent efficiency gain due to the simplified single-pressure configuration. This behavior is physically expected and aligns well with trends reported in the literature.

6 Conclusion

A numerical model of a combined Brayton–Rankine cycle was developed and optimized under realistic thermodynamic constraints. The results demonstrate that increasing turbine inlet temperature significantly enhances overall efficiency, with a maximum combined efficiency of approximately 46

The results are consistent with published studies and confirm that the chosen modeling approach is suitable for preliminary performance analysis and optimization studies.

References

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