DESIGN AND SIMULATION OF HRSG WITH COMBINED BRAYTON–RANKINE CYCLE

Assignment 2

Theory of Rankine and Brayton Cycles

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1 Introduction

Thermodynamic power cycles play a vital role in the conversion of energy from one form to another, particularly in converting heat energy into useful mechanical work. Almost all large-scale power generation systems operate on the principles of thermodynamics, where heat supplied from a fuel source, nuclear reactions, or renewable inputs is converted into work and finally into electrical energy. The performance, efficiency, and feasibility of power plants largely depend on the choice of the thermodynamic cycle and the way energy interactions are managed within the system. Therefore, the study of thermodynamic power cycles is essential for understanding modern energy conversion technologies and improving their efficiency.

Two of the most widely used power cycles in engineering applications are the Rankine cycle and the Brayton cycle. These cycles differ mainly in their working fluids, operating conditions, and practical applications:

- **Rankine Cycle:**
  - The Rankine cycle is primarily used in steam power plants for electricity generation.
  - Water is used as the working fluid, and the cycle involves phase change between liquid and vapor.
  - Heat is added to the working fluid in a boiler, and work is produced by expanding steam through a turbine.
  - This cycle is commonly employed in coal-fired, nuclear, and thermal power stations.
- **Brayton Cycle:**
  - The Brayton cycle is the ideal cycle for gas turbine power plants and jet propulsion systems.
  - Air or combustion gases act as the working fluid and remain in the gaseous phase throughout the cycle.
  - Heat addition takes place at constant pressure in a combustion chamber.
  - This cycle is widely used in gas turbine power generation and aircraft engines.

2 Rankine Cycle

2.1 Ideal Rankine Cycle

The Rankine cycle is the idealized thermodynamic cycle that describes the operation of steam power plants. Water is used as the working fluid and undergoes phase changes during the cycle. The ideal Rankine cycle assumes internally reversible processes and negligible heat losses.

2.2 Basic Processes

The ideal Rankine cycle consists of four basic processes:

- **Process 1–2 (Pump):** Isentropic compression of saturated liquid water from condenser pressure to boiler pressure.

- **Process 2–3 (Boiler):** Constant pressure heat addition, where water is converted into superheated steam.
- **Process 3–4 (Turbine):** Isentropic expansion of steam through the turbine, producing mechanical work.
- **Process 4–1 (Condenser):** Constant pressure heat rejection, where steam condenses back into saturated liquid.

2.3 Major Components

The major components of a Rankine cycle power plant are:

- Boiler
- Steam turbine
- Condenser
- Feedwater pump

2.4 T–s Diagram of Rankine Cycle

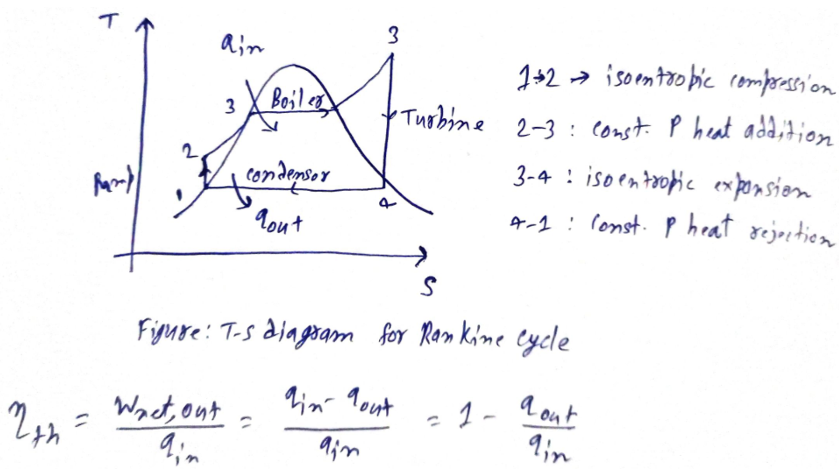

Figure 1: Temperature–Entropy diagram of the ideal Rankine cycle

2.5 Thermal Efficiency

The thermal efficiency of the Rankine cycle is defined as:

$$\eta_{th} = \frac{W_{turbine} - W_{pump}}{Q_{boiler}}$$

It represents the fraction of heat added in the boiler that is converted into useful work.

3 Brayton Cycle

3.1 Ideal Brayton Cycle

The Brayton cycle is the ideal cycle for gas turbine power plants. Air is commonly used as the working fluid, and the combustion process occurs at constant pressure. Unlike the Rankine cycle, the Brayton cycle does not involve phase change.

3.2 Basic Processes

The ideal Brayton cycle consists of four processes:

- **Process 1–2 (Compressor):** Isentropic compression of air.
- **Process 2–3 (Combustion):** Constant pressure heat addition.
- **Process 3–4 (Turbine):** Isentropic expansion producing work.
- **Process 4–1 (Heat Rejection):** Constant pressure heat rejection.

3.3 Major Components

The major components of a Brayton cycle system are:

- Compressor
- Combustion chamber
- Gas turbine

3.4 T–s Diagram of Brayton Cycle

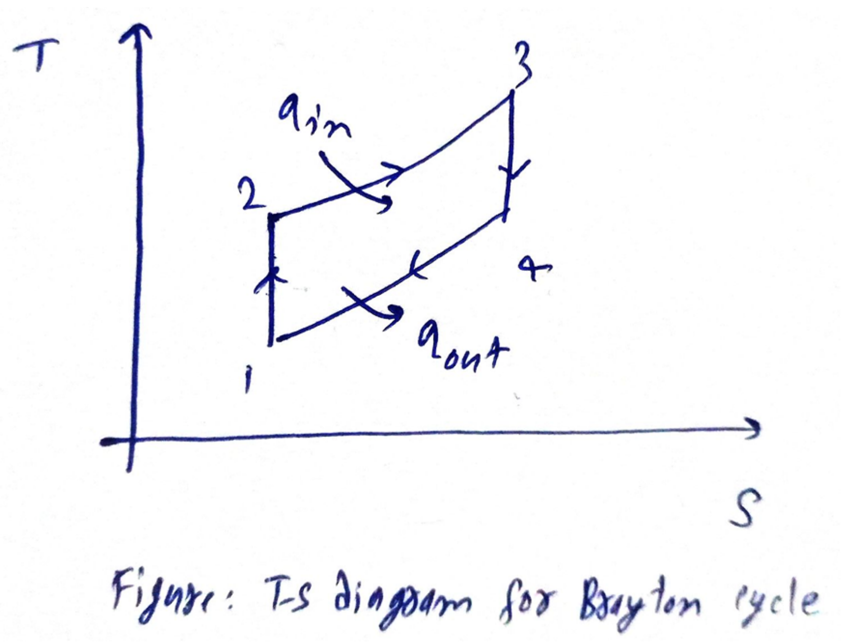

Figure 2: Temperature–Entropy diagram of the ideal Brayton cycle

3.5 Thermal Efficiency

The thermal efficiency of an ideal Brayton cycle is given by:

$$\eta_{th} = 1 - \frac{1}{r_p^{(\gamma-1)/\gamma}}$$

where r_p is the pressure ratio and γ is the ratio of specific heats.

4 Comparison of Rankine and Brayton Cycles

Feature	**Rankine Cycle**	**Brayton Cycle**
Working fluid	Water/Steam	Air/Gas
Phase change	Yes	No
Heat addition	Boiler	Combustion chamber
Typical use	Steam power plants	Gas turbines, jet engines

5 Conclusion

The Rankine and Brayton cycles are fundamental thermodynamic cycles that underpin modern power generation technologies. The Rankine cycle is best suited for large-scale steam power plants, while the Brayton cycle is ideal for gas turbine and aviation applications. A clear understanding of these cycles provides essential insight into energy conversion efficiency and thermal system design.

References

[1] Y. A. Cengel and M. A. Boles, *Thermodynamics: An Engineering Approach*, McGraw-Hill Education.

[2] M. J. Moran and H. N. Shapiro, *Fundamentals of Engineering Thermodynamics*, Wiley.