

# Assignment 2

## Theory of Rankine and Brayton Cycles

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## 1 Introduction

### 1.1 Importance of thermodynamic power cycles in energy conversion

In modern energy systems, thermodynamic power cycles hold a lot of importance. Most of the electricity we use daily, is produced by converting heat energy into useful work. This conversion of energy from one form to the other is done using these power cycles. These cycles provide a way to extract maximum useful energy from fuels such as coal, natural gas, nuclear fuel, etc.. Because of these thermodynamic power cycles, it is possible to produce power at a large-scale. They also help us increase the efficiency of power plants, reduce fuel consumption, minimize energy losses, while being able to generate maximum power output. Since, energy demand is increasing continuously, these power cycle become an even more essential part of our lives.

### 1.2 Brief overview of Rankine and Brayton cycles

The Rankine and Brayton cycles are two of the most widely used power cycles among all the power cycles we study.

The Rankine cycle is the ideal cycle for vapor power cycles. In the case of vapor power cycles, the working fluid is alternately vaporized and condensed. In Rankine cycle, water is heated to form steam, which then expands through a turbine to produce work. After that, the steam is condensed back into water and reused, and hence, it a closed cycle.

The Brayton cycle, on the other hand, is the ideal cycle for modern gas turbine engines. In the case of gas power cycles, the working fluid remains a gas throughout. In Brayton cycle, air or gas is the working fluid. Air is first compressed, followed by heating with fuel combustion, and then expanded in a turbine to generate power. Theoretically, Brayton cycle is a closed cycle but for our understanding we consider it to be an open cycle.

## 2 Rankine Cycle

### 2.1 Description and Processes

Rankine cycle is the ideal cycle for vapor power cycles. In this cycle, the working fluid is water which is alternately vaporized and condensed from water to steam and then again to water.

The ideal Rankine cycle does not involve any internal irreversibilities and consists of the following four processes:

- 1-2 Isentropic compression in a pump
- 2-3 Constant-pressure heat addition in a boiler
- 3-4 Isentropic expansion in a turbine
- 4-1 Constant-pressure heat rejection in a condenser

**1-2 Isentropic compression in a pump :** Water enters the pump at state 1 at low pressure and is compressed to a higher pressure isentropically. The input work required by the pump here is small because water is in liquid form.

**2-3 Constant-pressure heat addition in a boiler :** Water now enters the boiler at state 2, it is heated in the boiler and leaves the boiler as superheated vapor at state 3. Here we consider the boiler as a large heat exchanger where heat input from combustion gases is used to heat water at a constant pressure.

**3-4 Isentropic expansion in a turbine :** Superheated vapor at state 3 enters the turbine, where it expands isentropically. Here, work is produced by rotating the shaft connected to electric generator. This steam now goes to state 4 after its pressure and temperature reduces.

**4-1 Constant-pressure heat rejection in a condenser :** At state 4, it is a saturated liquid-vapor mixture with a very high quality. This steam now enters the condenser which is a large heat exchanger. Here, steam is condensed by rejecting heat to a cooling medium like a river or atmosphere. Steam leaves the condenser as saturated liquid water and enter the pump. In this way, the cycle is completed.

The Rankine cycle is made of 4 major components:

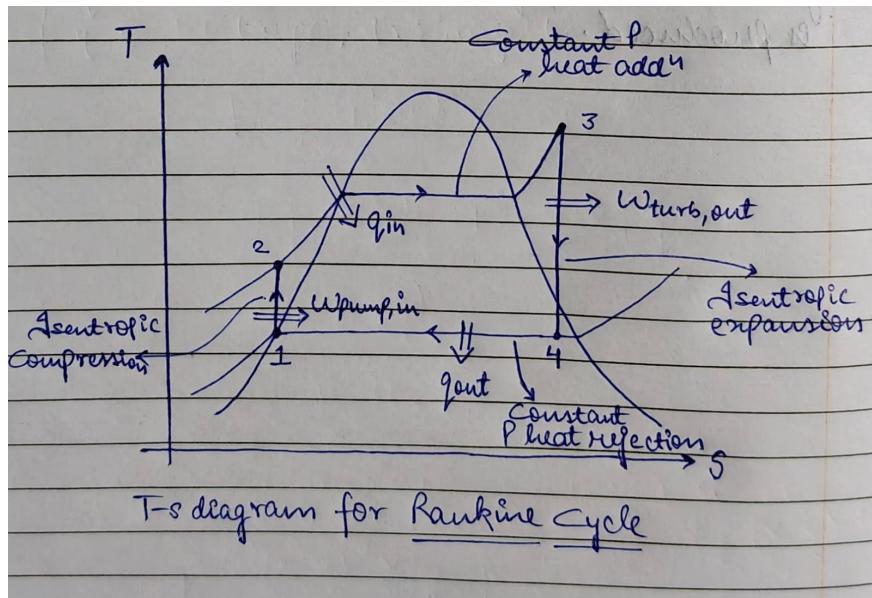
Pump: Increases the pressure of water

Boiler: Adds heat to convert water to steam

Turbine: Produces work from steam expansion

Condenser: Removes heat from steam and converts steam to water

## 2.2 Temperature-Entropy (T-s) diagram



## 2.3 Expression for Thermal Efficiency

The thermal efficiency of the Rankine cycle is determined from

$$\eta_{th} = \frac{\text{Net work output}}{\text{Heat added in boiler}} = \frac{w_{net}}{q_{in}} = 1 - \frac{q_{out}}{q_{in}}$$

where

$$w_{net} = q_{in} - q_{out} = w_{turb,out} - w_{pump,in}$$

## 3 Brayton Cycle

### 3.1 Description and Processes

Brayton cycle is the ideal cycle for gas turbine cycles. In this cycle, working fluid is air. Gas turbines usually operate on an open cycle but it can be modeled as a closed cycle. In the ideal Brayton cycle, all processes are assumed to be reversible, and combustion is represented as a heat-addition process at constant pressure.

- The ideal Brayton cycle is made up of four internally reversible processes:
- 1-2 Isentropic compression in a compressor
  - 2-3 Constant-pressure heat addition
  - 3-4 Isentropic expansion in a turbine
  - 4-1 Constant-pressure heat rejection

**1-2 Isentropic compression in a compressor** At state 1, we have fresh air at ambient conditions which is drawn into the compressor, where its pressure is raised. This also increases the temperature of air.

**2-3 Constant-pressure heat addition** The high pressure air at state 2 proceeds into the combustion chamber, where the fuel is burned at constant pressure. This process significantly increases the temperature of air.

**3-4 Isentropic expansion in a turbine** The high temperature gases at state 3 then enter the turbine, where they expand to the atmospheric pressure and this process produces power. When we consider it to be a closed process, this combustion process is replaced by a constant pressure heat addition process from an external source.

**4-1 Constant-pressure heat rejection** The exhaust gases at state 4 leaving the turbine are thrown out and not recirculated, so we classify the cycle to be an open cycle. But when we consider it as a closed cycle then this exhaust process is replaced by a constant pressure heat rejection process to the ambient air.

The Brayton cycle(closed) is made of 4 major components -

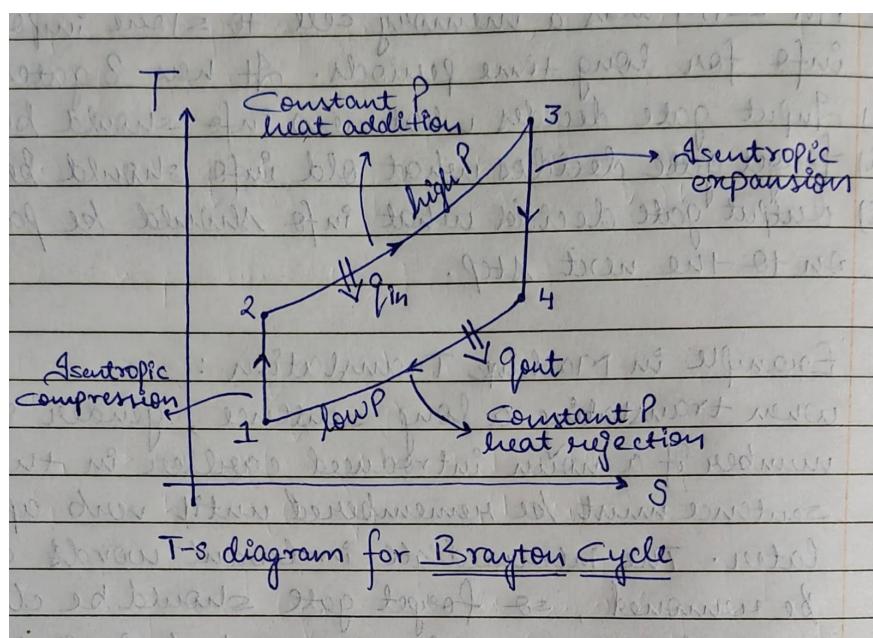
Compressor: Increases the pressure of incoming air

Heat Exchanger(a): Adds heat by burning fuel to increase temperature of air

Turbine: Produces work from gas expansion

Heat Exchanger(b): Removes heat from air(working fluid) to ambient air.

### 3.2 Temperature-Entropy (T-s) diagram



### 3.3 Expression for Thermal Efficiency

The thermal efficiency of the ideal Brayton cycle is expressed as -

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

where

$$r_p \text{ (pressure ratio)} = \frac{P_2}{P_1} \text{ and } \gamma \text{ is the specific heat ratio}$$

## 4 Comparison

### 4.1 Key differences between Rankine and Brayton cycles

Aspect	Rankine Cycle	Brayton Cycle
Working fluid	Rankine cycle uses water and steam alternately	The Brayton cycle uses air as the working fluid
Main Components	Rankine cycle uses a boiler, turbine, condenser, and pump	Brayton cycle uses a compressor, combustion chamber, and turbine
Nature of cycle	Rankine cycle is a closed cycle	Brayton cycle is usually open in real applications although we consider it to be a closed system to study
Phase change	In Rankine cycle, the working fluid i.e. water changes phase from water to steam and back to water	In Brayton cycle, there is no phase change, the fluid i.e. air remains in the gaseous state at all times

Table 1: Comparison between Rankine Cycle and Brayton Cycle

### 4.2 Typical Applications of each cycle

**Rankine Cycle :** Rankine cycle is used in steam power plants, coal based, nuclear, and thermal power stations.

**Brayton Cycle :** Brayton Cycle is used in gas turbine power plants, jet engines, and aircraft propulsion systems.

## 5 Conclusion

By studying the Rankine and Brayton cycles, we get to know how heat energy is converted into useful power in different systems. The Rankine cycle helps us understand how steam power plants work, where water is heated, converted into steam, and reused again and again in a closed system. It shows the role of components like the boiler, turbine, condenser, and pump in power generation. The Brayton cycle explains the working of gas turbines, where air is compressed, heated by burning fuel, and expanded to produce power. There is no phase change in this cycle. Learning both cycles makes it clear why different power plants use different methods to generate electricity. Overall, after studying these cycles, we are able to build a strong basic understanding of thermal power systems and energy conversion.

### References:

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