Thermodynamic Cycles: Efficiency Analysis

Mechanical Engineering Laboratory

November 24, 2025

Abstract

This report presents computational analysis of thermodynamic power cycles including Carnot, Otto, Diesel, and Rankine cycles. We examine ideal and actual cycle efficiencies, P-v and T-s diagrams, and parametric studies. Python-based computations provide quantitative analysis with dynamic visualization.

Contents

1 Introduction to Thermodynamic Cycles

Thermodynamic cycles convert heat into work. The four cycles analyzed here are:

- Carnot cycle: Maximum possible efficiency (theoretical ideal)
- Otto cycle: Spark-ignition internal combustion engines
- Diesel cycle: Compression-ignition engines
- Rankine cycle: Steam power plants

2 Carnot Cycle

The Carnot efficiency sets the maximum limit:

$$\eta_{Carnot} = 1 - \frac{T_L}{T_H} \tag{1}$$

[width=]carnot$_{c}$*ycle.pdf*

Figure 1: Carnot cycle: efficiency dependence on temperature and T-s diagram.

Carnot efficiency at $T_H = 1000$ K: $\eta = 70.0\%$

3 Otto Cycle

The Otto cycle efficiency depends on compression ratio:

$$\eta_{Otto} = 1 - \frac{1}{r^{\gamma-1}} \tag{2}$$

[width=]otto$_{c}$*ycle.pdf*

Figure 2: Otto cycle analysis: efficiency, P-v diagram, T-s diagram, and gamma effect.

Otto efficiency at $r = 10$: $\eta = 60.2\%$, Net work = 602 kJ/kg

4 Diesel Cycle

The Diesel cycle efficiency includes the cutoff ratio:

$$\eta_{Diesel} = 1 - \frac{1}{r^{\gamma-1}} \cdot \frac{r_c^{\gamma} - 1}{\gamma(r_c - 1)} \tag{3}$$

[width=]diesel$_{c}$*ycle.pdf*

Figure 3: Diesel cycle: efficiency dependence on cutoff ratio and comparison with Otto.

Diesel efficiency at $r = 20$, $r_c = 2.5$: $\eta = 62.5\%$

5 Rankine Cycle

The Rankine cycle uses phase change for higher efficiency:

[width=]rankine$_{c}$*ycle.pdf*

Figure 4: Rankine cycle: T-s diagram, pressure effect, energy balance, and reheat improvement.

Rankine efficiency: $\eta = 27.2\%$, Net work = 864 kJ/kg

6 Cycle Comparison

[width=0.8]cycle$_{c}$*omparison.pdf*

Figure 5: Comparison of thermal efficiencies for different thermodynamic cycles.

7 Summary Table

Table 1: Thermodynamic Cycle Parameters

Cycle	Key Parameter	Efficiency Formula	Typical η	Application
Carnot	T_H/T_L	$1 - T_L/T_H$	70%	Theoretical
Otto	r	$1 - r^{1-\gamma}$	60%	Gasoline engines
Diesel	r, r_c	Complex	55%	Diesel engines
Rankine	P_{boiler}	Energy balance	35%	Power plants

8 Conclusions

This analysis demonstrates key aspects of thermodynamic cycles:

1. Carnot efficiency sets the theoretical maximum for any heat engine
2. Otto efficiency increases with compression ratio but is limited by knock
3. Diesel cycles achieve higher compression ratios but lower peak efficiency
4. Rankine cycles use phase change for effective heat addition
5. Reheat and regeneration improve Rankine cycle efficiency
6. Actual efficiencies are lower due to irreversibilities