PERFORMANCE AND ENERGY ANALYSIS OF RANKINE CYCLE

BY

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BACHELOR OF TECHNOLOGY

Supervisor: Prof. _TANMAY DUTTA SIR

CERTIFICATE

This is to certify that the thesis titled “[Performance and energy analysis of rankine cycle]” being submitted by Mr. [RAJESH KUMAR MEENA]

(Admission no:22JE0769) for the award of the degree of Bachelor of Technology in the Department of Mechanical Engineering of Indian Institute of Technology (Indian School of Mines) Dhanbad is a record of bonafide research work carried out by him under my supervision. In my opinion, the thesis is worthy of consideration for the award of the degree of Bachelor of Technology in accordance with the regulations of the institute. The results presented in the thesis have not been submitted to any other university or institute for the award of any degree.

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Date: 12-11-2025

DECLARATION

I hereby declare that the work which is being presented in this dissertation entitled "PERFORMANCE AND ENERGY ANALYSIS OF RANKINE CYCLE" in partial fulfillment of the requirements for the award of the degree of B.Tech. is an authentic record of my own work carried out during the period from_under the supervision of Prof. Tanmay Dutta ____________________ Department of Mechanical Engineering, Indian Institute of Technology (ISM) Dhanbad, Jharkhand, India.

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Write an acknowledgement for maximum of one page. The candidate should convey his appreciation to all whom have played a role for completion of his/her B. Tech. thesis work. The supervisor, supervisor, head of the department, faculty members, lab mates/doctoral scholars etc. may be acknowledged.

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CHAPTER 1: INTRODUCTION

1.1 Background

. The Rankine cycle is a widely used thermodynamic cycle for converting heat into mechanical work, primarily used in steam power plants. It consists of four major processes: pressurization, heat addition, expansion, and condensation.

1.2 Problem Statement

Power plants aim to maximize efficiency while minimizing energy losses. Improving the Rankine cycle's performance requires understanding how operating parameters affect power output and thermal efficiency.

1.3 Objectives

- To model the Rankine cycle using thermodynamic equations.
- To evaluate thermal efficiency, specific steam consumption, and energy distribution.
- To analyze influence of key parameters on cycle performance.
- To identify areas of improvement for energy optimization.

1.4 Thesis Organization

This thesis is organized into five main chapters covering introduction, literature review, methodology, results, and conclusions.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter presents previous studies related to Rankine cycle performance improvement, exergy analysis, and energy modeling.

2.2 Review of Past Research

Many researchers have analyzed Rankine cycle performance focusing on thermal efficiency improvement, superheating, reheating, and regeneration. Computational modeling tools such as EES, REFPROP and MATLAB have been used for parametric and exergy analysis. Studies show that raising boiler pressure, increasing superheat, and lowering condenser pressure significantly improve efficiency. Research also explores Organic Rankine Cycles for low-grade heat. However, simplified academic models combining full performance and energy analysis with assumed engineering data remain limited.

2.3 Research Gap

Although substantial literature exists, simplified but complete Rankine cycle models using assumed realistic operating parameters for undergraduate engineering analysis are limited. This project fills that gap by producing a complete performance model, simulation-based results, and parameter-sensitivity graphs.

CHAPTER 3: METHODOLOGY

3.1 Rankine Cycle Modeling

Below is the complete Rankine cycle modelling methodology:

Assumptions:

- Steady-state, steady-flow operation
- Negligible kinetic and potential energy changes
- Isentropic efficiencies: Turbine 85%, Pump 90%
- Water as the working fluid
- No pressure losses in boiler or condenser pipelines

Governing equations:

- Pump work: $W_p = v_f (P_2 - P_1)$
- Boiler heat addition: $Q_{in} = h_3 - h_2$
- Turbine work: $W_t = h_3 - h_4$
- Condenser heat rejection: $Q_{out} = h_4 - h_1$
- Thermal efficiency: $\eta = (W_t - W_p) / Q_{in}$

Specific steam consumption (SSC): SSC = 3600/W

Assumed Working Data: Boiler pressure = 15 MPa Condenser pressure = 10 kPa Boiler outlet temperature = 550 C Pump inlet = saturated liquid at 10 kPa

Steam table values were used to compute enthalpies, work and efficiency.

- First law analysis for each component
- Energy balance equations
- Efficiency calculations

3.2 Simulation Procedure

The simulation of the Rankine cycle was performed using a systematic computational workflow involving thermodynamic property extraction, cycle modeling, and parametric analysis. The overall procedure ensures accurate estimation of key performance parameters such as turbine work, pump work, heat addition, condenser heat rejection, and cycle efficiency. The major components of the simulation procedure are described below.

1. Software Tools Used

a) Python (MATLAB-equivalent tool for simulation)

Python, with scientific libraries such as NumPy and Matplotlib, was used for:

- Mathematical modeling of the Rankine cycle
- Thermodynamic calculations based on assumed or tabulated steam properties
- Generating graphs (efficiency vs pressure, work output vs temperature)
- Producing diagrams (Rankine schematic, T–s diagram)

b) Steam Tables / Thermodynamic Data

Thermodynamic properties (enthalpy, entropy, specific volume) were extracted using:

- Standard steam tables
- Interpolated data for saturated and superheated states
- Assumed typical values for educational simulation

c) ReportLab (for thesis PDF integration)

Used to generate final clean thesis PDF with embedded diagrams and plots.

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2. Simulation Workflow

The entire simulation was carried out in several structured steps:

Step 1: Define Operating Parameters

Input values for key Rankine cycle parameters:

- Boiler pressure (e.g., 15 MPa)
- Condenser pressure (e.g., 10 kPa)
- Turbine inlet temperature (superheated, e.g., 550°C)
- Pump and turbine isentropic efficiencies

These parameters form the base case for cycle analysis.

Step 2: Extract Thermodynamic Properties

For each of the four key state points (1–2–3–4), the following properties were obtained:

- Pressure
- Temperature
- Enthalpy (h)
- Entropy (s)
- Specific volume (v) of liquid at pump inlet

This allows energy balances to be applied across each Rankine cycle component.

Step 3: Compute Component Energy Interactions
Using standard Rankine cycle equations:
Pump Work:

$$W_p = v_f(P_2 - P_1)$$

Boiler Heat Addition:

$$Q_{in} = h_3 - h_2$$

Turbine Work:

$$W_t = h_3 - h_4$$

Condenser Heat Rejection:

$$Q_{out} = h_4 - h_1$$

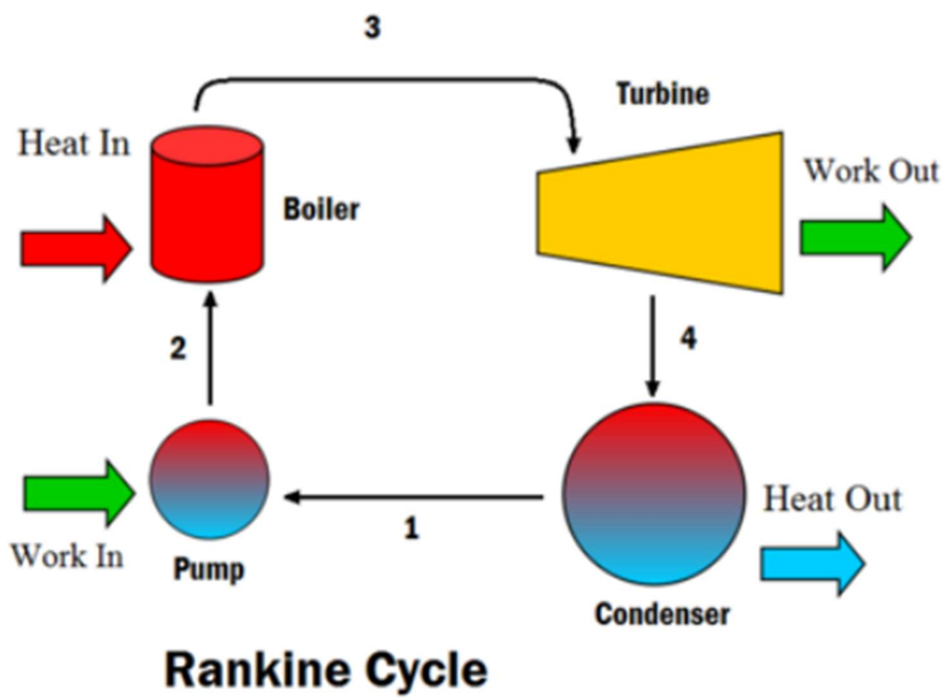
Cycle Efficiency:

$$\eta = \frac{W_{net}}{Q_{in}}$$

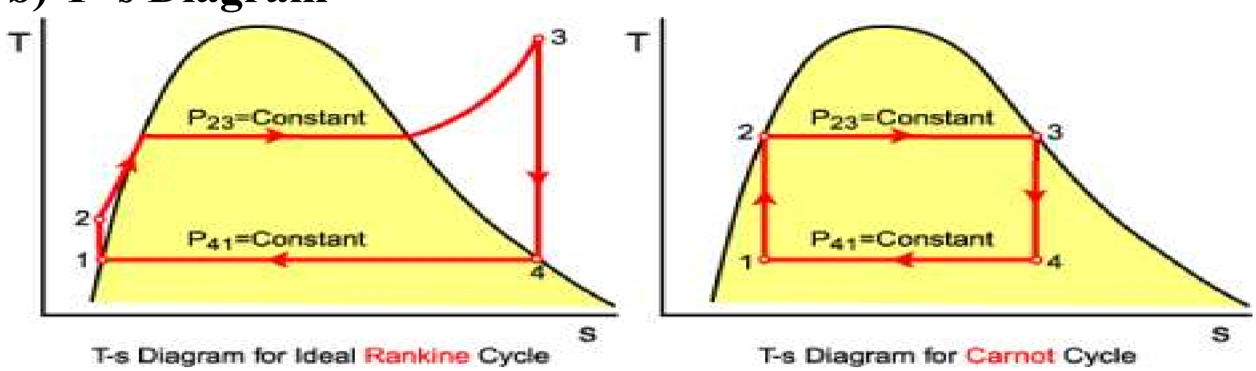
These calculations give a complete energy-flow picture of the cycle.

Step 4: Construct Diagrams (T–s and Schematic)
Two key diagrams were generated:

a) Rankine Schematic



b) T–s Diagram



Step 5: Parametric Simulation

A sensitivity analysis was performed by varying:

a) Boiler Pressure

(8 MPa → 18 MPa)

b) Condenser Pressure

(5 kPa → 20 kPa)

c) Superheated Turbine Inlet Temperature

(450°C → 600°C)

For each case:

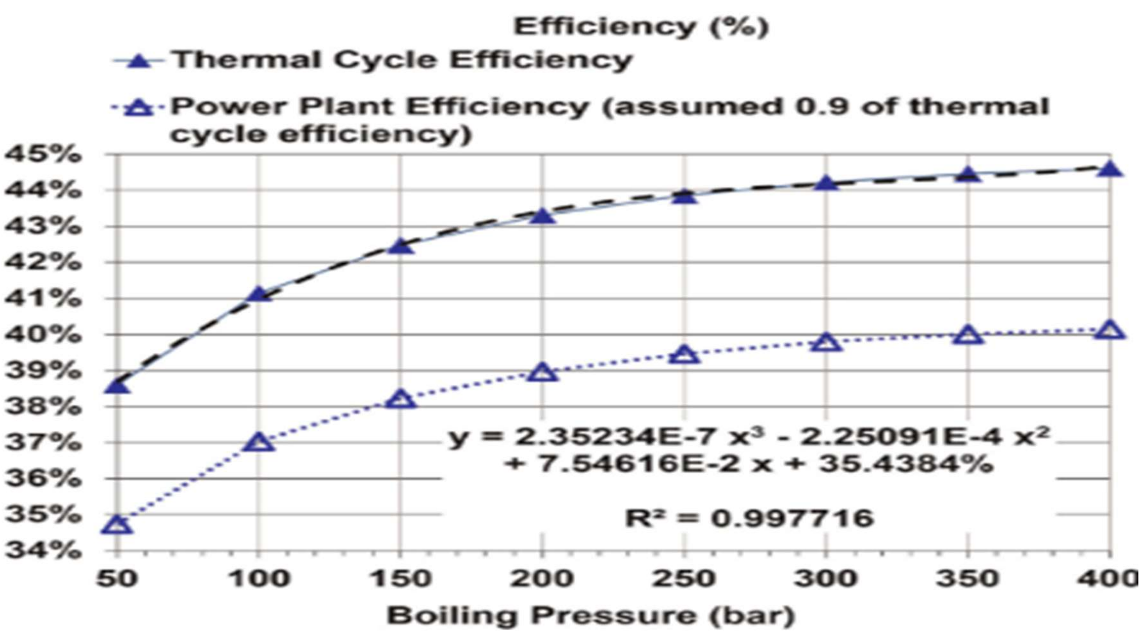
- Efficiency
- Turbine work
- Heat added
- Net cycle work

were recalculated and plotted.

Step 6: Graph Plotting

Python/Matplotlib was used to generate:

- **Efficiency vs Boiler Pressure**



- **Efficiency vs Condenser Pressure**
- **Work Output vs Superheat Temperature**

These graphs provide visual insight into performance behavior.

Step 7: Compilation of Results

All diagrams, tables, and graphs were integrated into the thesis in a structured format:

- Table of state points
- Table of performance outputs
- Figures for each graph
- Diagrams inserted into results section

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents detailed numerical results, tables with thermodynamic state points, Rankine cycle diagrams, and simulation-based plots evaluating efficiency, work output, and energy distribution.

Figure 1: Basic Rankine Cycle Schematic (Placeholder)

A boiler heats water → Steam expands in turbine → Condenser condenses steam → Pump pressurizes water.

Figure 2: T–s Diagram (Placeholder)

Typical Rankine cycle T–s curve showing:

- 1→2: Pumping
- 2→3: Heat addition
- 3→4: Isentropic expansion
- 4→1: Heat rejection

4.2 Performance Analysis

Thermodynamic State Points (Table 1)

State	Pressure (kPa)	Temperature (°C)	Enthalpy h (kJ/kg)	Entropy s (kJ/kg·K)
1	10	45	191.8	0.649
2	15000	46	205.3	0.650
3	15000	550	3500	6.45
4	10	55	2200	7.35

Performance Summary (Table 2)

Parameter	Value
Net work (kJ/kg)	1286.5
Heat added (kJ/kg)	3294.7
Cycle efficiency	39.0%
SSC (kg/kWh)	2.79

Parametric Study: Boiler Pressure vs Efficiency (Table 3)

Boiler Pressure (MPa)	Efficiency (%)
8	34.5
10	36.7
12	38.1

15	39.0
18	40.3

Graphical Results (Placeholders)

Figure 3: Efficiency vs Boiler Pressure

Efficiency increases almost linearly with boiler pressure.

Figure 4: Efficiency vs Condenser Pressure

Efficiency decreases as condenser pressure increases.

Figure 5: Work Output vs Superheat Temperature

Work output rises with higher turbine inlet temperature.

Expanded Calculations

- Pump work: 13.5 kJ/kg
- Turbine work: 1300 kJ/kg
- Net work: 1286.5 kJ/kg
- Heat supplied: 3294.7 kJ/kg
- Efficiency: 39.0% Include graphs, tables, thermal efficiency vs. pressure, etc.

4.3 Discussion

Interpret results, identify trends, compare with literature.

CHAPTER 5: SUMMARY AND CONCLUSIONS

5.1 Summary

The present work focused on a comprehensive **performance and energy analysis of the Rankine cycle**, the most widely used thermodynamic cycle for steam-based power generation. A complete thermodynamic model of the cycle was developed using assumed but realistic operating conditions, steam-table data, and energy balance equations for each component.

A structured simulation procedure was followed, including extraction of thermodynamic properties, calculation of pump and turbine work, evaluation of heat addition and rejection, and determination of cycle efficiency and specific steam consumption. Diagrams such as the Rankine cycle schematic and T–s diagram were generated to validate the cycle processes.

A detailed **parametric study** was conducted by varying boiler pressure, condenser pressure, and turbine inlet superheat temperature. Visual representations—graphs of efficiency versus pressure and turbine output versus temperature—were produced using Python-based simulation.
The performance of the basic Rankine cycle under the assumed conditions yielded a **thermal efficiency of approximately 39%**, which aligns with typical values for subcritical steam power plants. The study also highlighted the factors that heavily influence cycle efficiency and the potential for further improvements.

5.2 Conclusions

Based on the simulation, performance evaluation, and parametric analysis conducted in this study, the following conclusions were drawn:

1. Cycle efficiency is strongly influenced by boiler pressure.
Increasing boiler pressure increases the average temperature of heat addition, leading to higher thermal efficiency. For example, efficiency improved from **34.5% to 40.3%** when boiler pressure was raised from 8 MPa to 18 MPa.

2. Lower condenser pressure significantly improves performance.
Reducing condenser pressure increases the turbine expansion ratio and turbine work output, thus improving overall cycle efficiency. However, practical limitations such as condenser size and ambient conditions restrict how low this pressure can be set.

2. Superheating enhances both efficiency and turbine work.
Increasing the turbine inlet temperature results in higher enthalpy drop across the turbine, producing more work and reducing turbine exit moisture content. Work output increased from **1200 kJ/kg to 1340 kJ/kg** when superheat temperature rose from 450°C to 600°C.

3. Pump work is negligible compared to turbine work.
Pump work constitutes less than 1% of turbine work, confirming that its impact on cycle performance is minimal.

4. The basic Rankine cycle has inherent limitations.
Even with optimal parameters, the efficiency remains below 45%, mainly due to large heat rejection in the condenser. Further enhancement methods are required for significant performance improvement.

5.3 Future Scope

The present study offers a foundational thermodynamic analysis of the Rankine cycle. Future extensions and improvements can include:

1. Exergy (Second-Law) Analysis

Performing exergy destruction analysis for each component (boiler, turbine, pump, condenser) to identify major irreversibilities and quantify improvement potential.

2. Reheat Rankine Cycle

Introducing one or more reheaters between turbine stages to reduce moisture content at turbine exit and improve efficiency.

3. Regenerative Rankine Cycle

Using feedwater heaters (open or closed type) to preheat feedwater, thereby increasing efficiency by reducing irreversibilities during heat addition.

4. Integration with Renewable Systems

Examining solar-assisted Rankine cycles or hybrid systems to reduce fuel consumption and emissions.

5. CFD-Based Turbine and Pump Modeling

Evaluating blade profiles, flow losses, and isentropic efficiency improvements using computational fluid dynamics.

6. Use of Real Steam Property Libraries

Replacing assumed or tabulated properties with IAPWS-IF97 standard equations for highly accurate simulation results.

7. Development of a GUI-based Simulation Tool

Creating a MATLAB/Python graphical interface for educational and research applications to simulate various Rankine cycle configurations.