Thermodynamics -Curriculum

1.INTRODUCTION AND BASIC PRINCIPLES OF THERMODYNAMICS

1.1 Overview of Thermodynamics

- Thermodynamics is the study of energy, heat, and work in systems.
- It examines how energy changes form and impacts matter.
- Key principles include energy conservation and entropy.

1.2 Thermodynamic Systems

- A thermodynamic system is a defined region or quantity of matter under study.
- Systems are classified as open, closed, or isolated based on energy and matter exchange.
- Open systems exchange both energy and matter with their surroundings.
- Closed systems exchange only energy, while isolated systems exchange neither.

1.3 Thermodynamic Equilibrium

- Thermodynamic equilibrium occurs when a system's properties remain constant over time.
- There's no net flow of energy or matter within the system or with its surroundings.
- It includes thermal, mechanical, and chemical equilibrium.
- At equilibrium, the system's entropy is maximized.

1.4 Properties of Systems

- Volume, Process
- Temperature, Pressure
- Internal Energy, Gibbs Free Energy
- Enthalpy, Entropy
- Energy, Work and Heat

2.THE FIRST LAW OF THERMODYNAMICS

2.1 Introduction

- The first law of thermodynamics is the law of energy conservation.
- Energy cannot be created or destroyed, only transformed.
- The change in internal energy equals heat added minus work done by the system.
- It applies to all physical and chemical processes involving energy transfer.

2.2 The First Law of Thermodynamics Applied to a Cycle

- In a thermodynamic cycle, the total change in internal energy is zero.
- The heat added to the system equals the work done by the system.
- The energy entering the system as heat is completely converted into work.
- The first law ensures energy conservation throughout the cyclic process.

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2.3 The First Law of Thermodynamics Applied to a Process

- In a thermodynamic process, the change in internal energy equals heat added minus work done.
- Heat added to the system increases internal energy or does work on the surroundings.
- The first law governs energy flow during processes like heating, compression, or expansion.
- Energy conservation is maintained as heat input and work output balance the energy changes.

2.4 Enthalpy

- Enthalpy is the total heat content of a system, including internal energy and pressure-volume work.
- It is represented as $H = U + PV$, where U is internal energy, P is pressure, and V is volume.
- Enthalpy is useful for analyzing heat flow in processes occurring at constant pressure.
- Changes in enthalpy (ΔH) correspond to heat added or released in a system.

2.5 Latent Heat

- Latent heat is energy for phase changes without temperature change.
- It includes heat of fusion (melting) and vaporization (boiling).
- Key in processes like melting, freezing, and evaporation.
- Essential in weather phenomena like cloud formation.

2.6 Specific Heats

- Specific heat is the energy required to raise the temperature of a substance.
- It varies by material and is measured in J/kg · °C.
- Higher specific heat means more energy is needed for temperature change.
- Important in thermal energy calculations and climate studies.

3.THE SECOND LAW OF THERMODYNAMICS

3.1 Introduction

- The second law of thermodynamics states that entropy in an isolated system tends to increase.
- It implies that natural processes are irreversible and move toward disorder.
- Heat flows from hotter to colder bodies, not the other way around.
- This law sets limits on the efficiency of energy conversions.

3.2 Heat Engines, Heat Pumps and Refrigerators

Heat Engines

- Heat engines convert heat energy into mechanical work.
- They operate by transferring heat from a hot to a cold reservoir.
- The efficiency of a heat engine is limited by the second law of thermodynamics.
- Examples include steam engines and internal combustion engines.

Heat Pumps

- Heat pumps transfer heat from a cold to a hot reservoir.
- They require external work to operate, usually in the form of electricity.
- Heat pumps are used for heating or cooling spaces.
- They operate on the reverse cycle of a heat engine.

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Refrigerators

- Refrigerators transfer heat from a cold space to a warmer one.
- They use work (usually electrical energy) to remove heat from inside.
- Refrigerators maintain a low temperature by removing heat.
- They operate based on the refrigeration cycle.

3.3 Statements of the Second Law of Thermodynamics

Clausius Statement

- Heat can never spontaneously transfer from a colder object to a hotter one without external work.

Kelvin-Planck Statement

- It is impossible for any heat engine to convert all absorbed heat into work; some energy is always dissipated as waste heat.

Entropy Increase

- In an isolated system, the total entropy always increases over time, reflecting the irreversibility of natural processes.

Reversible Processes

- Only idealized, theoretical processes (involving no energy losses) are considered reversible, while all real processes are irreversible.

3.4 The Carnot Engine

Idealized Heat Engine

- The Carnot engine is a theoretical engine that operates on the Carnot cycle, which is the most efficient cycle for converting heat into work.

Two Heat Reservoirs

- It operates between two heat reservoirs—one at a high temperature (T1) and one at a low temperature (T2)—to transfer heat and perform work.

Reversible Process

- The Carnot engine operates in a completely reversible manner, meaning it does not produce any waste heat or entropy change, making it the most efficient engine possible.

Efficiency Formula

- The efficiency of a Carnot engine is given by the formula: $\eta=1-T1$

3.5 Carnot Efficiency

Maximum efficiency

- Carnot efficiency represents the theoretical maximum efficiency of a heat engine operating between two temperature reservoirs, and it sets an upper limit for all real engines.

Temperature-based

- The efficiency depends only on the temperatures of the hot (T1

Formula

- The Carnot efficiency is given by $\eta=1-T1$

Idealized Limit

- Carnot efficiency assumes a reversible, idealized process, meaning real engines will always have lower efficiency due to friction, heat loss, and other irreversibilities.

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4.ENTROPY

4.1 Introduction

- Entropy is a measure of disorder or randomness in a system.
- The second law of thermodynamics states that entropy tends to increase in isolated systems.
- Higher entropy indicates greater energy dispersal and less available energy for work.
- Entropy helps explain the direction and spontaneity of processes.

4.2 Entropy for an Ideal Gas with Constant Specific Heats

- Entropy change depends on temperature and volume changes.
- For ideal gases, entropy increases with increasing temperature or volume.
- Constant specific heats simplify entropy calculations.
- Entropy change formula: $\Delta S = C_v \ln(T_2/T_1) + R \ln(V_2/V_1)$.

4.3 Entropy for an Ideal Gas with Variable Specific Heats

- Entropy change depends on temperature, volume, and specific heat variation.
- Variable specific heats require integration for accurate entropy calculations.
- Entropy increases with rising temperature or expanding volume.
- Exact formula involves specific heat as a function of temperature.

4.4 Entropy for Substances Such as Steam Solids and Liquids

- Entropy changes in steam, solids, and liquids depend on temperature and phase.
- For liquids and solids, entropy change is calculated with specific heat and temperature.
- Phase changes, like boiling, cause large entropy increases.
- Steam's entropy changes with both temperature and pressure adjustments.

4.5 The Inequality of Clausius

- The Clausius inequality applies to cyclic processes in thermodynamics.
- It states that $\oint(\delta Q/T) \leq 0$ for any cyclic process.
- Equality holds for reversible processes; inequality for irreversible ones.
- This principle supports the second law of thermodynamics.

4.6 Entropy Change for an Irreversible Process

- Entropy increases in an irreversible process.
- Total entropy change is greater than in a reversible process.
- System and surroundings' entropy together always increase.
- Irreversibility results from factors like friction, unrestrained expansion, or heat transfer.

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5.POWER CYCLES

5.1 Rankine Cycle

Thermodynamic Cycle

- The Rankine cycle is a key thermodynamic cycle used in power plants to convert heat into mechanical work, typically to generate electricity.

Four main processes

- It consists of four stages—isentropic compression (pump), constant pressure heat addition (boiler), isentropic expansion (turbine), and constant pressure heat rejection (condenser).

Working Fluid

- A liquid, often water, is pressurized, heated to steam, expanded through a turbine to produce work, and then condensed back to liquid to complete the cycle.

Efficiency

- The Rankine cycle's efficiency depends on the temperature and pressure at which heat is added and removed, with higher efficiency achieved through superheating or reheating processes.

5.2 Carnot Cycle

Idealized Reversible Cycle

- The Carnot cycle is a theoretical thermodynamic cycle that defines the maximum possible efficiency for a heat engine operating between two temperature reservoirs.

Four stages

- It consists of two isothermal processes (heat addition and rejection) and two adiabatic (no heat transfer) processes, creating a closed loop in a pressure-volume diagram.

No entropy change

- Because the Carnot cycle is fully reversible, the total entropy change of the system over one cycle is zero, making it an idealized process.

Maximum efficiency

- The Carnot cycle efficiency is defined by $\eta=1-T1$

5.3 Regenerative Cycle

Enhanced Efficiency

- The regenerative cycle improves the thermal efficiency of a power cycle by using a regenerator to preheat the working fluid before it enters the boiler, reducing fuel consumption.

Heat Recovery

- In this cycle, some of the steam exiting the turbine is diverted to heat the feedwater, which recovers waste heat and reduces the load on the boiler.

Common in Rankine Cycles

- The regenerative cycle is often applied in Rankine cycle power plants, especially in steam turbines, to improve overall plant efficiency.

Improved Performance

- By reducing the temperature difference between the boiler and condenser, the regenerative cycle minimizes energy losses and enhances thermal performance in power generation systems

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CAPSTONE PROJECTS

1 Heat transfer in Quasi Static process from Internal Energy Relation

- Formulate and apply the first law of thermodynamics to analyze the relationships between heat transfer, work done, and changes in internal energy.
- Heat transfer (δQ) is the sum of the change in internal energy (dU) and the work done by or on the system (δW).
- Compare and contrast heat transfer and work in different types of quasi-static processes, highlighting the implications for system behavior.
- Analyze how quasi-static processes contribute to the efficiency and performance of thermodynamic cycles (e.g., Carnot cycle).

2 Efficiency of Carnot Engine

- Explain the four stages of the Carnot cycle (isothermal expansion, adiabatic expansion, isothermal compression, and adiabatic compression) and their significance in thermodynamic processe
- Analyze the role of heat transfer methods and their effects on the performance and efficiency of real engines versus the ideal Carnot engine.
- The efficiency of a Carnot engine is determined by the ratio of the work output to the heat input, and it depends on the temperatures of the hot and cold reservoirs.
- Use diagrams and simulations to visualize the Carnot cycle, aiding in the understanding of energy transformations and efficiency calculations.

3 Ideal Gas Law Simulation using matlab

- The Ideal Gas Law simulation in MATLAB models the relationship between pressure, volume, and temperature using the equation PV=nRT.
- MATLAB is used to visualize how changes in one variable (e.g., temperature) affect the others in a closed system.
- The simulation allows users to input values for the number of moles (n) and the gas constant (R), then adjust pressure, volume, or temperature interactively.
- Graphs can be plotted to show real-time changes in state variables, illustrating the behavior of an ideal gas.
- This simulation aids in understanding thermodynamic principles, providing an interactive way to study gas laws.

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LIVE PROJECT

1 **Development of Matlab code for Steam Power**

- The MATLAB code development for a steam power cycle models thermodynamic processes, such as isentropic expansion and heat addition.
- It calculates key parameters like pressure, temperature, and enthalpy at various stages of the cycle, based on steam tables.
- The code includes functions to analyze efficiency, work output, and heat transfer in each part of the steam cycle (boiler, turbine, condenser, and pump).
- Analyze the performance of the steam power cycle by calculating key parameters such as thermal efficiency, work output, and heat input.
- Plots and diagrams are generated to visualize the cycle, such as T-S (temperature-entropy) and P-V (pressure-volume) diagrams.
- This code helps in understanding steam power cycles and optimizing performance by simulating real-world power plant conditions.