ANALYZING CONCEPT OF

THE SECOND LAW OF THERMODYNAMICS

BY

NURUL ZAIDI KASBOLAH

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POLITEKNIK MALAYSIA
UNGKU OMAR

First published 2024

e ISBN 978-629-7635-31-6

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Published by:
Politeknik Ungku Omar,
Jalan Raja Musa Mahadi, 31400 Ipoh, Perak.
Tel: 05 - 5457656 Fax: 05-5471162

Our deepest gratitude goes to

En Rahizal Mohd Khir

(Head of Mechanical

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and

En Khirwizam Md Hkhir

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for your never-ending support.

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PREFACE

This eBook provides knowledge of theory, concept and application of principles to solve problems related to thermodynamics. It emphasizes on concept of non-flow process and flow process, properties of steam, Carnot cycle and Rankine cycle. This course also exposes the students to the demonstration of experiments in Thermodynamics by using the real equipment.

Our aim is to guide the readers, especially those from the Malaysia's Polytechnic to:

Apply Laws of thermodynamics and it processes (CLO2, C3, PLO1)

INTRODUCTION

1.1 Introduction to the first law of thermodynamics and its limitations.

Imagine you have a magic box, but instead of pulling out rabbits, you can only exchange different kinds of energy. The first law of thermodynamics is like the rulebook for this box. It says:

> "The total amount of energy in the universe is always the same, you can just juggle it around in different forms."

Think of these forms of energy as the coins in your magic box: heat, light, work, movement, even chemical energy. You can spend some coins (heat) to get others (work), but you can't create new coins or make them disappear.

Here's where things get tricky: the first law tells us how much energy you have, but not how you can use it.

This is where the limitations come in:

Direction:

- You can't just spend work coins to get heat coins back. Imagine trying to turn a moving car back into gasoline - it just doesn't work like that.

Spontaneity:

- Some energy exchanges happen naturally, like water flowing downhill. But others need a push, like pushing a car uphill. The first law doesn't tell us which way things will naturally go.

Efficiency:

- Even when you can exchange energy, you always lose some along the way. It's like trying to make toast without any crumbs - some energy is always wasted as heat.

So, the first law is like the basic budget for your magic energy box. It tells you how much you have, but it's up to you to figure out the best way to spend it, knowing that some things are just not possible and you'll always lose a little bit along the way.

1.2 Second law of thermodynamics and its significance.

The second law of thermodynamics has **two** main ways of being stated:

1. **Clausius statement**: "**Heat cannot pass from a colder body to a warmer body without some other change, connected therewith, occurring at the same time.**"
   - This means that **heat naturally flows from hot to cold**, not the other way around. Think of it like water always going downhill - it's the direction of spontaneous change.
2. **Entropy statement**: "**The total entropy of an isolated system always tends to increase over time**."
   - **Entropy is a measure of disorder or randomness.** This statement tells us that in any closed system (one that no energy or matter can leave or enter), natural processes will always lead to an increase in disorder. Imagine a clean, organized room naturally becoming cluttered over time.

Significance of the second law:

- It establishes the "**direction of time**": The tendency for entropy to increase implies a one-way arrow of time, where future states tend to be more disordered than past states.
- **Limits the efficiency of energy conversion**: No process can perfectly convert one form of energy into another without generating some waste heat. This limits the efficiency of engines and other machines.
- Explains **heat death**: Over time, the universe as a whole is also subject to the second law, leading to the hypothetical future scenario of "heat death" where everything is at the same temperature and no useful work can be done.
- Provides insights into **biological and natural processes**: The second law helps explain processes like the flow of energy in ecosystems, the aging of organisms, and the formation of crystals.

In summary, the s**econd law of thermodynamics sets fundamental limitations on how energy can be used and transformed in the universe**. It's a crucial concept in physics, chemistry, biology, and many other fields.

1.3 Concept of entropy and its role in the second law.

Imagine your room perfectly clean and organized. Books neatly stacked, clothes folded, dishes sparkling. Now imagine letting nature take its course. Entropy, the mischievous gremlin of the universe, would gradually creep in, scattering books, wrinkling clothes, and leaving a trail of dirty dishes. That's essentially what **entropy** is – **a measure of disorder or randomness in a system**.

Think of it like this:

- **Ordered systems** have **low entropy**. Your freshly cleaned room is a low-entropy state.
- **Disordered systems** have **high entropy**. The messy aftermath is a high-entropy state.

Now, here's where things get fun (or scary, depending on your perspective). The second law of thermodynamics dictates that in any closed system (one that doesn't exchange matter or energy with its surroundings), entropy always tends to increase over time. It's like an unstoppable force pushing towards chaos.

This has some pretty profound implications:

- **Heat flows from hot to cold**: Hot objects have high-entropy vibrations, while cold objects have low-entropy vibrations. When they touch, the high-entropy vibrations (heat) naturally spread to the cold object, increasing its entropy and decreasing the overall difference in entropy (seeking equilibrium). That's why ice cubes melt in your drink, not the other way around!
- **Perfect efficiency is impossible**: Engines and other machines can't convert energy perfectly into work without generating some waste heat. This waste heat represents an increase in entropy, limiting the efficiency of the process.
- **The universe is slowly dying**: The second law suggests that the entire universe is slowly becoming more and more disordered. Eventually, we might reach a state of maximum entropy, known as "heat death," where everything is at the same temperature and no useful work can be done. Don't worry, it's a long way off!

Entropy might seem like a pessimistic concept, but it's also fascinating. It helps us understand the arrow of time, the limitations of energy conversion, and the grand sweep of the universe's fate.

So next time you see your room getting messy, remember – it's not just laziness, it's the inexorable march of entropy!

1.4 Different ways to express the second law (Clausius inequality, Kelvin-Planck statement).

The second law essentially dictates the direction of change in isolated systems, emphasizing the tendency towards increased disorder (entropy). While the Clausius and Kelvin-Planck statements capture this essence, they offer different perspectives:

1. Clausius Inequality:
    - Statement: "It is impossible for a heat engine to operate in such a way that, in a continuous cycle, it produces no effect other than the transfer of heat from a lower-temperature reservoir to a higher-temperature reservoir."
    - Imagine: A perpetual motion machine extracting heat from a cold reservoir and converting it entirely into work without any waste heat. Clausius says this is impossible!
    - Analogy: Water naturally flows downhill, not uphill. Similarly, heat spontaneously flows from hot to cold, not the other way around.

2. Kelvin-Planck Statement:

- Statement: "It is impossible for a heat engine to operate in such a way that, in a continuous cycle, it absorbs heat from a single reservoir and produces no effect other than the performance of work."
- Imagine: An engine extracting heat from a single source and completely converting it into work, leaving no exhaust or changes in the surrounding environment. Kelvin-Planck declares this an impossibility.

Analogy: Imagine clapping your hands and generating only sound without any heat dissipation. According to Kelvin-Planck, that wouldn't work!

Key Differences:

- Clausius focuses on heat flow direction: It emphasizes the spontaneous flow of heat from hot to cold and the impossibility of reversing this naturally.
- Kelvin-Planck focuses on work extraction: It highlights the impossibility of extracting work from a single heat source without any exchange with the environment.

Both statements, though different in wording, ultimately convey the same core principle: In closed systems, spontaneous processes tend to increase entropy, making it difficult to achieve perfect efficiency or create perpetual motion machines.

Understanding these different expressions deepens our grasp of the second law and its implications in various fields, from engineering and physics to biology and even cosmology.

TEST YOUR KNOWLEDGE

Exercise 1: Second Law of Thermodynamics (5 Questions)

1. Explain the Clausius statement of the second law in your own words. Give an everyday example that illustrates this principle.

2. Briefly describe the concept of entropy and its role in the second law.

3. What are the implications of the second law for the efficiency of energy conversion processes? Explain with an example.

4. Discuss the concept of "heat death" and its connection to the second law. Do you think it's a likely scenario for the future of the universe? Explain your reasoning.

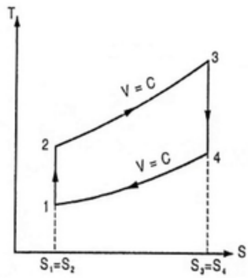
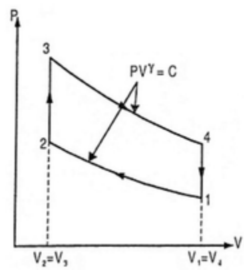
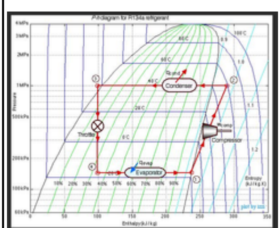
5. Imagine you're trying to design a perpetual motion machine that violates the second law. Explain why your attempt would be impossible, considering the principles of the second law.

PROPERTY DIAGRAMS AND ISENTROPIC PROCESSES

2.1 Concept of a property diagram and its different types (T-S, P-V, P-h).

Property diagrams are like **maps** of thermodynamic states.

They visualize the **relationships** between **different thermodynamic properties of a substance**, making it easier to analyze and understand processes involving heat, work, and energy transformations.

types of property diagrams	Axes	Key Features	diagrams
T-S Diagram (Temperature-Entropy Diagram)	Temperature (T) on the horizontal axis, entropy (S) on the vertical axis.	• Shows the direction of heat transfer and irreversibility. • Useful for analyzing heat engines and refrigeration cycles. • Isothermal processes (constant temperature) appear as horizontal lines. • Isentropic processes (constant entropy) appear as vertical lines.	
P-V Diagram (Pressure-Volume Diagram)	Pressure (P) on the vertical axis, volume (V) on the horizontal axis.	• Represents the mechanical work done during a process. • Used for analyzing compression and expansion processes in engines and pumps. • Isobaric processes (constant pressure) appear as horizontal lines. • Isochoric processes (constant volume) appear as vertical lines.	
P-h Diagram (Pressure-Enthalpy Diagram)	Pressure (P) on the vertical axis, enthalpy (h) on the horizontal axis.	• Enthalpy combines internal energy and flow work, making it convenient for flow processes. • Often used to analyze turbines, compressors, and heat exchangers. • Isobaric processes appear as horizontal lines.	

Key Points:

1. **Each point** on a property diagram represents a **unique** thermodynamic **state**.
2. **Lines connecting points** represent thermodynamic **processes**.
3. The **shape of the curve** on a property diagram reveals information about the **process and its properties**.
4. **Different diagrams** highlight **different relationships** and are best suited for **specific applications**.

By understanding property diagrams, you can:

1. Design and analyze thermodynamic systems more effectively.
2. Predict the behavior of substances under various conditions.
3. Optimize processes for energy efficiency and performance.

2.2 Define and explain isentropic processes and their properties on property diagrams.

Here's an explanation of isentropic processes and their properties on property diagrams:

Isentropic Processes: Keeping Entropy Constant

- **Meaning**: An isentropic process is a thermodynamic process that **occurs without any change in entropy**. This means the system's disorder or randomness remains constant throughout the process.
- **Idealization**: Isentropic processes are often considered idealizations because they are **reversible and perfectly efficien**t. In reality, most processes involve some degree of irreversibility and entropy generation.

- **P-V Diagram (Pressure-Volume Diagram):**
- Steeper Curve: Isentropic processes typically have steeper curves on a P-V diagram compared to non-isentropic processes.
- No Heat Transfer: This is because no heat is transferred during an isentropic process, leading to a more rapid change in pressure and volume.

- **P-h Diagram (Pressure-Enthalpy Diagram):**
- Not Directly Visible: Isentropic processes don't have a distinctive shape on a P-h diagram because enthalpy doesn't directly involve entropy.

Key Characteristics:

1. **Reversible**: Isentropic processes are reversible, meaning they can be reversed without any change in the system or surroundings.
2. **Adiabatic**: They are also adiabatic, meaning no heat is transferred between the system and its surroundings.
3. **Efficient**: Isentropic processes are the most efficient possible processes for a given set of conditions.

Applications:

Isentropic processes are important theoretical concepts in thermodynamics and are used to model various real-world processes, including:

1. **Turbines and Compressors**: The ideal operation of turbines and compressors is often approximated as isentropic.
2. **Nozzles and Diffusers**: Flow through nozzles and diffusers in gas dynamics is often analyzed using isentropic assumptions.
3. **Thermodynamic Cycles**: Isentropic processes are often used as idealized steps in thermodynamic cycles, such as the Carnot cycle.

2.3 Analyze the change in temperature, pressure, and other properties during isentropic expansion and compression processes.

Isentropic Expansion and Compression: A Dance of Temperature, Pressure, and More

Isentropic processes, those magical thermodynamic wonders, hold a special place in the world of energy transformations. They're a testament to **efficiency**, where entropy, the measure of disorder, remains unchanged.

But what happens to temperature, pressure, and other properties during these expansions and compressions?

Let's delve into:

Isentropic Expansion:
Imagine a **balloon** filled with air. Now, imagine poking a tiny hole in it and letting it slowly **deflate**. That's an **isentropic expansion**!

As the balloon expands, the following happens:

- **Temperature: Decreases:** Think of the balloon as a giant sponge. As it expands, the air molecules spread out, losing their kinetic energy and consequently, their temperature. This makes sense, right? More space, less bumping around, less heat.
- **Pressure: Decreases:** As the volume increases, the pressure exerted by the air molecules on the balloon walls decreases. This is like spreading the same number of people across a larger room – the density, and hence the pressure, reduces.
- **Volume: Increases:** This is the essence of expansion. The balloon gets bigger, allowing the air molecules more room to roam.
- **Internal Energy: Decreases:** Since temperature falls, internal energy (the sum of kinetic and potential energies of the molecules) also decreases. The work done by the expanding gas against the surrounding pressure comes from this internal energy.

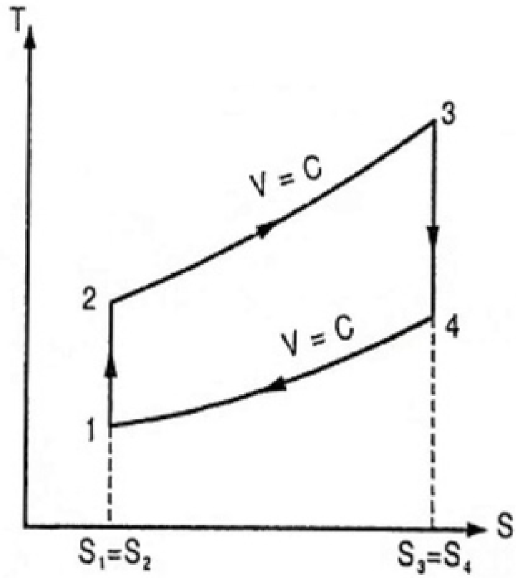
Isentropic Compression:
Now imagine **reversing** the balloon scenario. We squeeze the air back in, making it smaller. This is an i**sentropic compression**, and the changes are just the opposite:

- **Temperature: Increases:** As the balloon shrinks, the air molecules get squeezed together, bumping into each other more frequently and gaining kinetic energy. This translates to a rise in temperature.
- **Pressure: Increases:** With the molecules packed closer, they exert more pressure on the balloon walls. Think of it like pushing people closer together in a room – the pressure rises.
- **Volume: Decreases:** The balloon gets smaller, compressing the air inside.
- **Internal Energy:** Increases: The work done on the gas by the external force (squeezing) increases its internal energy.

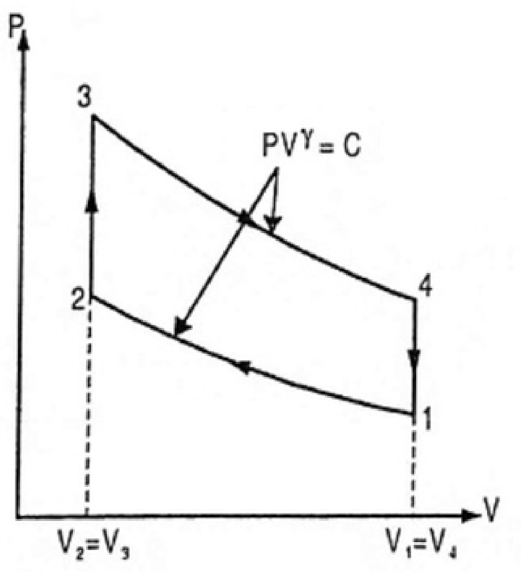
Visualizing the Changes:

Property diagrams act like maps, showing the **relationships between different thermodynamic properties**.

T-S Diagram: Isentropic processes appear as vertical lines because entropy stays constant. On an expansion line, temperature decreases downwards, while on a compression line, it rises upwards.



- **P-V Diagram**: Isentropic processes typically have steeper curves compared to non-isentropic ones. Expansion curves slope downwards (increasing volume, decreasing pressure), while compression curves slope upwards (decreasing volume, increasing pressure).



Remember:

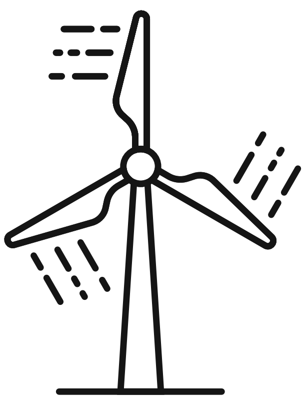
- Isentropic processes are idealizations, meaning they don't occur perfectly in the real world due to friction and other factors.
- The specific changes in temperature, pressure, and other properties depend on the initial state and the specific process conditions.

So, the next time you see a balloon expanding or a compressor working its magic, remember the fascinating dance of temperature, pressure, and other properties that unfolds during these isentropic transformations. They're a proof to the laws of thermodynamics and their influence on energy and its transformations.

We hope this explanation, along with the visuals, helps you visualize and understand the changes in various properties during isentropic expansion and compression processes.

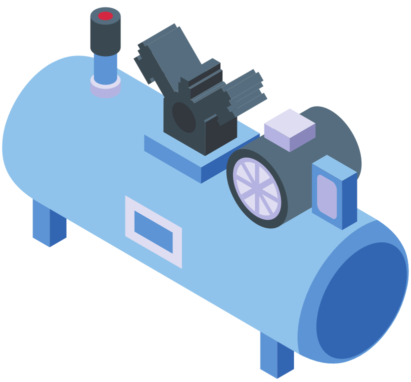
2.3 Examples of practical applications of isentropic processes.

1. **Turbines**:
   - Imagine a giant windmill harnessing the wind's kinetic energy. Inside its core lies a marvel of engineering – the turbine! As wind blades spin, they drive the turbine rotors, which compress air adiabatically (almost isentropically) due to their rapid rotation. This compression increases the air's internal energy, which then gets converted into useful work: generating electricity in power plants or propelling aircraft using jet engines.



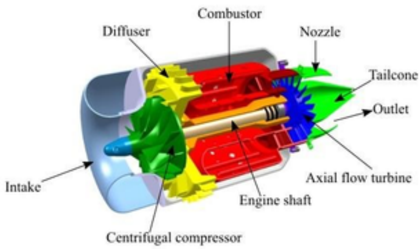
12. **Compressors:**

- From inflating your car tires to powering industrial processes, compressors are everywhere. These workhorses rely on isentropic principles to squeeze air or other gases to higher pressures. Think of squeezing a balloon – the pressure inside rises. Similarly, compressors take advantage of this principle to drive various applications, like air conditioning systems, refrigeration units, and pneumatic tools.



3. Nozzles:

- Picture a rocket soaring into the sky. That powerful thrust comes from its rocket engines, where hot, high-pressure gases accelerate through a converging nozzle. This nozzle acts like a funnel, further increasing the gas velocity and converting the internal energy into kinetic energy. The resulting supersonic jet propels the rocket at breathtaking speeds.



4. Diffusers:

- While nozzles accelerate flow, diffusers do the opposite. In aircraft engines, air entering the intake needs to slow down efficiently before reaching the compressor. Diffusers achieve this by gradually increasing the flow area, converting the kinetic energy of the air into pressure, ensuring smooth and efficient operation of the engine.

5. Cryogenic Engines:

- Deep in space, where temperatures plummet, even small temperature changes matter. Cryogenic engines, used in spacecraft and satellites, rely on extremely cold propellants like liquid hydrogen and oxygen. Isentropic principles guide the expansion of these propellants through nozzles, maximizing their thrust and ensuring efficient fuel usage in the hostile environment of space.

These are just a few examples of how isentropic processes, though idealized, provide valuable insights into real-world energy transformations.

While real-world processes involve some degree of irreversibility and entropy generation, the concept of isentropic processes serves as a fundamental theoretical framework for analyzing and optimizing these systems.

TEST YOUR KNOWLEDGE

Exercise 2: Isentropic Processes (5 Questions)

1. What is the key difference between an isentropic process and a non-isentropic process? What does "isentropic" literally mean?

2. Describe the changes in temperature, pressure, and volume that occur during an isentropic expansion process. Explain these changes using the concept of internal energy.

3. Draw a schematic diagram of a turbine and label the parts involved in the isentropic compression of air. Briefly explain the energy conversions at each stage.

4. Compare and contrast the changes in temperature, pressure, and volume during isentropic and non-isentropic compression processes. Use a P-V diagram to illustrate your answer.

5. Give two real-world examples of practical applications where isentropic processes play a crucial role. Explain how the principles of these processes contribute to the functionality of the system.

BONUS

Research and explain the Carnot cycle, a theoretical thermodynamic cycle that operates entirely on isentropic and isothermal processes.

How does it relate to the theoretical maximum efficiency of heat engines?

SUGGESTED ANSWERS

Exercise 1: Second Law of Thermodynamics

1. Clausius statement: "Heat spontaneously flows from a hotter body to a colder body, not the other way around." Example: Ice in a drink melts naturally, not the other way around, because heat flows from the warmer drink to the colder ice.
2. Entropy: Entropy is a measure of disorder or randomness in a system. The second law states that entropy in a closed system always tends to increase over time.
3. Efficiency: No process can perfectly convert one form of energy into another without generating any waste heat. This limits the efficiency of engines and other machines. Example: A car engine generates waste heat alongside useful work (motion).
4. Heat death: Heat death is a hypothetical scenario where the universe reaches maximum entropy and all temperatures equalize, preventing any useful work from being done. It's a long-term possibility based on the second law.
5. Perpetual motion machine: Such a machine would violate the second law by continuously creating energy without consuming any. This is impossible because it would decrease the overall entropy of the universe, which contradicts the second law's fundamentals.

Exercise 2: Isentropic Processes

1. Key difference: Isentropic processes have no change in entropy, while non-isentropic processes experience entropy generation due to friction or other factors. "Isentropic" literally means "equal entropy."
2. Isentropic expansion: Temperature decreases, pressure decreases, and volume increases. Internal energy decreases as work is done against the surrounding pressure.
3. Turbine diagram: Label intake, compressor blades, combustion chamber, turbine blades, and exhaust. Explain how air is compressed adiabatically, heated, expanded through the turbine to generate work, and finally expelled.
4. Isentropic vs. non-isentropic compression: Isentropic compression has a steeper P-V curve, less temperature increase, and less entropy generation compared to non-isentropic compression.
5. Real-world applications: Turbines in power plants and jet engines use isentropic compression for efficient energy conversion. Compressors in air conditioning and refrigeration rely on it for efficient pressure increase.

Bonus Challenge:

- Carnot cycle: This cycle uses two isothermal and two adiabatic processes to achieve the theoretical maximum efficiency of a heat engine. Its efficiency depends only on the temperatures of the heat source and sink. It provides a benchmark for real-world engine performance.

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e ISBN 978-629-7635-31-6

9 786297 635316

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