

Lecture 6 Entropy as a thermodynamic function of state. The entropy balance equation

Goal of the lecture: To study entropy as a state function of thermodynamics and to understand the formulation and applications of the entropy balance equation for closed and open systems.

Brief lecture notes: This lecture introduces the physical meaning and mathematical formulation of entropy as a thermodynamic property of state. It explores how entropy differs from energy and why it serves as a measure of disorder and energy dispersal. We examine the derivation of the entropy balance equation, which describes how entropy changes in real systems due to heat transfer and irreversibility. Applications include the analysis of reversible and irreversible processes, and the evaluation of entropy generation in engineering systems.

Main Part

Entropy as a Thermodynamic Property

Entropy, denoted as S , is a state function, meaning its change depends only on the initial and final states of a system, not on the path taken. It quantifies the degree of *energy dispersion* within a system and provides a criterion for the spontaneity of processes.

In thermodynamics, the infinitesimal change in entropy for a reversible process is given by:

$$dS = \frac{\delta Q_{rev}}{T}$$

where δQ_{rev} is the reversible heat transfer and T is the absolute temperature. For irreversible processes, entropy increases due to internal generation, indicating that energy becomes less available for performing useful work.

Entropy is an extensive property, meaning it depends on the size or mass of the system. The specific entropy (s) is defined per unit mass: $s = S/m$.

Entropy Change for Various Processes

Entropy change can be calculated directly when temperature and heat exchange are known. For a reversible isothermal process:

$$\Delta S = \frac{Q_{rev}}{T}$$

For an ideal gas undergoing a reversible process:

$$\Delta S = mc_v \ln \frac{T_2}{T_1} + mR \ln \frac{v_2}{v_1}$$

This relation shows that entropy depends both on temperature and volume (or pressure) changes, linking thermodynamics to the microscopic molecular motion of gases.

The Entropy Balance Equation

The entropy balance provides a quantitative statement of the second law of thermodynamics for real systems. For any process, the total change in entropy of a system can be written as:

$$\Delta S_{system} = \int \frac{\delta Q}{T} + S_{gen}$$

where

- $\int \frac{\delta Q}{T}$ — entropy transfer due to heat exchange with surroundings,
- S_{gen} — entropy generation due to irreversibilities (always ≥ 0).

In differential form for a control volume at steady flow:

$$\dot{S}_{in} - \dot{S}_{out} + \dot{S}_{gen} = 0$$

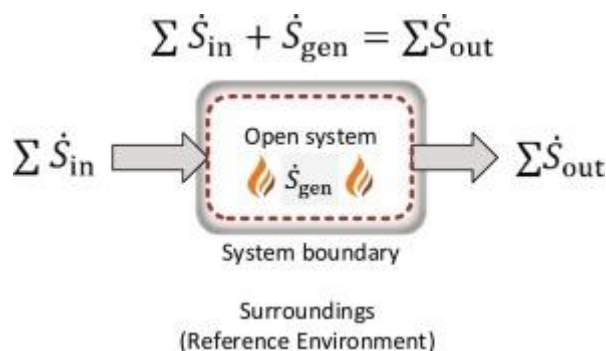
This expression allows engineers to evaluate how processes deviate from reversibility and identify inefficiencies.

Entropy Transfer and Generation

Process Type	Entropy Transfer ($\delta Q/T$)	Entropy Generation (S_{gen})	Net Effect
Reversible	Exists	0	No increase in total entropy
Irreversible	Exists	> 0	Total entropy increases
Adiabatic reversible	0	0	Entropy constant (isentropic)
Adiabatic irreversible	0	> 0	Entropy increases

Entropy generation is the measure of irreversibility in real systems — caused by friction, mixing, unrestrained expansion, heat transfer through finite temperature differences, or chemical reactions.

Figure 1. Visualization and Physical Meaning



Entropy in Closed and Open Systems

For closed systems, entropy change is determined by the net heat transfer and internal generation.

For open systems (control volumes), entropy also enters and leaves with mass flow:

$$\dot{S}_{in} - \dot{S}_{out} + \sum \frac{\dot{Q}}{T_b} + \dot{S}_{gen} = 0$$

Here T_b represents the boundary temperature where heat transfer occurs. This form is widely used for steady-flow devices such as turbines, compressors, and heat exchangers.

Engineering Implication

Entropy analysis provides deep insight into the efficiency and sustainability of engineering systems. By minimizing S_{gen} , designers can approach ideal performance. Entropy balance is used to evaluate:

- efficiency losses in power plants,
- irreversibilities in compressors and turbines,
- thermal optimization of heat exchangers, and
- entropy production in chemical and environmental processes.

Thus, the entropy function connects theory to practical energy management.

Questions for Self-Control

1. Why is entropy considered a thermodynamic state function?
2. How is entropy related to reversible and irreversible heat transfer?
3. What are the main terms in the entropy balance equation and what do they represent?
4. How does entropy generation affect the efficiency of real systems?
5. In what types of engineering systems is entropy analysis most useful?

Literature

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