Chapter 6 - Entropy

Lecture 23

Sections 6.10-6.11

MEMS 0051 Introduction to Thermodynamics

Mechanical Engineering and Materials Science Department
University of Pittsburgh

Student Learning Objectives

At the end of the lecture, students should be able to:

- Understand and apply the increase of entropy principle applied to closed systems

Developing Entropy Balance

- Let us consider two processes, an irreversible process from State 1 to 2, and a reversible process from State 2 to 1:

$$\int_1^2 \left(\frac{\partial Q}{T}\right)_{irr} + \int_2^1 \left(\frac{\partial Q}{T}\right)_{rev} = -\sigma$$

- We introduce a term σ, which is the strength of entropy production (our book calls this S_{gen})
- The reversible process is simply the change of the entropy at States 2 and 1 such that

$$\underbrace{S_2 - S_1}_{\text{entropy change}} = \underbrace{\int_1^2 \left(\frac{\partial Q}{T}\right)_{irr}}_{\text{entropy transfer}} + \underbrace{\sigma}_{\text{entropy production}}$$

- This is the entropy balance equation for a closed system

Entropy Balance For Closed Systems

- The first term on the RHS is the entropy transfer associated with heat transfer, and follows the sign convention associated with heat transfer processes

$$\underbrace{S_2 - S_1}_{\text{entropy change}} = \underbrace{\int_1^2 \left(\frac{\partial Q}{T}\right)_{irr}}_{\text{entropy transfer}} + \underbrace{\sigma}_{\text{entropy production}}$$

- The second term on the RHS is a measure of the change of irreversibilities, other than those associated with heat transfer, within the system:

$$\sigma = \begin{cases} > 0 \, \text{irreversibilities present} \\ = 0 \, \text{no irreversibilities} \\ < 0 \, \text{not possible} \end{cases}$$

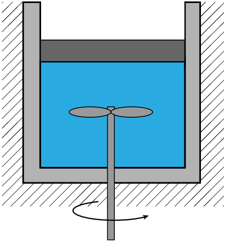
Change in Entropy

- Conversely, the change of entropy, $S_2 - S_1$ is bounded between negative infinity and positive infinity

$$S_2 - S_1 = \begin{cases} > 0 \, \text{entropy enters system} \\ = 0 \, \text{no change in entropy} \\ < 0 \, \text{entropy exits system} \end{cases}$$

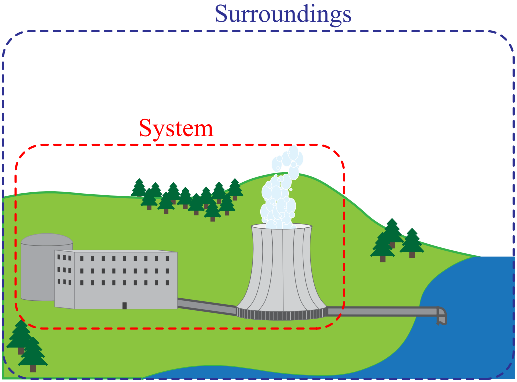
Example #1

- Let us consider a modification to Joule's experiment on determining specific heat. Say we have saturated liquid water at 100 °C, contained within a piston-cylinder setup. If the piston-cylinder is friction-less, the cylinder is perfectly insulated, and energy is put into the system via the use of a paddle wheel until the liquid becomes a saturated vapor, determine the increase of entropy per unit mass.



Isolated System

- Consider a system and its surroundings, with the latter large enough to consider any effect a change in the system may impart - we will call this an isolated system



Balance of Energy

- Recall energy must be conserved: that the system provides to the surroundings is equal to what the surroundings receives from the system:

$$\Delta E_{\text{isolated}} = 0 \implies \Delta E_{\text{system}} + \Delta E_{\text{surroundings}} = 0$$

- The change of entropy of an isolated system follows suit:

$$\Delta S_{\text{isolated}} = \cancelto{0}{\int \left(\frac{\delta Q}{T}\right)_b} + \sigma$$

- The isolated system is comprised of the system and the surroundings:

$$\implies \Delta S_{\text{system}} + \Delta S_{\text{surroundings}} = \sigma$$

- This is known as the **increase of entropy principle** - the sum of the change of entropy must be zero or positive

Example #2

- A 0.3 [kg] steel bar initially at 1,200 K is cooled in a tank of water (m=9 [kg]), which is initially at 300 K. This system can be assumed isolated. If the final temperature of the bar-water system is 303 K, determine the change of entropy a) for the steel bar, b) the water and c) the system.

Example #2

Student Learning Objectives

At the end of the lecture, students should be able to:

- Understand and apply the increase of entropy principle applied to closed systems
  - The increase of entropy principle states that the sum of change of entropy associated with our system and surroundings must be greater than or equal to zero, and is formulated as

$$dS = \int_1^2 \left(\frac{\partial Q}{T}\right)_{irr} + \sigma$$

Suggested Problems

- 6.115, 6.116, 6.125, 6.128, 6.131, 6.134, 6.151, 6.158