Chapter 3 - First Law of Thermodynamics and Energy

Lecture 8

Sections 3.1, 3.3, 3.5

MEMS 0051 Introduction to Thermodynamics

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Student Learning Objectives

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

- Apply the formulation of work and heat to closed systems.

Energy and the C.o.E.

- Recall the C.o.E.

$$dE = dU + d(KE) + d(PE) = \delta Q - \delta W$$

- This tells us the energy within a process or cycle has to be conserved, and that energy is a point variable - it is evaluated at the initial and final states
- However, we have to evaluate heat and work terms, both of which have path dependence
- Before we get into the path dependence and evaluation, lets look at each term

Formulation of Work

- Recall from physics, work is defined as a force F acting through a displacement x (i.e. from point (state) 1 to 2), such that the displacement is in the direction of the force:

$$\delta W = F\,dx \implies W_{1\to 2} = \int_1^2 F dx \text{ [J, N-m]}$$

- In thermodynamics, work has a more general meaning: work is done by a system(s) if the sole effect on the surrounding *could be* the movement of mass.

Work

- Odd huh? Well, even if the mass is not moved, work can still be done to said mass (i.e. energy is added in the form of heat, original experiments by Black), or such that energy is transferred across a system boundary (refrigerator, heat pump).
- Work done by a system (output) is positive. Work done on a system (input) is negative.

Units of Work

- Power ($\dot{W}$) is the time rate of change of work:

$$\dot{W} = \frac{\delta W}{dt} \text{ [J/s, W]}$$

- Recalling previous definition for specific volume, specific work is per unit mass such that:

$$w = \frac{W}{m}$$

- Notice, this definition is only valid for a fixed-boundary CS!

Example #1

- Consider a piston-cylinder device filled with an ideal gas. The initial pressure inside the device is 0.2 [MPa] and has a volume of 40,000 [cm^3]
  a) If heat is added such that the volume increases to 100,000 [cm^3], calculate the amount of work done by the system.
- Now imagine the device contains 0.5 [kg] of ammonia at -20 °C with a quality of 25%.
  b) If heated is added to increase the temperature to 20 °C, where the volume increases by a factor of 1.41, and the pressure increases linearly with volume, determine the work produced.

Example #1

Solution:

Example #1

Solution:

Heat

- **Heat** (Q, [J, BTU]) is the form of energy that is transferred across the boundary given there exists a temperature difference between the system and surroundings
- Heat always flows from a high to low potential, i.e. from hot to cold
- A body/system does not contain heat - heat is only identifiable as it crosses the boundary of the system
- Once two systems are in thermal equilibrium, heat transfer ceases

Heat

- Unlike work, heat transferred to a system is a positive (+) quanity, and heat transferred from a system is a negative (-) quantity
- If no heat is transferred, Q=0, then the process is referred to as **adiabatic**
- Heat is path dependent from State 1 and 2, expressed as

$$Q_{1\to 2} = \int_1^2 \delta Q$$

Heat

- The rate at which heat is transferred, just like work, is expressed at the time rate of change

$$\dot{Q} = \frac{\delta Q}{dt} \text{ [J/s], [W]}$$

- Heat transfer per unit mass is simply

$$q = \frac{Q}{m}$$

Example #2

- Consider a piston-cylinder device containing air. The piston has a mass of 45 [kg] and an area of 900 [cm^2]. Heat is applied to the assembly such that the volume increases by 45,000 [cm^3].
- If the mass of air in the system is 0.27 [kg], and the internal energy increased by 42 [kJ/kg], determine the amount of heat transferred.

Example #2

Solution:

Example #2

Solution:

Student Learning Objectives

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

- Apply the formulation of work and heat to closed systems.
  - colorblue Work and heat are both quantities that are able to cross a control surface - they are not quantities that a system contains. The transference of work and/or heat causes a change to the energy of the system.

Suggested Problems

- 3.41, 3.43