Chapter 3 - First Law of Thermodynamics and Energy

Lecture 10
Sections 3.7, 3.10

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:

- Calculate the change of internal energy through the formulation of constant-volume specific heat

Internal Energy

- Recall from the C.o.E.

$$dE = \delta Q - \delta W$$

- We have formulated how to solve for δW for any process through the use of the polytropic index
- We also recall that the total energy is the sum of the internal, kinetic and potential
- Consider a system where this is no change in kinetic or potential energy

$$dU = \delta Q - \delta W$$

Conservation of Energy

- Rearranging the C.o.E. equation

$$Q_{1\to 2} = dU + \delta W$$

- Recalling the definition of work

$$Q_{1\to 2} = dU + P d\forall$$

- The heat input (output) of the system can easily be determined from the change of internal energy and work done (onto) the system

Specific Heat

- Considering a single, homogeneous phase, the **specific heat** (C) is defined as the amount of heat required per unit mass to raise the temperature by one degree
- This concepts dates back to 1761 when Joseph Black discovered latent heat - the melting of ice does not cause the temperature to increases, rather there is an increase in the amount of liquid in the solid/liquid mixture

Constant Volume Specific Heat $C_\forall$

- Taking the C.o.E. for a quasi-equilibrium process

$$Q_{1\to 2} = dU + P d\forall$$

- If the volume is constant between States 1 and 2

$$\partial Q = dU$$

- The **Constant Volume Specific Heat** ($C_\forall$) is the amount of heat required per unit to mass to raise the temperature by on degree

$$C_\forall = \frac{1}{m}\left(\frac{\partial Q}{\partial T}\right)_\forall = \frac{1}{m}\left(\frac{\partial U}{\partial T}\right)_\forall$$

Constant Volume Specific Heat $C_\forall$

- There, $C_\forall$ is

$$\boxed{C_\forall = \left(\frac{du}{dT}\right)_\forall}$$

- We can arrive at the same solution considering $u{=}u(T,\nu)$ with the chain rule applied with respect to T and ν

$$du = \left(\frac{\partial u}{\partial T}\right)_\nu dT + \left(\frac{\partial u}{\partial \nu}\right)_T d\nu$$

- For $\forall$=c, $d\nu{=}0$

Constant Volume Specific Heat $C_\forall$

- Recalling the C.o.E. in specific terms

$$du = \partial q - p d\nu$$

- The second term is once again zero

$$\partial q = du = \left(\frac{\partial u}{\partial T}\right)_\nu dT$$

- Rearranging

$$\left(\frac{\partial u}{\partial T}\right)_\nu = \left(\frac{\partial q}{\partial T}\right)_\nu$$

Constant Volume Specific Heat $C_\forall$

- It is evident the increase in specific energy is due to heat transference, therefore, by definition of specific heat

$$\boxed{C_\forall = \left(\frac{du}{dT}\right)_\forall}$$

- "Constant Volume" is a misnomer
- We considered a constant volume process, but in actuality $C_\forall$ is a thermodynamic property that is defined in terms of a derivative of a variable with respect to temperature, rather than a quantity related to the heat transferred in the process!

Constant Volume Specific Heat $C_\forall$

- Since the derivatives are defined at any point in a quasi-equilibrium process, $C_\forall$ is a thermodynamic property of the substance of interest and depends only on the state!
- $C_\forall$ can be used whenever we are interested in a change of internal energy

$$\boxed{du = C_\forall dT}$$

- THE PROCESS DOES NOT HAVE TO BE CONSTANT VOLUME FOR US TO USE THE CONSTANT-VOLUME SPECIFIC HEAT!

Example #1

- A piston-cylinder device contains He gas initially at 150 [kPa], 20 °C and 0.5 [m^3]. The He gas is compressed in a polytropic process to 400 [kPa] and 140 °C. Assume the He gas satisfies the ideal gas law. For He, R=2.0771 [kJ/kg-K] and $C_\forall$=3.116 [kJ/kg-K].
- Determine the work into or out of the system during this process and the heat loss or gain during this process.

Example #1

<u>Solution</u>:

Example #1

Solution:

Example #1

Solution:

Example #1

Solution:

Student Learning Objectives

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

- Calculate the change of internal energy through the formulation of constant-volume specific heat
  - The constant-volume specific heat is calculated as the change of internal energy per the change of temperature:

$$C_\forall = \frac{du}{dT}$$

Suggested Problems

- The text does not have problems related to calculating the change of specific internal energy using $C_\forall$. We shall have to wait till we complete Lecture 11.