

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

Chapter 3 - First
Law of
Thermodynamics
and Energy

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Learning Objectives

3.7 - Internal
Energy

3.10 - Constant
Volume Specific
Heat

Summary

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



- ▶ 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 there is no change in kinetic or potential energy

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



- ▶ Rearranging the C.o.E. equation

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

- ▶ Recalling the definition of work

$$Q_{1 \rightarrow 2} = dU + PdV$$

- ▶ 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_V

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

$$Q_{1 \rightarrow 2} = dU + PdV$$

- ▶ If the volume is constant between States 1 and 2

$$\partial Q = dU$$

- ▶ The **Constant Volume Specific Heat** (C_V) is the amount of heat required per unit to mass to raise the temperature by one degree

$$C_V = \frac{1}{m} \left(\frac{\partial Q}{\partial T} \right)_V = \frac{1}{m} \left(\frac{\partial U}{\partial T} \right)_V$$



Constant Volume Specific Heat C_V

- There, C_V is

$$C_V = \left(\frac{du}{dT} \right)_V$$

- 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_V

- ▶ 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_V

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

$$C_V = \left(\frac{du}{dT} \right)_V$$

- ▶ “Constant Volume” is a [misnomer](#)
- ▶ We considered a constant volume process, but in actuality C_V 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_V

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

$$du = C_V dT$$

- ▶ 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 [m³]. 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 $C_V=3.116$ [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

Solution:

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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:

$$C_V = \frac{du}{dT}$$



Suggested Problems

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

