Chapter 3 - First Law of Thermodynamics and Energy

Lecture 12
Section 3.11

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 the concept of internal energy, enthalpy and specific heat of Ideal Gases under the Ideal Gas law framework

Internal Energy and $C_{\forall 0}$

- Recall u is determined from two independent properties such as T, P, ν, etc.
- For low to medium density gases, u depends primarily on T and less on P, that is u=$u(T)$
- Recalling the Ideal Gas law, if u=$u(T)$ implies u is independent of P and ν

$$P\forall = mRT \implies P\nu = RT$$

- Therefore, recalling constant-volume specific heat, the $C_\forall$ is independent of $\forall$ (ν)

$$C_\forall = \left(\frac{\delta u}{\delta T}\right)_\forall \implies \boxed{C_{\forall 0} = \frac{du}{dT}}$$

- $C_{\forall 0}$ is the **constant-volume specific heat of an Ideal Gas** (notice the 0)

Enthalpy and C_{P0}

- Recalling the definition of enthalpy in a constant-volume specific heat framework

$$h = u + P\nu$$

- From the Ideal Gas law, $P\nu = RT$

$$h = u + RT$$

- It is evident that $h = h(T)$
- Therefore, recalling constant-pressure specific heat, the C_P is independent of P

$$C_P = \left(\frac{\delta h}{\delta T}\right)_P \implies \boxed{C_{P0} = \frac{dh}{dT}}$$

- C_{P0} is the **constant-pressure specific heat of an Ideal Gas** (notice the 0)

$C_{\forall 0}$ and C_{P0}

- These two properties are given in Table A.5
- $C_{\forall 0}$ and C_{P0} are related through the definition of enthalpy of an Ideal Gas

$$h = u + P\nu = u + RT$$

- Differentiating this equation,

$$dh = du + d(RT) = du + RdT + TdR$$

- The gas constant R is constant, and dh and du can be expressed in terms of C_{P0} and $C_{\forall 0}$, respectively

$$dh = du + RdT \implies C_{P0}dT = C_{\forall 0}dT + RdT$$

- Rearranging, the gas constant R is the difference of C_{P0} and $C_{\forall 0}$

$$\boxed{R = C_{P0} - C_{\forall 0}}$$

$C_{\forall 0}$ and C_{P0}

- Note Table A.5 has C_{P0} and $C_{\forall 0}$ as constants taken at STSP
- Table A.6 Has C_{P0} as a function of temperature

$$C_{P0} = C_0 + C_1\theta + C_2\theta^2 + C_3\theta^3$$

- Note θ=(T [K])/1,000
- h is also tabulated as a function of temperature in Table A.8

$C_{\forall 0}$ and C_{P0}

- When evaluating the change of enthalpy between two states, there are multiple ways to evaluate C_{P0} (order of worst to best)

1. If dT is small and near 25 °C, use Table A.5
2. If dT is small, and between 250 and 1,200 [K], use Table A.6
3. If dT is large, use the integral of C_{P0} from Table A.6 (up to 1,200 [K])
4. Use published values in Table A.8 (up to 3,000 [K])

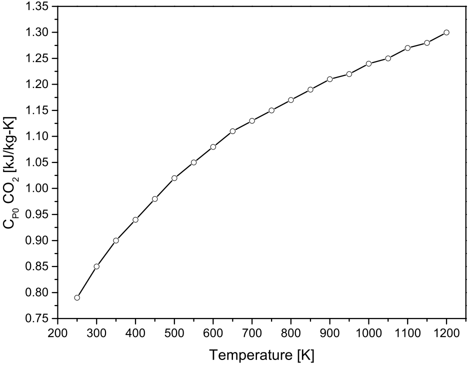
Example #1

- Calculate the change of enthalpy of CO_2 from 250 to 1,200 [K], assuming Ideal Gas behavior using the following techniques:
  1. Treat C_{P0} as a constant from Table A.5
  2. Treat C_{P0} as a constant, averaged between 250 and 1,200 [K], from Table A.6
  3. Evaluate the integral of C_{P0} between the temperature bounds from Table A.6
  4. Use the values published on Table A.8

Example #1

Solution:

We first look at the behavior of C_{P0} as a function of temperature: it increases by 64% over our range of interest



Example #1

Solution:

Example #1

Solution:

Example #2

- Determine the final temperature of 15 [kg] of carbon dioxide, that while undergoing a constant-pressure process which starts at a temperature of 25 °C, receives 10.2 [MJ] of heat, by treating the constant-pressure specific heat as:
  (a) A constant taken from Table A.5;
  (b) A constant evaluated at the average temperature using the polynomial expression from Table A.6;
  (c) A constant evaluated at the average constant-pressure specific heat using the polynomial expression from Table A.6;
  (d) As the integral-average evaluated between the initial and final temperature using the polynomial expression from Table A.6.

Example #2

Solution: (a)

Example #2

Solution: (b)

Example #2

Solution: (b)

Example #2

Solution: (c)

Example #2

Solution: (c)

Example #2

Solution: (d)

Example #2

Solution: (d)

Student Learning Objectives

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

- Understand the concept of internal energy, enthalpy and specific heat of Ideal Gases under the Ideal Gas law framework
  - The change of internal energy for an Ideal Gas is merely the constant-volume specific heat times change of temperate.
  - The enthalpy an Ideal Gas can be expressed as the internal energy plus pressure times specific volume, or internal energy plus the gas constant times temperature
  - The change of enthalpy for an Ideal Gas is merely the constant-pressure specific heat times change of temperate.
  - Table A.6 provides $C_P(T)$

Suggested Problems

- 3.127, 3.128, 3.130, 3.131, 3.139, 3.140, 3.143, 3.213, 3.214