Chapter 3 - First Law of Thermodynamics and Energy

Lecture 11
Sections 3.9-3.10

MEMS 0051 Introduction to Thermodynamics

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Student Learning Objectives

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

- Understand the concept of enthalpy and be able to determine said value from the Steam Tables
- Under and apply the formulation of constant pressure specific heat

Enthalpy

- Recall from the C.o.E.

$$dE = \partial Q - \partial W$$

- Ignoring changes in kinetic and potential energies, and expressing work in terms of pressure and volume,

$$dU = \partial Q - \int_1^2 P \, d\forall$$

- Assuming this is a constant-pressure process, and rearranging for heat input,

$$\partial Q = dU + P \, d\forall$$

Enthalpy

- Expressing this in terms of change of properties between initial and final states,

$$Q_{1\to 2} = (U_2 - U_1) + P(\forall_2 - \forall_1)$$

- Pressure is constant, P=P_1=P_2, and grouping like terms,

$$Q_{1\to 2} = (U + P\forall)_2 - (U + P\forall)_1$$

- U, P and $\forall$ are functions only of the state of the system, thus their summation also has the same characteristics of the state of the system.

Enthalpy

- **Enthalpy** (H, h) is an extensive property defined as:

$$\boxed{\begin{aligned} H &\equiv U + P\forall \\ h &\equiv u + P\nu \end{aligned}}$$

- Therefore, for a constant pressure, quasi-equilibrium process:

$$Q_{1\to 2} \equiv H_2 - H_1$$

- Understand the assumptions made when using this formulation!

Enthalpy

- Enthalpy is tabulated and is a function of two independent properties ($h(T,P)$, $h(T,\nu)$, $h(T,u)$, $h(P,x)$, etc.).
- Specific enthalpy can be calculated just like specific volume and specific internal energy:

$$\boxed{\begin{aligned} h &= (1-x)h_f + xh_g \\ h &= h_f + x(h_g - h_f) \end{aligned}}$$

- The enthalpy of compressed liquid water is usually not given $\implies$ use the saturated liquid water tables at the same temperature!

Example #1

- A piston/cylinder has a volume of 0.1 [m^3] and contains 0.5 [kg] of water at 0.4 [MPa]. Heat is transferred to the steam until it reaches 300 °C, while the pressure remains constant. Determine the heat transfer for this process:

Solution:

Example #1

Solution:

Constant Pressure Specific Heat C_P

- The C.o.E. for a quasi-equilibrium, P=c process is,

$$Q_{1\to 2} = dU + Pd\forall = (U + P\forall)_2 - (U + P\forall)_1$$

- Expressing the change of internal energy as the change of enthalpy,

$$\partial Q = dH$$

- The **Constant Pressure Specific Heat** (C_P) is the amount of heat required per unit to mass to raise the temperature by one degree:

$$C_P = \frac{1}{m}\left(\frac{\partial Q}{\partial T}\right)_P = \frac{1}{m}\left(\frac{\partial H}{\partial T}\right)_P$$

Constant Pressure Specific Heat C_P

- Therefore, C_P is

$$\boxed{C_P = \left(\frac{dh}{dT}\right)_P}$$

- Once again, C_P is a property of the substance, and hence "constant pressure" is a misnomer!
- THE PROCESS DOES NOT NEED TO BE CONSTANT PRESSURE FOR US TO USE CONSTANT-PRESSURE SPECIFIC HEAT!
- Thus, a change of enthalpy between two states can be expressed as:

$$dh = C_P dT \implies h_2 - h_1 = C_P(T_2 - T_1)$$

C_P for Liquids and Solids

- Interestingly, when evaluating $C_\forall$ and C_P for incompressible liquids and solids, we notice

$$dh = du + d(P\nu) = du + Pd\nu + \nu dP$$

- For solids and liquids, they are assumed incompressible, $d\nu$=0, and looking at the order of magnitudes, the specific volume is small in comparison to the internal energy, $\nu \approx$0

$$dh \approx du \approx CdT$$

- That is, for solids and liquids, $C_\forall \approx C_P \approx C$

$$\boxed{h_2 - h_1 \approx u_2 - u_1 \approx C(T_2 - T_1)}$$

Example #2

- How much heat must be supplied to heat 1 [kg] of copper from 25 °C to 100 °C?

Solution:

Student Learning Objectives

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

- Understand the concept of enthalpy and be able to determine said value from the Steam Tables
  - Enthalpy is merely the sum of the internal energy plus the produce of the volume pressure.
- Under and apply the formulation of constant pressure specific heat
  - C_P is expressed as the change of enthalpy per the change of temperature:

$$C_P = \frac{dh}{dT}$$

Suggested Problems

- 3.89, 3.90, 3.116, 3.118, 3.126, 3.152, 3.159, 3.169, 3.181