

Chapter 3 - First Law of Thermodynamics and Energy

Lecture 7 Sections 3.1-3.2

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

- ▶ Formulate the 1st Law of Thermodynamics and Conservation of Energy equations
- ▶ Apply the Conservation of Energy equation to closed systems

Learning Objectives

3.2 The First Law
of Thermodynamics

3.1 The Energy
Equation

Summary



1st Law of Thermodynamics

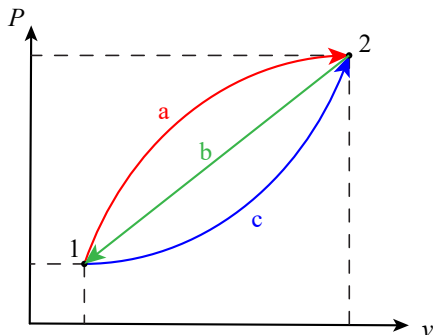
- ▶ The **First Law of Thermodynamics**, also known as the **Conservation of Energy** (C.o.E.), states that energy cannot be created or destroyed
- ▶ Imagine we have a cycle. That is, we heat saturated water until it becomes a vapor, run the vapor through a turbine, then after it exits the turbine, it is run through a condenser before being sent into a pump, after which it repeats.
- ▶ During this cycle, the cyclic integral of heat (net heat transfer during the cycle) is proportional to the cyclic integral of work (net work during the cycle)

$$\oint \delta Q = \oint \delta W$$



Cycle of a C.M.

- ▶ Let us visualize the cyclic integrals by considering a C.M. undergoing a cycle, simplifying our analysis to two states, 1 and 2

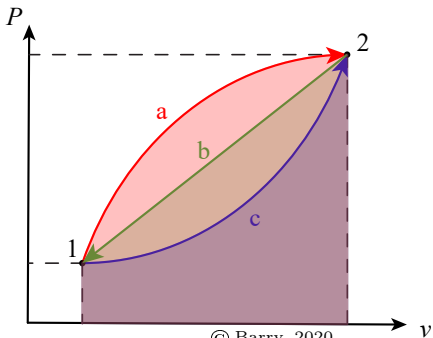


- ▶ We can go from state 1 to 2 via path a or c , but we return from state 2 to 1 via b



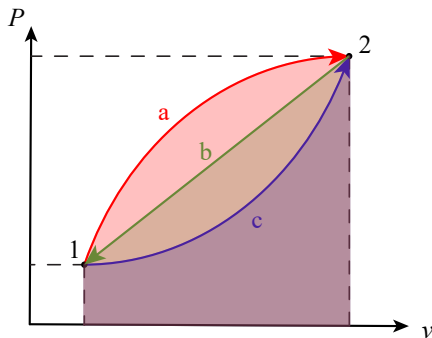
Work and Heat

- ▶ Our property of interest (work, heat) is the area under the curve of each path.
- ▶ For instance the red area is the work produced by going from States 1 to 2 via a, and the blue area is the work produced going from States 1 to 2 via c
- ▶ The work to go from State 2 to 1 via b would be the green area



Path Dependence

- ▶ We do not know how P varies with v for all possible processes, i.e. work ($\delta W = P dV$) is **path dependent** quantity, and as indicated by a partial derivative δ
- ▶ The same goes for heat, which is not the same formulation as work



- Imagine we take path a from State 1 to 2, and path b from State 2 back to 1, which allows us to express the 1st law as

$$\oint \delta Q = \oint \delta W \implies \int_1^2 \delta Q_a + \int_2^1 \delta Q_b = \int_1^2 \delta W_a + \int_2^1 \delta W_b \quad (1)$$

- Now imagine we take path c from State 1 to 2, and path b back:

$$\oint \delta Q = \oint \delta W \implies \int_1^2 \delta Q_c + \int_2^1 \delta Q_b = \int_1^2 \delta W_c + \int_2^1 \delta W_b \quad (2)$$



Path Independence

- ▶ We note the initial and final states are the same, however we took different paths to get there.
- ▶ It is advantageous to eliminate the path dependence of processes. Subtracting (2) from (1):

$$\begin{aligned} \int_1^2 \delta Q_a + \int_2^1 \delta Q_b &= \int_1^2 \delta W_a + \int_2^1 \delta W_b \\ - \left(\int_1^2 \delta Q_c + \int_2^1 \delta Q_b &= \int_1^2 \delta W_c + \int_2^1 \delta W_b \right) \\ \hline \int_1^2 (\delta Q_a - \delta Q_c) &= \int_1^2 (\delta W_a - \delta W_c) \end{aligned}$$

- ▶ Grouping like paths:

$$\Rightarrow \int_1^2 (\delta Q - \delta W)_a = \int_1^2 (\delta Q - \delta W)_c$$



Conservation of Energy

- ▶ We notice the quantity $(\delta Q - \delta W)$ is the same for all processes between States 1 and 2.
- ▶ Therefore, $(\delta Q - \delta W)$ is a **point function** - it depends only on States 1 and 2 and does not depend on the path!
- ▶ $(\delta Q - \delta W)$ is a differential property of the mass, and is referred to as **Energy**, expressed in the form of the C.o.E.:

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

- ▶ Generally speaking, the change of energy of the system is equal to the energy in less the energy out



Conservation of Energy

- ▶ When the C.M. is evaluated between two states,

$$E_2 - E_1 = Q_{1 \rightarrow 2} - W_{1 \rightarrow 2}$$

- ▶ The expressions for Q and W represent the heat transferred to and work done by the C.M. during the process of going from State 1 to 2 - there is directionality associated with the scalar values
- ▶ Heat supplied to the C.V. is a positive value; the reverse is negative
- ▶ Work done by the C.V. is a positive value; the reverse is negative



Energy and the C.o.E.

- ▶ We have already seen the expression for total energy E and specific energy e in terms of the summation of internal, kinetic and potential energies

$$E = me = U + KE + PE = m \left(u + \frac{\mathbf{V}^2}{2} + gz \right)$$

- ▶ The energy of a system between one state and another must be conserved for any process, as dictated by the 1st law
- ▶ Therefore, the C.o.E. can be expressed in its entirety as

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



- ▶ **Internal Energy** (U , [kJ]) is another **extensive** property that will be used to characterize a thermodynamics state
- ▶ Just like specific volume, specific internal energy (u) is the internal energy (U) divided by mass and has units [kJ/kg]
- ▶ Internal energy is another independent property of a pure substance, and is reported in the steam tables



Formulations of Internal Energy

- ▶ The total internal energy is the summation of the internal energy of the liquid and vapor phases

$$U = U_f + U_g = m_f u_f + m_g u_g$$

- ▶ Specific internal energy can be calculated based upon the saturated liquid and saturated vapor values and quality

$$u = u_f + x(u_g - u_f)$$

- ▶ For instance, the specific internal energy of saturated water at 0.6 [MPa] and $x=0.95$ is

$$\begin{aligned} u &= 669.9 \text{ [kJ/kg]} + 0.95(1,897.5 \text{ [kJ/kg]}) \\ &= 2,472.544 \text{ [kJ/kg]} \end{aligned}$$



Example #1

- ▶ A vessel with a volume of 5 [m³] contains 0.05 [m³] of saturated liquid water and the remaining is saturated water vapor at 0.1 [MPa]. Heat is transferred into the vessel until it is completely filled with saturated vapor. Determine the amount of heat transferred during this process.

Solution:



Example #1

Solution:

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Example #1

Solution:

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Summary

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

- ▶ Formulate the 1st Law of Thermodynamics and Conservation of Energy equations
 - ▶ The C.o.E. states energy can neither be created nor destroyed such that the change of the sum of the internal, kinetic and potential energies must be equal to the heat supplied less the work done:

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

- ▶ Apply the Conservation of Energy equation to closed systems



Suggested Problems

► 3.48, 3.49, 3.51

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