ENGR 292 Fluids and Thermodynamics

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Timeline

- Last week, Reading Break
- Feb.21: Thermodynamics 1
- Feb.24: Midterm Review (Fluid Statics and Fluid Dynamics) + Examples
- Assignment 2 Due: Feb.24
- Feb.28: Midterm
- Mar.03: Thermodynamics 2

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Big Picture

- Thermodynamics
- Heat Transfer
- Thermal-Fluid Analytical Tools

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Big Picture

- Thermodynamics
  - The science of thermodynamics deals with amount of heat transfer as a system undergoes a process from one equilibrium state to another, makes no reference to how long the process will take.
- Heat Transfer
  - But in engineering, we are often interested in the rate of heat transfer, which is the topic of the science of heat transfer.

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Big Picture

- Thermodynamics
  - The first law of thermodynamics
  - Control volume analysis
  - Rankine Cycle
  - Isentropic Efficiency
  - Refrigerators and Heat Pumps
  - The second law of thermodynamics
  - Entropy
    - T-S Diagram

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Big Picture

- Heat Transfer
  - Conduction
    - Finned Surfaces and Examples
  - Convection
    - Convective Heat Transfer – Finding ‘h’
  - Radiation (briefly introduction)

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Big Picture

- ***Thermal-Fluid Analytical Tools***
  - ***General Energy Equation***
  - ***Navier-Stokes Equation***
  - ***Dimensional Analysis***
  - ***Similitude***
  - ***Lagrangian and Eulerian Reference Frames***

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Basic Concepts

- ***System***
- ***Surrounding***
- ***Boundary***
- ***Closed system***
- ***Open system***
- ***Property***
- ***Intensive Property***
- ***Extensive Property***

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Basic Concepts

- ***State***
- ***Process***
- ***Cycle***
- ***Phases***
  - ***Solid***
  - ***Liquid***
  - ***Gas***

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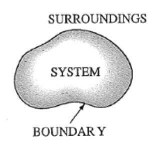
System

- ***A <u>system</u> is defined as a quantity of matter or a region in space chosen for study.***
- ***The mass or region outside the system is called <u>surroundings</u>.***
- ***The real or imaginary surface that separate the system from its surroundings is called <u>boundary</u>.***



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System

- ***The boundary of a system can be fixed or movable.***

- ***Note: the boundary is the contact surface shared by both the system and the surroundings. Mathematically speaking, the boundary has zero thickness, and thus it can neither contain any mass nor occupy any volume in space***

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System

- ***Systems may be considered to be closed or open, depending on whether a fixed mass or a fixed volume in space is chosen for study.***

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System

- **_A closed system (also known as a control mass): consists of a fixed amount of mass, and no mass can cross its boundary, but energy, in the form of heat or work can cross the boundary. The volume of a closed system does not have to be fixed._**
- **_If as a special case, even energy is not allowed to cross the boundary, that system is called an isolated system._**

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Closed System

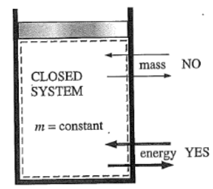

FIGURE 1-21
Mass cannot cross the boundaries of a closed system, but energy can.

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Closed System

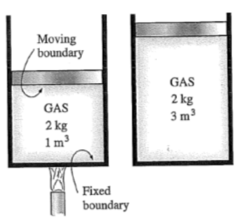

FIGURE 1-22
A closed system with a moving boundary.

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System

- **_An open system or a control volume, as it is often called, is a properly selected region in space. Both mass and energy can cross the boundary of a control volume._**

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Open System

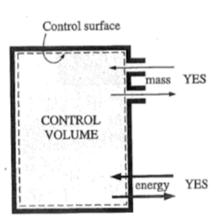

FIGURE 1-23
Both mass and energy can cross the boundaries of a control volume.

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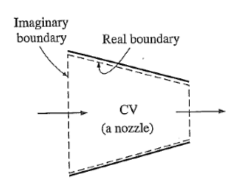
Open System



(*a*) A control volume with real and imaginary boundaries

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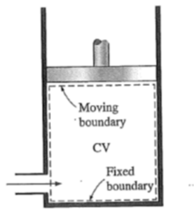
Open System



(*b*) A control volume with fixed and moving boundaries

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Open System

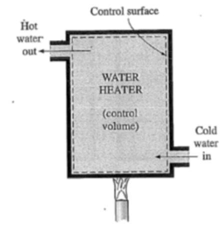

FIGURE 1-25
An open system (a control volume) with one inlet and one exit.

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Thermodynamics

- ***Thermodynamics: The science of energy***

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Properties of A System

- ***Any characteristic of a system is called property***
  - ***Mass***
  - ***Density***
  - ***Volume***
  - ***Temperature***
  - ***Pressure***
  - ***….***

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Properties of A System

- ***Properties are considered to be either intensive or extensive***
  - ***Intensive properties are those that are independent of the size of a system, such as temperature, pressure, and density***
  - ***Extensive properties are those whose values depend on the size or extent of the system, such as Mass, Volume and total energy …***

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Properties of A System

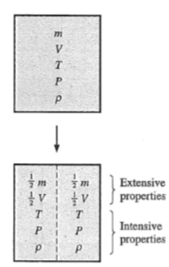

FIGURE 1-27
Criteria to differentiate intensive and extensive properties.

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State and Equilibrium

- Consider a system not undergoing any change. At this point, all the properties can be measured or calculated throughout the entire system, which give us a set of properties that completely describes the condition, or the <u>state</u>.
- If the value of even one property changes, the state will change to different one.

State and Equilibrium

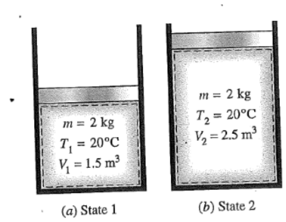

FIGURE 2-1
A system at two different states.

State and Equilibrium

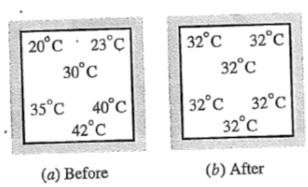

FIGURE 2-2
A closed system reaching thermal equilibrium.

State Postulate

- As noted earlier, the state of a system is described by its properties.
- But we know from experience that we do not need to specify all the properties in order to fix a state.
- The number of properties required to fix the state of a system is given by the state postulate:
- The state of a simple compressible system is completely specified by two independent, intensive properties.

State Postulate

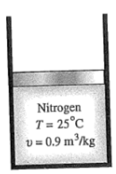

FIGURE 2-3
The state of nitrogen is fixed by two independent, intensive properties.

Process

- Any change that a system undergoes from one equilibrium state to another is called process.
- The series of states through which a system passes during a process is called the path of the process.

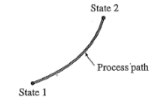

FIGURE 2-4
A process between states 1 and 2 and the process path.

Cycle

- A system is said to have undergone a cycle if it returns to its initial state at the end of the process

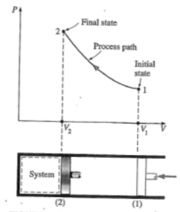

FIGURE 2-7
The *P-V* diagram of a compression process.

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Phases

- *We all know from experience that substances exist in different phases.*
- *At room temperature and pressure, copper is a solid, mercury is a liquid, and nitrogen is a gas.*

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Energy

- ***Energy: the ability to cause changes***
  - *Fundamental concept of thermodynamics*
  - *One of the most significant aspects of engineering analysis*

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Energy

- ***Create list examples of energy generation or consumption in our daily lives:***
  - *Power Plant*
  - *Wind Mill*
  - *Automotive engines*
  - *Refrigerators*
  - *Air conditioning systems*

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Energy

- ***Conservation of Energy:***
  - *The total amount of energy in the system is conserved.*
  - *Energy can be: stored, transformed or transferred*

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Energy

Zeroth Law of Thermodynamics

Two bodies are in thermal equilibrium if both have the same temperature reading even if they are not in contact.

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Energy

Zeroth Law of Thermodynamics

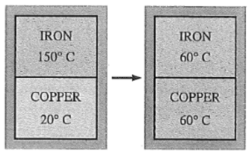


FIGURE 2-14

Two bodies reaching thermal equilibrium after being brought into contact in an isolated enclosure.

Energy

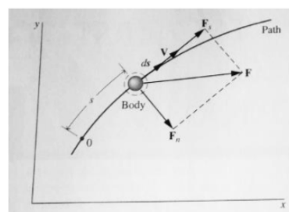
First Law of Thermodynamics

The law of conservation of energy states that the total energy of an isolated system is constant; energy can be transformed from one form to another, but can not be created or destroyed.

Forms of Energy

- ***Newton formulated a general description of motion under applied force, which led to the concepts of:***
  - ***Work***
  - ***Kinetic Energy***
  - ***Potential Energy***

Energy



where:

F= force acting on the body in motion

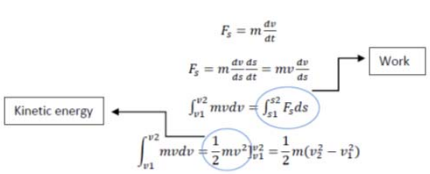
F_s= force component along path or 'streamline'. Affects magnitude

F_n= force component normal to the path or 'streamline'. Affects direction.

F=F(s)

Energy

Equations:



$$F_s = m\frac{dv}{dt}$$

$$F_s = m\frac{dv}{ds}\frac{ds}{dt} = mv\frac{dv}{ds}$$

$$\int_{v1}^{v2} mvdv = \int_{s1}^{s2} F_s ds$$

$$\int_{v1}^{v2} mvdv = \frac{1}{2}mv^2\Big]_{v1}^{v2} = \frac{1}{2}m(v_2^2 - v_1^2)$$

Work

Work:

The work of the resultant force on the body equals the change in it's kinetic energy

Units:

- ***Metric = Nm = J***
- ***Imperial =BTU***

General Equation:

$$\frac{1}{2}m(v_2^2 - v_1^2) = \int_{s_1}^{s_2} Fds$$

Work

Work:

Work done by the body can be considered a transfer of energy to the body, where it is stored as kinetic energy

Work

$$W = \int_{s_1}^{s_2} F ds$$

A means of transferring energy

Work

Work is done by a system on it's surroundings if the sole effect on everything external to the system could have been the raising of a weight.

This is very analogous to mechanics.

Work

Sign conventions:

- W>0: Work is done by the system
- W<0: Work is done on the system

Kinetic Energy

Kinetic Energy:

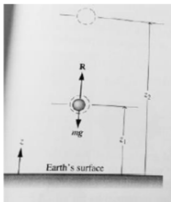
Change in kinetic energy $=\frac{1}{2}m(v_2^2 - v_1^2)$

Potential Energy

Potential Energy:

The energy that an object has due to its position in a force field or that a system has due to the configuration of its parts.

Potential Energy



mg = force due to gravity

R = resultant of all other forces acting on the system

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Potential Energy

Apply governing equation for multiple forces in the z direction:

$$\frac{1}{2}m(v_2^2 - v_1^2) = \int_{z_1}^{z_2} Rdz - \int_{z_1}^{z_2} mgdz$$

$$\int_{z_1}^{z_2} mgdz = mg(z_2 - z_1)$$

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Potential Energy

Potential Energy:

Therefore:

$$\frac{1}{2}m(v_2^2 - v_1^2) + mg(z_2 - z_1) = \int_{z_1}^{z_2} Rdz$$

Gravitational potential energy =mgz

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Power

Power:

The rate of energy transfer by work = $\dot{W}$ or P

$$\dot{W} = Fv$$

Therefore

$$W = \int_{t_1}^{t_2} \dot{W}dt = \int_{t_1}^{t_2} Fvdt$$

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Expansion or Compression Work

Expansion or Compression Work:

Piston-cylinder assembly

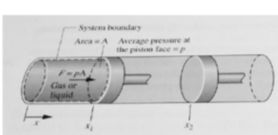

Figure 2.4 Expansion or compression of a gas or liquid.

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Expansion or Compression Work

Expansion or Compression Work:

$$dW = pAdx = pdV$$

$$W = \int_{V_1}^{V_2} pdV$$

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Power Transmitted by a shaft

A rotating shaft with angular velocity, ω , and exerting a torque, T, on it's surroundings produces the following power:

$$\dot{W} = F_t v = \left(\frac{T}{R}\right)(R\omega) = \omega T$$

$$\dot{W} = 2\pi n T$$

Where:

- R ***= radius***
- F_t ***= tangential force***
- n ***= shaft speed***

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Energy

Adiabatic process – No thermal interactions between the system and it's surroundings

Change in energy between two states:

$$E_2 - E_1 = -W_{ad}$$

Where W_{ad}= net work for any adiabatic process between two states. Negative sign means work done on the system.

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Internal Energy

E denotes total energy, including kinetic, potential energy and others. These 'others' are considered internal energy, U.

Examples of internal energy:

1. ***Compress a spring***
2. ***Charge a battery***
3. ***Others?***

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Internal Energy

Internal Energy

Therefore, the change in total energy of the system is defined as:

$\Delta E = \Delta KE + \Delta PE + \Delta U$ ***(for an adiabatic process)***

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Heat Transfer

Heat Transfer

Non-Adiabatic Process – A process that involves a thermal interaction between a system and it's surroundings

Energy transfer Q is only induced as a result of temperature difference between the system and the surroundings and only occurs in the direction of the decreasing temperature. Energy transfer by heat.

$$Q = (E_2 - E_1) + W$$

Or

$$\Delta KE + \Delta PE + \Delta U = Q - W$$

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Heat Transfer

Heat Transfer

Change in the amount of energy contained within the system during some time interval	=	Net amount of energy transferred in across the system boundary by heat transfer during the time interval	–	Net amount of energy transferred out across the system boundary by work during the time interval

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Heat Transfer

Heat Transfer

Sign conventions (opposite of work)

- ***Q>0: Heat transfer to the system***
- ***Q<0: Heat transfer from the system***

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Heat Transfer

Heat transfer rate:

Heat transfer rate, $\dot{Q}$, is the amount of heat transfer per unit time.

$$Q = \int_{t_1}^{t_2} \dot{Q} dt$$

Heat flux:

$$\dot{Q} = \int_A \dot{q} dA$$

Where $\dot{q}$ is heat transfer per unit area

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Heat Transfer

Heat transfer Mechanisms:

Conduction: *Energy transfer in solids, liquids or gases. The rate of heat transfer across any plane normal to the x direction, $\dot{Q}_x$, is proportional to the wall area, A and temperature gradient in the x direction.*

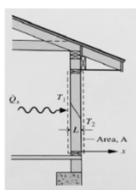
$$\dot{Q}_x = -kA\left[\frac{T_2 - T_1}{L}\right]$$

where

k *= thermal conductivity*

(available in table

L *is the wall thickness*



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Heat Transfer

Heat transfer Mechanisms:

Thermal radiation: *Emitted by matter as a result of changes in the electronic configuration of the atoms or molecules within it.*

Energy is transported by electromagnetic waves. No intervening medium is required and can therefore occur in a vacuum.

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Heat Transfer

Heat transfer Mechanisms:

$$\dot{Q}_e = \varepsilon\sigma A T_b^4$$

where

T_b *is temperature of the surface*

ε *is the emissivity, a property of the surface. How effectively it radiates.*

σ *is the Stefan-Boltzmann constant*

Highly sensitive to temperature T_b

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Heat Transfer

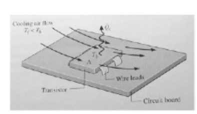
Heat transfer Mechanisms:

Convection: *Energy transfer between a solid surface at T_b and the adjacent moving gas or liquid at temperature T_f*

$$\dot{Q}_c = hA(T_b - T_f)$$

where

h *is the heat transfer coefficient*



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Heat Transfer

Heat transfer Mechanisms:

Forced convection: when fans or pumps cause the fluid to move.

Natural convection: buoyancy induced motion

Applications	h ($W/m^2 \cdot K$)	h ($Btu/h \cdot ft^2 \cdot °R$)
Free convection		
Gases	2–25	0.35–4.4
Liquids	50–1000	8.8–180
Forced convection		
Gases	25–250	4.4–44
Liquids	50–20,000	8.8–3500

What is next?

- ***Any Questions?***
- ***Next class, Midterm Review (Fluid Statics and Fluid Dynamics) + Examples***
- ***Thermodynamics 2:***
  - ***Control volume energy analysis***
    - ***Open systems with energy transfer through a moving fluid***
    - ***Application of continuity and energy balance***
  - ***Properties relations***
  - ***Thermodynamic cycles***