Recitation Handout 1

Topics covered in class: Chapters 1 and 2
Topics covered in recitations: Units, Heat Transfer, Sign Conventions, First law of thermodynamics

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AGENDA

1. Units and Dimensions
2. Heat Transfer Modes
3. Sign Conventions
4. First Law of thermodynamics
5. * Problem from HW

UNITS AND DIMENSIONS

What are units? A unit is a specified amount of quantity by comparison with which any other quantity of the same kind is measured.

Primary dimensions:
Basic physical quantities from which others can be measured – Example: length, time. Standard set: Mass, length, time.

Secondary dimensions:
Other physical quantities which are measured using the Primary dimensions– Example: velocity, area.

Additional primary dimensions: Temperature, Electric current.

SI UNITS: International System of Units – based on mass, length, time

Mass – kilogram – kg
Length – meter – m
Time – second – s

Secondary dimension Eg. : Force = Mass*acceleration = kg*m/s^2 = newton = N

ENGLISH ENGINEERING UNITS: based on mass, length, time

Mass – pound mass– lb
Length – foot – ft
Time – second – s

Secondary dimension Eg. : Force = Mass*acceleration = lb*ft/s^2

1 pound force = 1 lbf = 32.174 lb*ft/s^2

***TEMPERATURE SCALES*:** Section 1-6
Thermodynamic temperature scale: A scale where the temperature values **do not depend** on the properties of any substance(s) used in the measurement process.

1. **KELVIN SCALE**: A thermodynamic scale – denoted by K - lowest temp is 0K
   Standard fixed point – necessary for comparing different scales: Triple point of water = 273.16K; Ice point of water = 273.15K; steam point of water = 373.15K
2. **CELSIUS SCALE**: T(^{o}C) = T(K) – 273.15
3. **RANKINE SCALE**: T(^{o}R) = 1.8 T(K)
4. **FAHRENHEIT SCALE**: T(^{o}F) = T(^{o}R) – 459.67 = 1.8T(^{o}C) + 32

UNITS OF WORK: Section 2.1 - Work has dimension of force * distance

SI Units: Energy unit = newton * meter = N.m = joule = J

English Units: ft * lbf, Btu (British thermal unit)

Reminder: 1 lbf = 32.174 lb*ft/s^2

What is 1 Btu? It is the amount of energy needed to raise the temperature of 1 lb of water at 39 ^{o}F by 1^{o}F.

1 Btu = 778 ft*lbf = 1055 J

UNITS OF POWER: Section 2.2.2 - Power has dimension of Work / time

SI Units: watt = joule/s = J/s

English Units: ft * lbf / s; Btu /hr; horsepower, hp

1 hp = 2545 Btu/hr = 746 watt

<u>Evaluating Work</u>
Section 2.2

General formula: $W = \int_{s_1}^{s_2} \mathbf{F} \cdot d\mathbf{s}$

Power: $\dot{W} = \mathbf{F} \cdot \mathbf{V}$

The above equation can be integrated from time t_1 to time t_2 to get the total work done during the time interval

$$W = \int_{t_1}^{t_2} \dot{W} dt = \int_{t_1}^{t_2} \mathrm{F} \cdot \mathrm{V} dt$$

Work in quasi-equilibrium expansion or compression processes:

Quasi-equilibrium process $\Rightarrow$ equilibrium states at all time during the process

For this class, we assume things to happen **slowly** so we can most of the time assume almost equilibrium.

On a P-V diagram, the area under the process curve represents the work done for a quasi-equilibrium process.

Various formulae are expressed as follows:

1) General: $W = \int_{V_1}^{V_2} pdV$
2) Polytropic process (PV^n =constant): $W = \frac{p_2V_2 - p_1V_1}{1-n} \quad (n \neq 1)$

   Isothermal case ($n=1$) $W = (p_1V_1)\ln\left(\frac{V_2}{V_1}\right) = (p_2V_2)\ln\left(\frac{V_2}{V_1}\right)$
3) Isobaric process (constant pressure, $n=0$): $W = p_0(V_2 - V_1)$

   ($p_1 = p_2 = p_0$ = constant)
4) Isochoric (or isometric) process (Constant volume): $W = 0$

HEAT TRANSFER MODES

Schematics of these are given in class

Conduction:

$\dot{Q}_x = -kA\frac{dT}{dx}$ k= Thermal conductivity = (W/m.K), A=area through which heat transfer occurs

In the case of temperature varying linearly (or for thin walls of width L),

$$\frac{dT}{dx} = \frac{T_2 - T_1}{L}(< 0)$$

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

Convection:

$\dot{Q}_c = hA(T_b - T_f)$ h= Heat transfer coefficient = (W/m^2.K), A=area through which heat convection occurs, T_b and T_f are e.g. the temperatures of the wall and the fluid.

Radiation:
May or may not be used in this class, but nice to know.

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

ε =surface emissivity, σ =constant

SIGN CONVENTIONS
The following sign conventions are used throughout the book.

Work:
W > 0: work done *by* the system
W < 0: work done *on* the system

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

Note: In certain instances to be discussed in future lectures, we may use opposite signs for convenience of presentation. For now you assume the notation to be given as above.

Energy balance for closed systems:
Section 2.5:

The **energy balance** can be expressed as

$$E_2 - E_1 = Q - W$$

An alternative form is:

$$\Delta\mathrm{KE} + \Delta\mathrm{PE} + \Delta U = Q - W$$

The instantaneous **time rate form of the energy balance** is

$$\frac{dE}{dt} = \dot{Q} - \dot{W}$$

An alternative form is:

$$\frac{dKE}{dt} + \frac{dPE}{dt} + \frac{dU}{dt} = \dot{Q} - \dot{W}$$

where Q is energy transferred by heat, W is energy transferred by work, KE is kinetic energy, PE is potential energy, and U is internal energy.

Hints regarding the Homework

Question: In the swimming pool problem, the pressure is varying. How do we do integral to get the force? Do we need to integrate for this problem?

Answer: You can write down the integral as Force = integral of Pressure*dA. dA can be specified as length or width times dx, then you can integrate that. You can definitely play with math to get the answer, but an alternative method is to use a force balance on the water (just compute the weight/volume of the water, that's the force you need).

Question: In Problem 5, what does it mean that the insulation is at steady state?

Answer: Steady state means that there is no change of the energy contained within the system at that time. (i.e. dE/dt = 0) This simplifies the energy balance equation greatly.

Question: In problem 4, do I use F=kx to compute the spring force?

Answer: Based on what the problem tells you (linear relation of F and volume V and zero force when $V=V_2$), you can write immediately $F=k(V- V_2)$. You can then compute k since you know F when $V= V_1$. The rest of the problem is just a force balance on the piston!

Question: In problem 5, how do I find the `minimum' thickness?

Answer: Can you use an energy balance and find L in terms of the surface temperature? If you can, then plot this relation and from that graph you can see what is the needed minimum L!

Other hints:

Problem 1:
- Everything in same units
- $pV^{1.4}=C$
- $W = \int_{V_1}^{V_2} pdV$ ←substitute for p

Problem 2:
- Drawing out problem
- Force balance (don't forget p_{atm})
- Finding volume
- P/A→which area?

Problem 3:
- Force Balance

- Quasi-static
- Process 1= constant p; Process 2= const vol
- $W = \int_{V_1}^{V_2} pdV$

Problem 4:

- Force Balance
- Fs= k(V- V_2)***

Problem 5:

- Draw it out
- Steady State ($\dot{Q}_x = \dot{Q}_c$)**can get it easily from here

Problem 6:

- Closed
- $\frac{dE}{dt} = \dot{Q} - \dot{W}$ (signs important)
- Unit conversions at end (kwh→kJ)
- One form is $\frac{dE}{dt}$,one is ΔE