1 Fundamentals: Week 1 (Jul 30–Aug 3)

1.1 Lecture 1: Jul 30

1. Fuel consumption is central to power generation. Heat generated from burning of fuels is an input to engines, power plants. We desire work output from these devices by means of rotation of wheels, generation of electricity, etc. Relations between heat and work is dealt with in the subject of Thermodynamics (TD)
2. TD – science of relations between heat, work, and properties of system: Relates changes with matter undergoes to the influence to which it is subjected
3. TD does not cover: (a) Rate of a process: dealt with in topics like heat transfer, mass transfer, and chemical kinetics (b) Microscopic structure of matter: TD treats matter as continuum. All our discussions on properties and their values makes sense only in this framework.
4. Discussion on course structure, logistics; Grading only based on exams; tutorials are not graded.

Starting out on fundamental concepts ...

System, Surroundings:

1. TD system: region contained within a boundary where attention is focused for thermodynamic analysis; Everything other than a system is called surrounding. System + Surrounding = Universe.
2. Two main types of TD system:
   (a) *Control mass (also called closed system or just 'system)* – only energy interactions are possible across a boundary
   (b) *Control volume (also called open system)* – energy and mass interactions are possible across a boundary – typically used to analyse flow devices (turbines, nozzles, etc.)
3. Special case: Isolated system – does not permit mass or energy interactions across its boundary. Example: Universe
4. Mass of a *control mass* is fixed: In a process the system boundary may have to deform to accommodate the same mass throughout the process
5. Volume of a *control volume (CV)* is ypically fixed (this is one advantage in choosing a CV based analysis over a system. Nonetheless, the boundary of a CV may also be chosen to deform during a process, and hence its volume is not necessarily fixed (Example: engine-intake-process discussed in class).

Property:

1. Any measurable or calculatable attirbute of a system
2. Example: pressure, temperature, volume, energy
3. Classification of property
   (a) Extensive: depends on the extent, *i.e.* amount of substance. Example: volume, energy
   (b) Intensive: independent of amount of substance. Example: pressure, temperature
   (c) Specific properties: Extensive property per unit mass: are intensive too. Example: volume/mass (=specific volume, denoted as v), energy/mass (=specific energy, denoted as e).

1.2 Lecture 2: Jul 31

1. Clarification on notion of continuum presented: property measurement in a small box containing 10 (small number) vs 10^6 (large number) molecules
2. Note: In some cases, the same problem can be analysed with a system approach or a CV approach. Example: filling of methane gas cylinder discussed in class

Discussion of fundamental concepts continues ...

1. State of a system: totality of the properties of a system: a complete description of the system
2. State-point: Point on a diagram representing the properties of a system at any moment (the diagram is called the property diagram)
   Note: The moment a point is marked on a property diagram, the same value of that property is understood to manifest throughout the system. Marking an intensive property, such as pressure $p \implies$ there is one uniform value of pressure throughout the system; Marking extensive property (such as E) is always okay – since it is any way one value for the entire extent of the system (no notion of spatial variation exists in this case).
3. Process: Succession of states encountered by a system as it changes state from initial state to final state.
4. When a system starts from state A, undergoes a process, and returns to state A, it is said to have undergone a *cyclic process*
5. *Important!*: Sketching a thermodynamic process on a process diagram is ONLY possible when the change of state is slow: essentially a quasi-equilibirum process. In that case, the system passes through every intermediate state as it changes from A to B.
6. Example of (a) piston held with stops, where stops are moved abruptly (non-equilbrium process, shown by broken/dashed line on process diagram) vs (b) piston moved out slowly by connecting an external rod to provide enough resistance to move it slowly (quasi-equilbrium process, shown by continuous/solid line on process diagram)
7. Path-independence of property: Change in value of a property as the system moves from state 1 (initial state) to 2 (final state) depends only on the initial and final states, and does not depend on the path 1 to 2. Example: $\Delta p_{12}|_{\text{any path}} = p_2 - p_1$, $\Delta V = V_2 - V_1$.
8. Above is a 'if and only if' statement: In fact, those attributes of a system, whose change depends on the initial and final states only and does not depend on the path/process that led to the change are called properties.
9. Algebraic manipulation of properties is also a property. Example: $p^2 V$ is a property.

1.3 Lecture 3: Aug 2

Discussion of path-dependent vs path-independent functions ...

1. Path-independence of property: Change in value of a property as the system moves from state 1 (initial state) to 2 (final state) depends only on the initial and final states, and does not depend on the path 1 to 2. Example: $\Delta p_{12}|_{\text{any path}} = p_2 - p_1$, $\Delta V = V_2 - V_1$.

Graphically determine whether a quantity is property or not

1. Tutorial problem P3 (A-B-C, A-D-C, A-C) worked out
2. For path-dependent functions, evaluating integrals along different paths gave different answers
3. (a) $\int_A^C pdV, (b) \int_A^C Vdp$, and their difference (d) $\int_A^C (pdV - Vdp)$ were found to be path-dependent (inexact differentials)
4. Interestingly, their sum (c) $\int_A^C pdV + Vdp$ was found to be path-independent.

Mathematically determine whether a quantity is property or not

1. If $z(x, y)$ is a path-independent function, then dz is an exact differential, *i.e.* $dz = \dfrac{\partial z}{\partial x}dx + \dfrac{\partial z}{\partial y}dy$. It follows that, the following relationship holds:
$$\frac{\partial}{\partial y}\left(\frac{\partial z}{\partial x}\right) = \frac{\partial}{\partial x}\left(\frac{\partial z}{\partial y}\right) \tag{1}$$
by symmetry of second derivatives
2. Given an expression $dz = f(x, y)dx + g(x, y)dy$, we identify the partial derivatives as $\dfrac{\partial z}{\partial x} = f(x, y)$ and $\dfrac{\partial z}{\partial y} = g(x, y)$, Checking for condition (1) is equivalent to calculating $\dfrac{\partial f}{\partial y}, \dfrac{\partial g}{\partial x}$ and examining if they are the same.
3. If $\dfrac{\partial f}{\partial y} = \dfrac{\partial g}{\partial x}$, then $z(x, y)$ is a path-independent function, and therefore a thermodynamic property (for our objective), and dz is an exact differential. Then, the function form of z can be obtained by integration.
4. If $\dfrac{\partial f}{\partial y} \neq \dfrac{\partial g}{\partial x}$, then $z(x, y)$ is a path-dependent function, and therefore NOT a thermodynamic property, and δz is an inexact differential. Note the use of symbol δz in place of dz for denoting the differential.
5. Example worked out in class: tutorial problem: Given expression for dp, is p a property or not? p was found to be a property, and its functional form was obtained by integrating in steps (with respect to T and V separately)

Notion of a system is far wider than having a unique property value

1. Methane filling example: line pressure higher than cylinder pressure; yet, this can be analysed as a sytem: only that you can never mark one value of pressure on the property diagram, since different parts of the system have different values of p
2. In this system, I can still note extensive property values, for instance, total E (extensive property) and volume on a property diagram, but cannot mark any of the spatially varying intensive property values
3. If the valve is regulated to allow slow filling of methane, then the process 1–2 can be drawn with a solid line on the property diagram.
4. If not (valve is operated abruptly), then, we connect 1–2 with a broken line, since we do not know the intermediate states with certainty. Although we cannot say about the intermediate states, we can still find out the initial and final states, since they are equlibrium states.
5. Other examples of systems from tutorial: battery, spring, etc.
6. In a nutshell, TD system: draw a boundary around the entity of interest. Depending on mass or energy interactions across this boundary, classify it as a system (control mass) or CV and proceed with the TD analysis.

1.4 Lecture 4: Aug 4

Pressure and its measurement

1. Fluid exerts forces on boundaries
2. Pressure: force exerted on a surface, normal to the surface, per unit area of the surface.
3. Pressure is a distributed force

Pressure measurement devices

1. Works on Pascal's principle: pressure is the same measured at every point on a horizontal plane through the same continuous liquid at equilibirum.
2. Manometer: typical fluid is Hg. Measures difference in pressures between its two arms ($p_1 - p_2 = \rho g h$, where ρ is the density of Hg); level of Hg in limb attached to gas with pressure p_2 is higher.
3. If one limb is opened to atmosphere, ($p_1 - p_{atm} = \rho_{Hg} g h$), the pressure relative to background gas, here atmosphere) is measured.
4. If $p_1 > p_{atm}$, we call $p_1 - p_{atm}$ the 'gauge pressure' of gas 1, and if $p_1 < p_{atm}$, we call $p_{atm} - p_1$ the 'vaccuum pressure' of gas 1.
5. Barometer: tube filled with Hg is inverted over a Hg-bath tub. Hg level in the tube drops till it reached a final value. Note: space above Hg in the tube is essentially vaccuum. The height of Hg in the tube corresponds to atmospheric pressure. Used in meteorological works.
6. Bourdon gage: has a tube with one end free to move and the other fixed to the fluid whose pressure is to be measured. The free end coils/uncoils in response to pressure differences between background gas (of the chamber where it is housed) and the pressure exposed to its tube end. The movement of the free end is coupled to a gear mechanism that amplifies the movement to show the pressure difference, calibrated on a dial.
7. Examples worked out in class: (a) 1 m tube with a central 10 cm Hg column turned vertical (b) J-shaped manometer filled with Hg until it spills