THERMODYNAMICS: COURSE INTRODUCTION

Course Learning Objectives:

To be able to use the First Law of Thermodynamics to estimate the potential for thermo-mechanical energy conversion in aerospace power and propulsion systems.

Measurable outcomes (assessment method):

1) To be able to state the First Law and to define heat, work, thermal efficiency and the difference between various forms of energy. (quiz, self-assessment, PRS)

2) To be able to identify and describe energy exchange processes (in terms of various forms of energy, heat and work) in aerospace systems. (quiz, homework, self-assessment, PRS)

3) To be able to explain at a level understandable by a high school senior or non-technical person how various heat engines work (e.g. a refrigerator, an IC engine, a jet engine). (quiz, homework, self-assessment, PRS)

4) To be able to apply the steady-flow energy equation or the First Law of Thermodynamics to a system of thermodynamic components (heaters, coolers, pumps, turbines, pistons, etc.) to estimate required balances of heat, work and energy flow. (homework, quiz, self-assessment, PRS)

5) To be able to explain at a level understandable by a high school senior or non-technical person the concepts of path dependence/independence and reversibility/irreversibility of various thermodynamic processes, to represent these in terms of changes in thermodynamic state, and to cite examples of how these would impact the performance of aerospace power and propulsion systems. (homework, quiz, self-assessment, PRS)

6) To be able to apply ideal cycle analysis to simple heat engine cycles to estimate thermal efficiency and work as a function of pressures and temperatures at various points in the cycle. (homework, self-assessment, PRS)

Teaching & Learning Methods

1) Detailed lecture notes are available on the web (for viewing and/or downloading). You should download a copy of these and bring them with you to lecture.

2) Preparation and participation will be important for learning the material. You will be responsible for studying the notes prior to each lecture. Several reading

assignments will be given to help promote this activity (1/3 of participation grade).

3) Several active learning techniques will be applied on a regular basis (turn-to-your-partner exercises, muddiest part of the lecture, and ungraded concept quizzes). We will make extensive use of the PRS system (2/3 of participation grade).

4) Homework problems will be assigned (approximately one hour of homework per lecture hour). The Unified Engineering collaboration rules apply.

THERMODYNAMICS CONCEPTS

I. Thermodynamics (VW, S & B: Chapter 1)

A. **Describes processes that involve changes in temperature, transformation of energy, relationships between heat and work.**

B. **It is a science, and more importantly an engineering tool, that is necessary for describing the performance of propulsion systems, power generation systems, refrigerators, fluid flow, combustion, ...**

C. **Generalization of extensive empirical evidence (however most thermodynamic principles and can be derived from kinetic theory)**

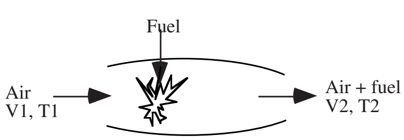
D. **Examples of heat engines**

$$\begin{bmatrix} \text{Combustion Heat} \\ \text{Solar Heat} \\ \text{Nuclear Heat} \end{bmatrix} \longrightarrow [\text{Heat Engine}] \longrightarrow \begin{bmatrix} \text{Mechanical Work} \\ \text{Electrical Energy} \end{bmatrix}$$

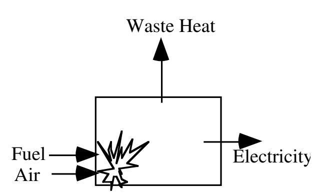
$$[\text{Heat Engine}] \dashrightarrow [\text{Waste Heat}]$$

OR

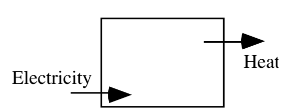
$$\begin{bmatrix} \text{Mechanical Work} \\ \text{Electrical Energy} \end{bmatrix} \longrightarrow [\text{Heat}]$$



1. propulsion system



2. power generation



3. Refrigerator

E. Questions:

1. Describe the energy exchange processes in ___________ (fill in the blank, e.g. a nuclear power plant, a refrigerator, a jet engine).

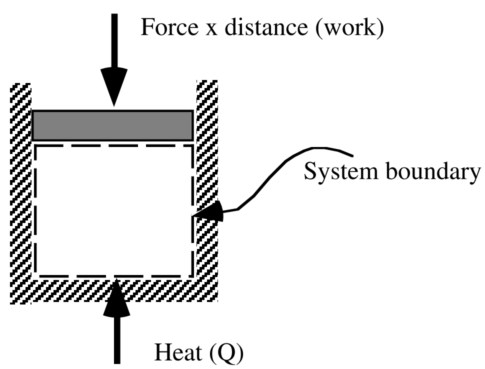
2. Given that energy is conserved, where does the fuel+oxidizer energy that is used to power an airplane go?

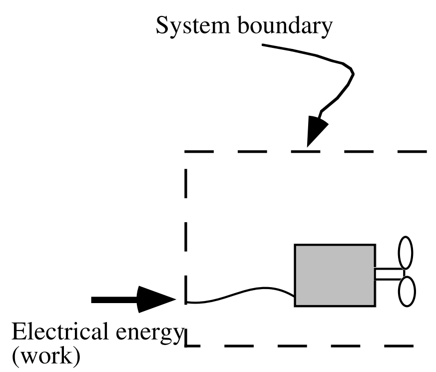
3. Describe the energy exchange processes necessary to use electricity from a nuclear power plant to remove heat from the food in a refrigerator.

4. Describe the energy exchange processes necessary for natural gas to be used to provide electricity for the lights in the room you are in.

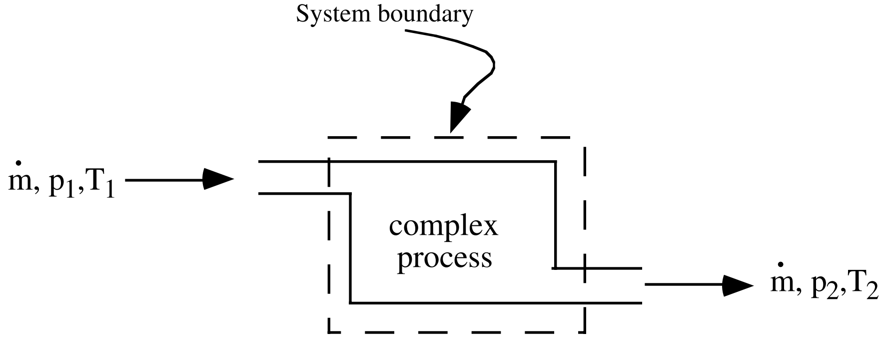
II. Concept of a thermodynamic system *(VW, S & B: 2.1)*

A. A quantity of matter of fixed identity, boundaries may be fixed or movable, can transfer heat and work across boundary but not mass





B. Identifiable volume with <u>steady flow</u> in and out, a control volume. Often more useful way to view devices such as engines



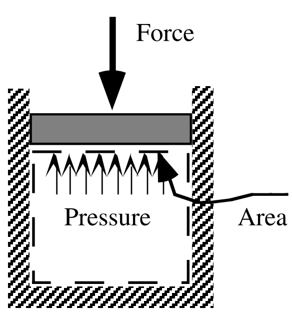
III. Thermodynamic state of a system

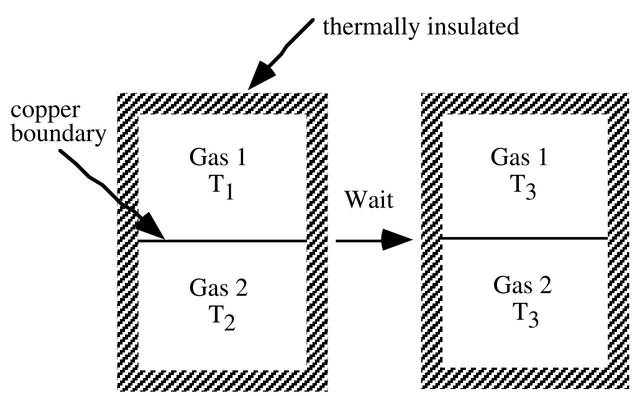
A. The thermodynamic state of a system is defined by specifying a set of measurable properties sufficient so that all remaining properties are determined. Examples of properties: pressure, temperature, density, internal energy, enthalpy, and entropy.

B. For engineering purposes we usually want gross, average, macroscopic properties (not what is happening to individual molecules and atoms) thus we consider substances as continua -- the properties represent averages over small volumes. For example, there are 10^{16} molecules of air in 1 mm^3 at standard temperature and pressure. ***(VW, S & B: 2.2)***

. Intensive properties do not depend on mass (*e.g*. p, T, ρ, v=1/ρ, u and h); extensive properties depend on the total mass of the system (*e.g*. V, M, U and H). Uppercase letters are usually used for extensive properties. ***(VW, S & B: 2.3)***

D. Equilibrium: States of a system are most conveniently described when the system is in equilibrium, *i. e.* it is in steady-state. Often we will consider processes that change "slowly" -- termed quasi-steady. ***(VW, S & B: 2.3-2.4)***





1. mechanical equilibrium
(force balances pressure times area)

2. thermal equilibrium
(same temperature)

E. Two properties are needed to define the state of any pure substance undergoing a steady or quasi-steady process. (This is an experimental fact!) ***(VW, S & B: 3.1, 3.3)***

1. For example for a thermally perfect gas (this is a good engineering approximation for many situations, but not all (good for $p \ll p_{crit}$, and $T > 2T_{crit}$ up to about $4p_{crit}$). *(VW, S & B: 3.4)*:

$$p\,\bar{v} = \mathcal{R}T$$

$\bar{v}$ is volume per mol of gas, $\mathcal{R}$ is the universal gas constant $\mathcal{R}$ = 8.31kJ/Kmol-K. Dividing by molecular weight,

$$p\,\bar{v}/\mathcal{M} = (\mathcal{R}/\mathcal{M})\,T$$

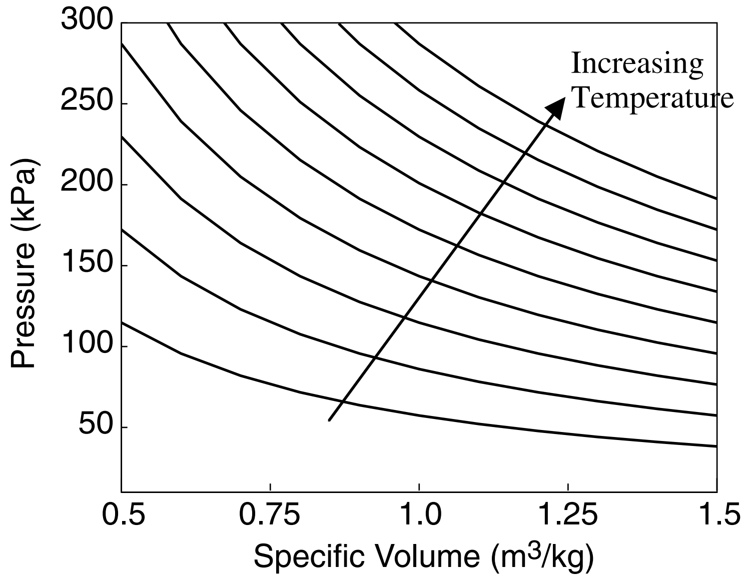
where $\mathcal{M}$ is the molecular weight of the gas. Most often written as

$$pv = RT \quad \text{or} \quad p = \rho RT$$

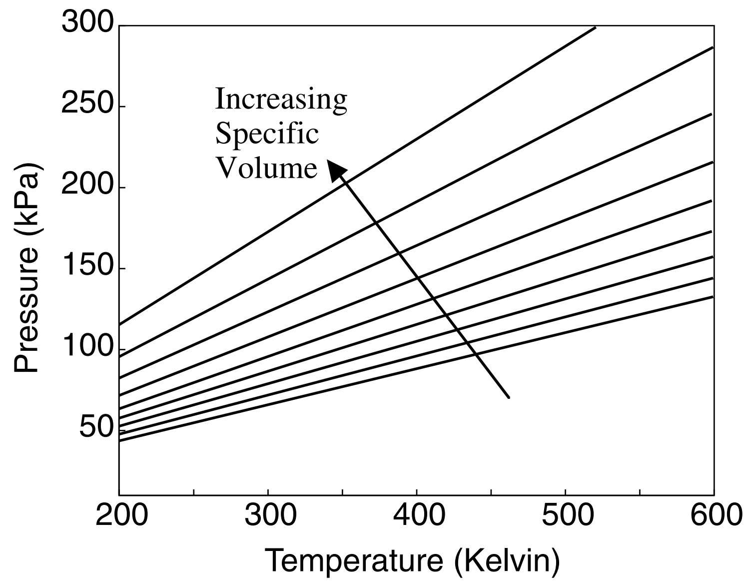
where v is the specific volume and R is the gas constant (which varies depending on the gas. R = 287J/kg - K for air).

Thus, if we know p and T we know ρ, if we know T and ρ, we know p, *etc.*

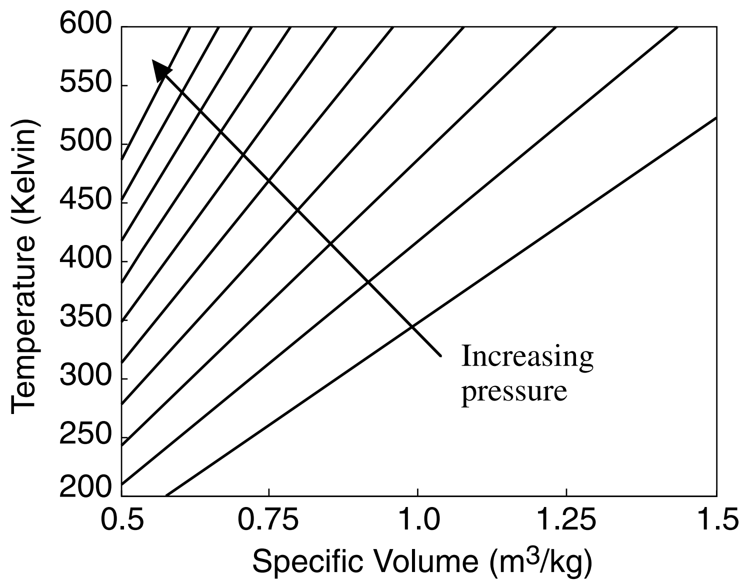
F. For thermodynamic processes we are interested in how the state of a system changes. So typically we plot the behavior as shown below. It is useful to know what a constant temperature line (isotherm) looks like on a p-v diagram, what a constant volume line (isochor) looks like on a T-p diagram, *etc.*



1.p-v diagram

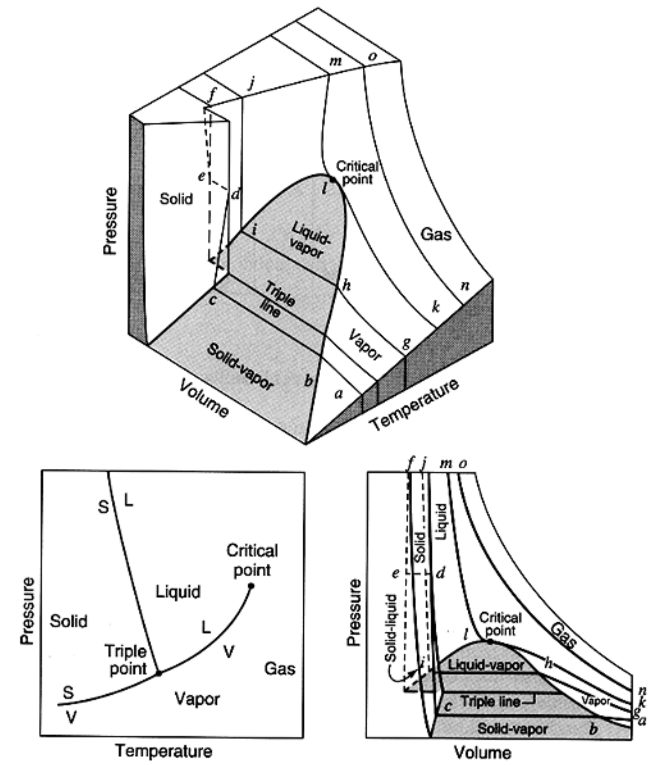


2. p-T diagram



3. T-v diagram

G. Note that real substances may have phase changes (water to water vapor, or water to ice, for example). Many thermodynamic devices rely on these phase changes (liquid-vapor power cycles are used in many power generation schemes, for example). You will learn more about these in 16.050. In this course we will deal only with single-phase thermodynamic systems.



Pressure-temperature-volume surface for a substance that expands on freezing
(from*VW, S & B: 3.7*)