Review of the Fundamentals

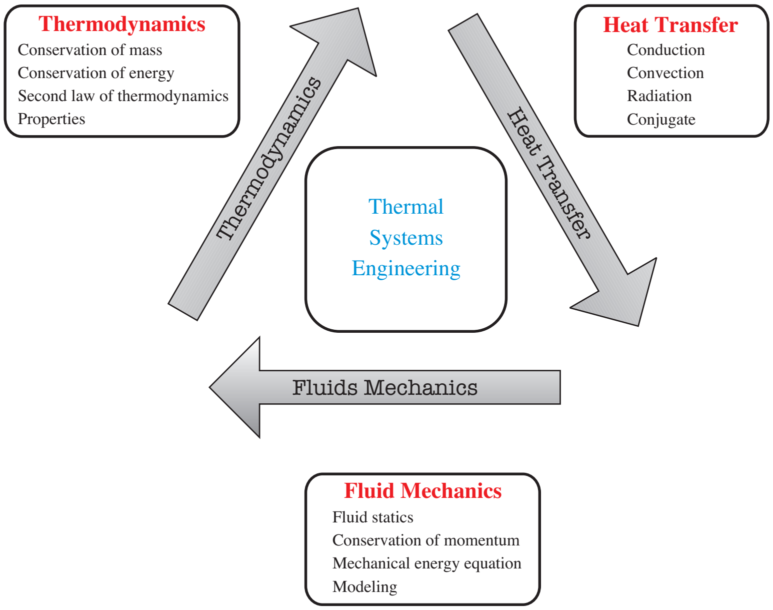
Reading

Review Chapter 3 and property tables
More specifically, look at:
3.2 → 3.4, 3.6, 3.7, 8.4, 8.5, 8.6, 8.8

Problems

Thermal Sciences

The thermal sciences involve the *storage*, *transfer* and *conversion* of energy.



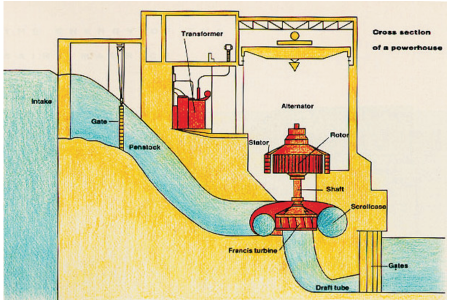
Thermodynamics: the study of energy, energy transformations and its relation to matter. The analysis of thermal systems is achieved through the application of the governing conservation equations, namely *Conservation of Mass*, *Conservation of Energy* (1st law of thermodynamics), the 2nd law of thermodynamics and the property relations.

Heat Transfer: the study of energy in transit including the relationship between energy, matter, space and time. The three principal modes of heat transfer examined are conduction, convection and radiation, where all three modes are affected by the thermophysical properties, geometrical constraints and the temperatures associated with the heat sources and sinks used to drive heat transfer.

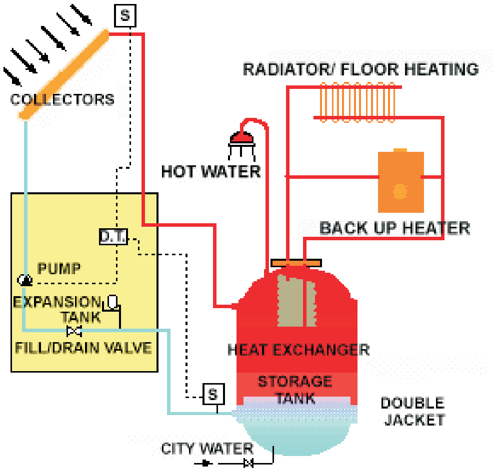
Fluid Mechanics: the study of fluids at rest or in motion. While this course will not deal extensively with fluid mechanics we will be influenced by the governing equations for fluid flow, namely *Conservation of Momentum* and *Conservation of Mass*.

Examples of Energy Conversion

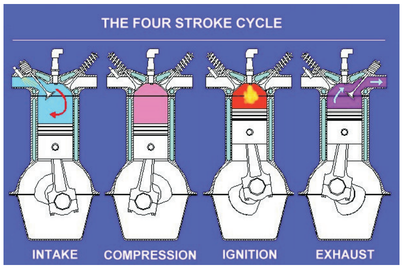
hydroelectric
(gravitational potential)



windmills
(kinetic energy)



solar energy
(photo-thermal conversion)

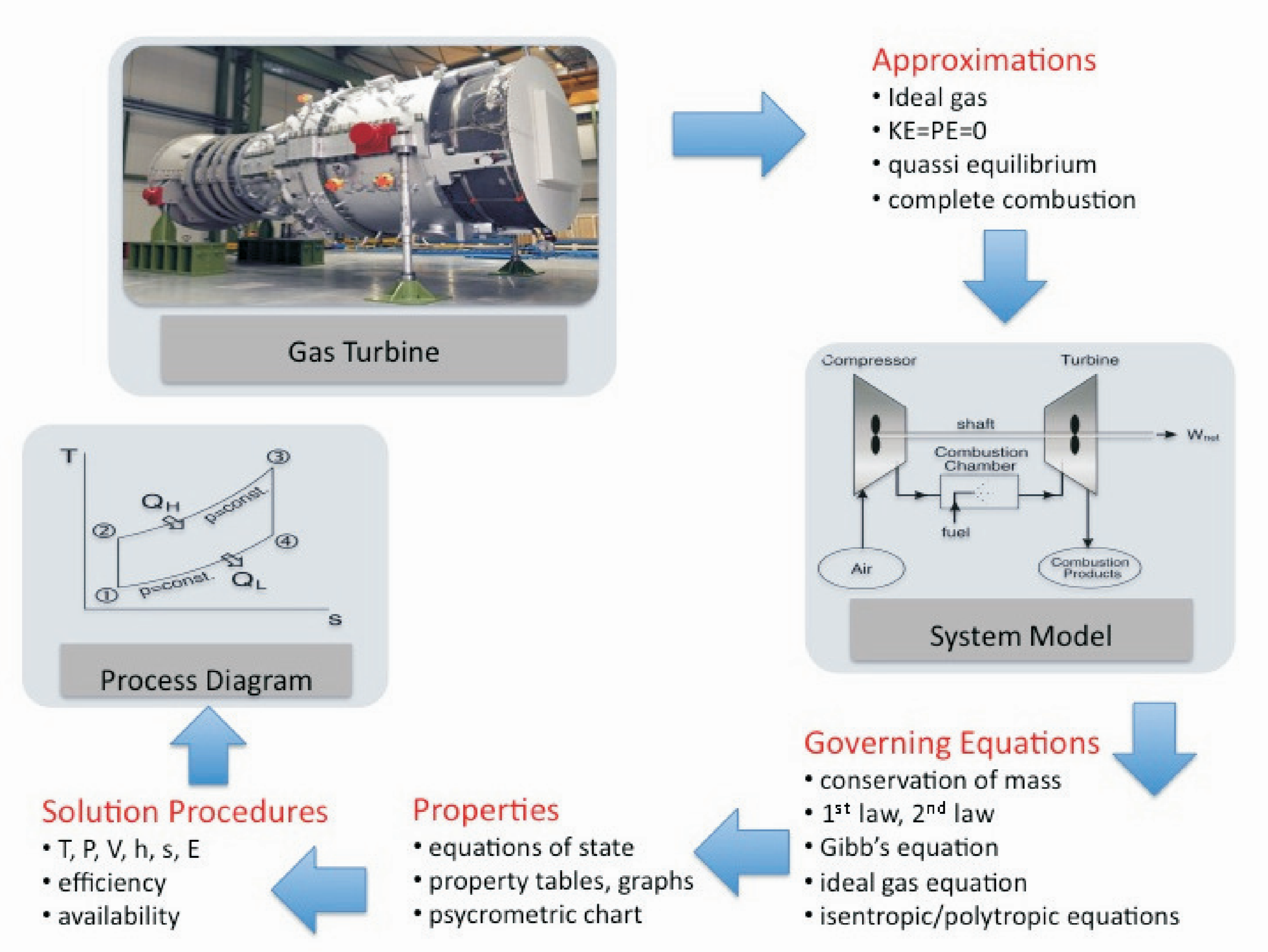


automotive engine
(chemical conversion)

Other Examples

- power plants
- refrigeration systems
- automotive engines
- jet engines
- heating, ventilation and air conditioning
- human body

Modelling & Analysis of Thermodynamic Systems



Approximations
- Ideal gas
- KE=PE=0
- quassi equilibrium
- complete combustion

Governing Equations
- conservation of mass
- 1st law, 2nd law
- Gibb's equation
- ideal gas equation
- isentropic/polytropic equations

Properties
- equations of state
- property tables, graphs
- psycrometric chart

Solution Procedures
- T, P, V, h, s, E
- efficiency
- availability

Modelling and Analysis of Thermodynamic Systems

Step 1: System Identification

Step 2: Assumptions

Step 3: System Model

Step 4: Governing Equations

Step 5: Properties

Step 6: Solution Procedure

Step 7: Process Identification

We need a good understanding of Thermodynamics fundamentals (as presented in ME250: Thermodynamics 1) in order to proceed with our system modeling and analysis.

Thermodynamic Fundamentals

We will need to characterize the thermophysical properties of the three distinct homogeneous phases of materials as they move through a range of temperature, pressure and volume.

- ME250: Thermodynamics 1 looked at equations of state, thermophysical properties and property relationships
- we will review the various sources for determining material properties

Gases

Thermodynamic relations are generally given in three different forms:

Tables: water (Tables B.1.1 → B.1.5), Ammonia (Table B.2.1), R134a (Tables B.5.1 → B.5.2)

Graphs: water (Figures E.1 & E.4 [psychrometric chart])

Equations: (Appendix D)

Ideal Gases

- gases that adhere to a pressure, temperature, volume relationship

  $$Pv = RT \qquad \text{or} \qquad PV = mRT$$

  are referred to as ideal gases

For an ideal gas with constant c_p and c_v

$$\begin{aligned} Pv &= RT \\ u_2 - u_1 &= c_v(T_2 - T_1) \\ h_2 - h_1 &= c_p(T_2 - T_1) \end{aligned}$$

There are 3 forms of a change in entropy as a function of T & v, T & P, and P & v.

$$\begin{aligned} s_2 - s_1 &= c_v \ln \frac{T_2}{T_1} + R \ln \frac{v_2}{v_1} \\ &= c_p \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1} \\ &= c_p \ln \frac{v_2}{v_1} + c_v \ln \frac{P_2}{P_1} \end{aligned}$$

$$R = c_p - c_v$$

What can be done when the ideal gas assumption in not viable?

Compressibility Factor

- provides a quantitative procedure for determining the suitability of the ideal gas assumption
- the compressibility factor is given as

$$Z = \frac{P\,v}{RT}$$

  where $Z = 1$ for an ideal gas and any deviation from 1 is a measure of the suitability of the ideal gas assumption

- if we "reduce" the properties with respect to the values at the critical point, i.e.

$$\text{reduced pressure} = P_r = \frac{P}{P_c} \qquad P_c = \text{critical pressure}$$

$$\text{reduced temperature} = T_r = \frac{T}{T_c} \qquad T_c = \text{critical temperature}$$

- Table A.2 lists the critical pressure and critical temperature for various gases

Is Water Vapor an Ideal Gas?

- Figure E.1 can be used to determine the regions where water vapor behaves as an ideal gas

Isentropic and Polytropic Processes for Ideal Gases

Given:

- constant specific heats over a wide range of temperature
- $ds = 0$
- $du = c_v dT \equiv c_v = \left(\frac{\partial u}{\partial T}\right)_V$
- $dh = c_p dT \equiv c_p = \left(\frac{\partial h}{\partial T}\right)_P$

The product of $P \cdot v^k$ remains constant for an ideal gas when:

- specific heats are constant
- the gas undergoes an isentropic process → reversible + adiabatic

Combining this result with the ideal gas equation of state

$$\boxed{\frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{k-1} = \left(\frac{P_2}{P_1}\right)^{(k-1)/k}}$$

The isentropic process is a special case of a more general process known as a polytropic process

where → $Pv^n = constant$ and n is any number.

Special Cases

$n = 1$ $\quad Pv = RT = constant \Rightarrow$ isothermal process

$n = 0$ $\quad Pv^0 = constant = P \Rightarrow$ isobaric process (constant pressure)

$n = k$ $\quad Pv^k = constant \Rightarrow$ isentropic process ($k = c_p/c_v$)

$n = \infty$ $\quad Pv^\infty = constant \Rightarrow$ isochoric process (constant volume)

Relative Pressure and Relative Specific Volume

- **Procedure:**
  - given T_1, P_1 and P_2 for an isentropic process
  - determine P_{r1} at T_1 from Table A.7.2
  - calculate P_{r2}, where

$$\left(\frac{P_2}{P_1}\right)_{s=const} = \frac{P_{r2}}{P_{r1}}$$

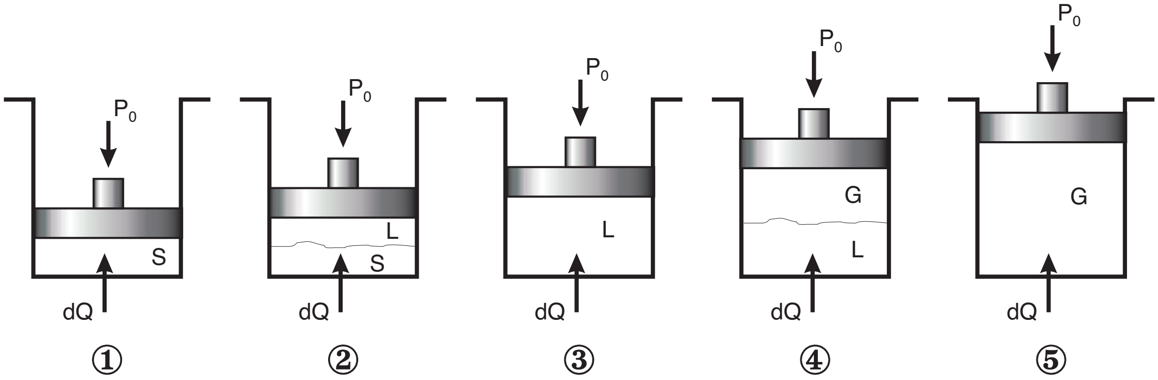
  - read T_2 from Table A-7.2 for the calculated value of P_{r2}
- use a similar procedure if volume is known instead of pressure, where

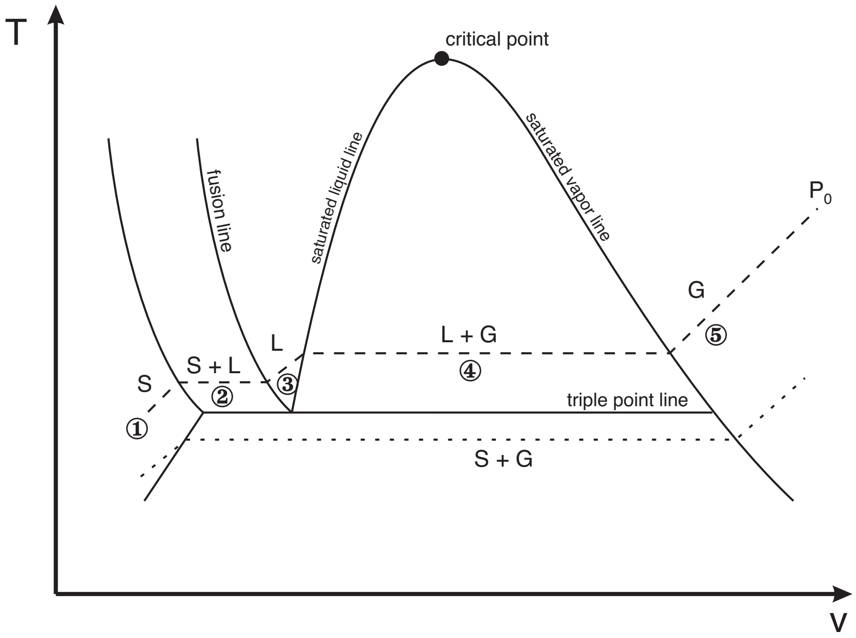
$$\left(\frac{v_2}{v_1}\right)_{s=const} = \frac{v_{r2}}{v_{r1}}$$

Liquids

$T - v$ Diagram for a Simple Compressible Substance

- consider an experiment in which a substance starts as a solid and is heated up at constant pressure until it all becomes as gas





- depending on the prevailing pressure, the matter will pass through various phase transformations. At P_0:

  1. solid
  2. mixed phase of liquid and solid
  3. sub-cooled or compressed liquid
  4. wet vapor (saturated liquid-vapor mixture)
  5. superheated vapor

Properties of Saturated Mixtures

- all the calculations done in the vapor dome can be performed using Tables.
  - in Table B.1.1, the properties are listed under Temperature
  - in Table B.1.2, the properties are listed under Pressure

Properties of Superheated Vapor

- superheated means $T > T_{sat}$ at the prevailing P, eg. water at $100\ kPa$ has a saturation temperature of $T_{sat}(P) = 99.63\ °C$.
- Table B.1.3 for superheated water

Properties of Sub-cooled (Compressed) Liquid

- sub-cooled liquid means $T < T_{sat}$ at the prevailing P, eg. water at $20\ °C$ and $100\ kPa$ has a saturation temperature of $T_{sat}(P) = 99.63\ °C$.
- Table B.1.4 for compressed liquid water (if not available, you can use the approximations listed above)

Reference Values for u, h, s

- values of enthalpy, h and entropy, s listed in the tables are with respect to a datum where we arbitrarily assign the zero value. For instance:

  Tables B.1.1, B.1.2: saturated liquid - the reference for both h_f and s_f is taken as $0\ °C$. This is shown as follows:

$$\begin{aligned} u_f(@T = 0\ °C) &= 0\ kJ/kg \\ h_f(@T = 0\ °C) &= 0\ kJ/kg \\ s_f(@T = 0\ °C) &= 0\ kJ/kg \cdot K \end{aligned}$$

  Tables B.5.1, B.5.2: saturated R134a - the reference for both h_f and s_f is taken as $-40\ °C$. This is shown as follows:

$$\begin{aligned} h_f(@T = -40\ °C) &= 0\ kJ/kg \\ h_f(@T = -40\ °C) &= 0\ kJ/kg \\ s_f(@T = -40\ °C) &= 0\ kJ/kg \cdot K \end{aligned}$$

Guidelines to Solve Thermodynamic Problems

1. Read the problem carefully and understand the requirements.
    (a) hi-lite or underline specific conditions and/or information requested
2. Sketch the necessary diagrams.
    (a) **System diagram:** indicate the system components/stages
    (b) **Process diagram:** indicate the states
3. State assumptions and idealizations.
4. Apply the laws of thermodynamics (1st and 2nd laws, conservation of mass).
5. Simplify the general equations based on assumptions and idealizations.
6. Obtain the necessary thermodynamic properties from figures and tables or using the equations of state.
    (a) clearly indicate where you obtained the information
7. Solve the problem.
8. Clearly label your final answer.
9. Give comments if you have any.

PROBLEM STATEMENT:

Two rigid, $\mathbf{0.03}\ \boldsymbol{m^3}$ tanks are connected by a valve. Initially tank $\boldsymbol{A}$ contains argon gas at $\mathbf{400}\ \boldsymbol{K},\ \mathbf{2}\ \boldsymbol{atm}$ and tank $\boldsymbol{B}$ is a vacuum. The valve is opened and argon flows from tank $\boldsymbol{A}$ to tank $\boldsymbol{B}$ until the tanks each reach the same pressure. Each tank is adiabatic.

a) Determine the final pressure. $[\boldsymbol{atm}]$
b) Assuming that the gas that remains in tank $\boldsymbol{A}$ underwent a reversible, adiabatic process, determine the temperature $[\boldsymbol{K}]$ and mass $[\boldsymbol{kg}]$ at state A2
c) Determine the mass $[\boldsymbol{kg}]$ and temperature $[\boldsymbol{K}]$ at state B2.
d) Determine the entropy produced $[\boldsymbol{kJ/kg \cdot K}]$ in the process