

2023 SGT Aero 2405 Midterm 1 Review Document – Blank Problem Set

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Chapter 1: Introduction to Basic Concepts

- 1.1 Thermodynamics and Energy 2
- 1.2 Importance of Dimensions and Units 3
- 1.3 Systems and Control Volumes 10
- 1.4 Properties of a System 12
- 1.5 Density and Specific Gravity 13
- 1.6 State and Equilibrium 14
- 1.7 Processes and Cycles 15
- 1.8 Temperature and the Zeroth Law of Thermodynamics 17
- 1.9 Pressure 22
- 1.10 Pressure Measurement Devices 27
- 1.11 Problem Solving Technique 34

Chapter 2: Energy, Energy Transfer

- 2.1 Intro 52
- 2.2 Forms of Energy 53
- 2.3 Energy Transfer by Heat 60
- 2.4 Energy Transfer by Work 62
- 2.5 Mechanical Forms of Work 66
- 2.6 First Law of Thermodynamics 70
- 2.7 Energy Conversion Efficiencies 78

Chapter 3: Properties of Pure Substances

- 3.1 Pure Substance 112
- 3.2 Phases of a Pure Substance 112
- 3.3 Phase-Change Processes of Pure Substances 113
- 3.4 Property Diagrams for Phase-Change Processes 118
- 3.5 Property Tables 124
- 3.6 Ideal Gas Equation of State 134
- 3.7 Compressibility Factor 138
- 3.8 Other Equations of State 141

Chapter 4: Energy Analysis of Closed Systems

- 4.1 Moving Boundary Work 164
- 4.2 Energy Balance for Closed Systems 169
- 4.3 Specific Heats 174
- 4.4 Internal Energy, Enthalpy, and Specific Heats of Ideal Gases 176

Chapter 1

1.1 Thermodynamics and Energy

Conservation of Energy: energy cannot be created or destroyed

1st Law of Thermodynamics: CoE and energy is a thermodynamic property

2nd Law of Thermodynamics: energy has quality as well as quantity

Classical : Macroscopic :: Statistical : Microscopic

1.2 Importance of Dimensions and Units

Dimensions: **Primary/Fundamental** (m, l, t, T) or **Secondary** (v, E)

Can be English or Metric SI, but must be consistent (dimensionally homogeneous)

1.3 Systems and Control Volumes

Surroundings: mass or region outside of a system

Boundary: real or imaginary surface that separates the system from its surroundings

Can be *fixed* or *movable*

Closed System (Control Mass): Fixed amount of mass (e.g. piston)

Special Case: Isolated System when even energy cannot cross the boundary

Open System (Control Volume): Both mass and energy flows in and out of a system

Any arbitrary region can be selected as the volume and the boundaries (Control Surfaces) can be real or imaginary

1.4 Properties of a System

Property: characteristic of a system

- Intensive: independent of the mass of the system (T, P, ρ)
- Extensive: depend on size (or extent) of the system (m, \mathcal{V})
- Specific: per unit mass (v, e)

Continuum: assumption that matter is continuous and homogeneous and properties vary continually with no jump discontinuities

The size of the system is large relative to the space between the molecules

1.5 Density and Specific Gravity

Density, ρ : mass per unit volume

$$\rho = \frac{m}{V}$$

Specific Volume, v : volume per unit mass (reciprocal of ρ)

$$v = \frac{V}{m} = \frac{1}{\rho}$$

Specific Gravity: relative density, usually compared to ρ_{H_2O} @4°C (1000 kg/m³)

$$SG = \frac{\rho}{\rho_{H_2O}}$$

Specific Weight: weight of a unit volume of a substance

$$\gamma_s = \rho g$$

1.6 State and Equilibrium

State: a point where all properties have fixed values

- Equilibrium: a state of balance without driving forces
 - Thermal Eq: the temperature is same throughout the system
 - Mechanical Eq: no change in pressure with time throughout the system
 - Phase Eq: when the mass of each phases remains constant
 - Chemical Eq: when no chemical reactions occur

The State Postulate: The state of a simple compressible system is completely specified by two independent, intensive properties.

Independent properties if one can vary while the other is constant (e.g. T & v)

Simple Compressible System: a system in the absence of electrical, magnetic, gravitational, motion, and surface tension effects

1.7 Processes and Cycles

Process: the cycle from one equilibrium state to another

Path: series of states to get there

Cycle: if it returns to its initial state

Quasi-static/Quasi-equilibrium Process: system remains infinitesimally close to equilibrium

Other Processes:

Isothermal (constant T), isobaric (constant P), and isochoric (constant \mathcal{V})

Steady Flow Process: a process during which a fluid flows through a control volume steadily

- Properties can change from point to point but remain constant at any fixed point
- Volume, mass and energy of the control volume remain constant

1.8 Temperature and the Zeroth Law of Thermodynamics

Zeroth Law of Thermodynamics: two bodies are in thermal equilibrium if both have the same temperature even if they are not in contact

Temperature Scales:

- Two-point Scales
 - Celsius: (SI) based on water freezing at 0°C and boiling at 100°C
 - Fahrenheit: (English) based on water freezing at 32°F and boiling at 212°F
$$T(^{\circ}\text{F}) = 1.8T(^{\circ}\text{C}) + 32$$
- Thermodynamic Temperature Scale (independent of water behavior)
 - Kelvin: SI-based ($1\text{ K} = 1^{\circ}\text{C}$)
$$T(\text{K}) = T(^{\circ}\text{C}) + 273.15$$
 - Rankine: English-based ($1\text{ R} = 1^{\circ}\text{F}$)
$$T(\text{R}) = T(^{\circ}\text{C}) + 459.67$$
$$T(\text{R}) = 1.8T(\text{K})$$

1.9 Pressure

Pressure ($\text{Pa} = \text{N}/\text{m}^2$): a normal force exerted by a fluid per unit area (Normal Stress in solids)

Can also be measured in bar, atm, kgf/cm^2 , or psi (lb/in^2)

- Absolute Pressure: actual pressure measured relative to a vacuum
- Gage Pressure: (most commonly measured) the difference between the absolute pressure and the local atmospheric pressure
 - Can be positive or negative, if negative it is sometimes called vacuum pressure

$$P_{\text{gage}} = P_{\text{abs}} - P_{\text{atm}}$$

$$P_{\text{vac}} = P_{\text{atm}} - P_{\text{abs}}$$

Variation of Pressure with Depth: pressure in a static fluid increases linearly with depth

$$P_{\text{below}} = P_{\text{above}} + \rho g |\Delta z|$$

If the “above” point is at the free surface of a liquid and exposed to normal atmosphere:

$$P = P_{\text{atm}} + \rho gh \text{ or } P_{\text{gage}} = \rho gh$$

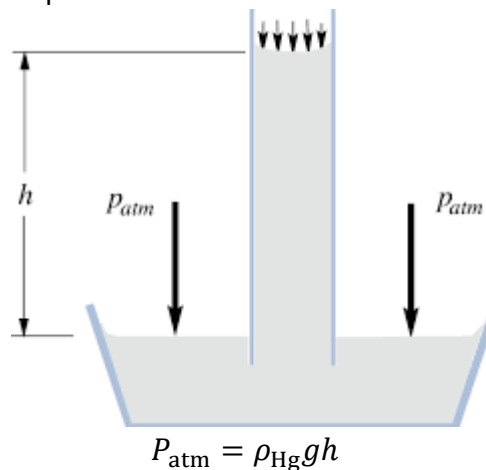
Variation of density for a liquid is negligible but for gases when the elevation change is large:

$$\Delta P = P_2 - P_1 = \int_1^2 \rho g dz$$

Pascal’s Law: pressure applied to a confined fluid increases the pressure throughout by the same amount

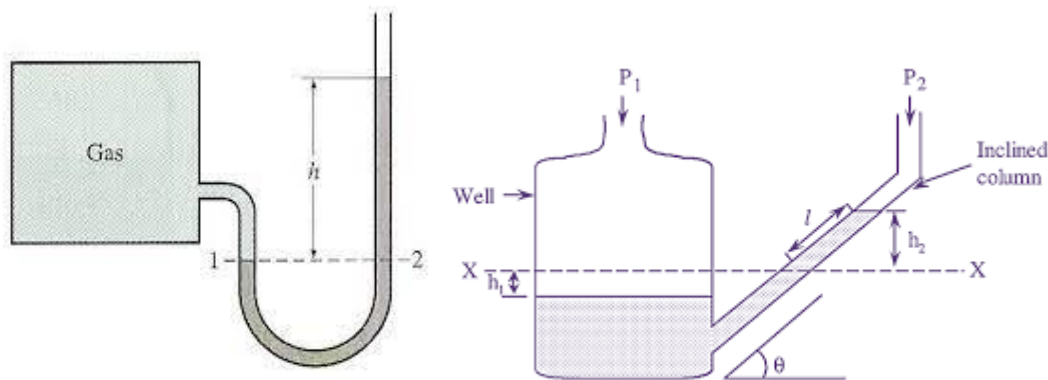
1.10 Pressure Measurement Devices

Barometer: Measures atmospheric pressure using an inverted mercury-filled tube in a container exposed to the atmosphere



Barometric Pressure is measured in mmHg or torr and 1 atm = 760 mmHG

Manometer: Used to measure pressure differences, typically relative to atmospheric pressure



$$P_2 = P_{\text{atm}} + \rho gh$$

Sometimes, inclined manometers are used for more precise measurements, or multiple liquids are used due to Pascal’s law

Other Pressure Measurement Devices:

- Bourdon Tube: a bent, coiled, or twisted hollow metal tube whose end is connected to a dial indicator needle, and when fluid is pressurized, the tube's deflection is measured
- Pressure Transducers: convert pressure effects to electrical effects for very precise measurements
 - Gage PT: calibrated to atmospheric pressure regardless of altitude
 - Absolute PT: calibrated to vacuum
 - Differential PT: measures pressure difference between two locations
 - Strain-gage PT: measures the deflection of a diaphragm between two pressures
- Piezoelectric Transducers (Solid-state Transducers): measure the electric potential that is generated when pressure is applied to crystalline substances (bad at low pressures)
- Deadweight Tester: primarily used for calibration; measures pressure directly through the application of a weight on a piston to provide a force per unit area

1.11 Problem Solving Technique

1. Problem Statement: the problem, given information, and objectives
2. Schematic: a realistic sketch to represent important properties of the system
3. Assumptions and Approximations: used to simplify the problem and fill in missing info
4. Physical Laws: all relevant physical laws and where they apply
5. Properties: determine unknown properties at known states using tables or relations
6. Calculations: find the unknowns
7. Reasoning, Verification, and Discussion: verify results and discuss their significance

Engineering Software Packages: useful tools but still understand the physical phenomena

Equation Solvers: useful for performing large amounts of calculations and still require you to understand the physical phenomena

Significant Digits: engineering calculations generally give three significant digits so that means answers should be to three significant digits

Chapter 2

2.1 Introduction

Reminder: Energy must always be conserved in a system.

2.2 Forms of Energy

Energy can exist in numerous forms such as thermal, mechanical, kinetic, potential, electric, magnetic, chemical, and nuclear.

Total Energy (E):

$$e = \frac{E}{m} \text{ Units: kJ/kg}$$

- Macroscopic forms of energy are those a system possesses as a whole with respect to some outside reference frame. Ex: Kinetic, potential energy
- Microscopic forms of energy are those related to the molecular structure of a system and the degree of the molecular activity, and they are independent of outside reference frames.
- Internal energy (U) is the sum of all the microscopic forms of energy
- Kinetic Energy (KE) is the energy that a system possess as a result of its motion relative to some reference frame.

$$KE = m \frac{V^2}{2} \text{ Units: kJ}$$

- Potential energy (PE) is the energy that a system possesses as a result of its elevation in a gravitational field.

$$PE = mgz \text{ Units: kJ}$$

- Mechanical Energys can be defined as the form of energy that can be converted to mechanical work completely and directly by an ideal mechanical device such as an ideal turbine.

$$e_{mech} = \frac{P}{\rho} + \frac{V^2}{2} + gz$$

Stationary systems are closed systems whose velocity and elevation of the center of gravity remain constant during a process.

Mass flow rate (\dot{m}):

$$\dot{m}_{dot} = \rho V_{avg} A_c \text{ Units: kg/s}$$

Energy flow rate (\dot{E}):

$$\dot{E}_{dot} = \dot{m}_{dot} e \text{ Units: kJ/s or kW}$$

2.3 Energy Transfer by Heat

Heat is defined as the form of energy that is transferred between two systems (or a system and its surroundings) by virtue of a temperature difference.

An adiabatic process is a process during which there is no heat transfer.

Heat transfer per unit mass (q):

$$q = \frac{Q}{m} \text{ Units: kJ/kg}$$

Heat transfer is transferred by three mechanisms:

- Conduction is the transfer of energy from the more energetic particles of a substance to the adjacent less energetic ones as a results of interactions between particles.
- Convection is the transfer of energy between a solid surface and the adjacent fluid that is in motion, and it involves the combined effects of conduction and fluid motion.
- Radiation is the transfer of energy due to the emission of electromagnetic waves (or photons).

2.4 Energy Transfer by Work

If the energy crossing the boundary of a closed system is not heat, it must be work. Work is the energy transfer associated with a force acting through a distance.

$$w = \frac{W}{m} \text{ Units: kJ/kg}$$

Power is the work done per unit time (\dot{W}).

Both heat and work are directional quantities, and thus have both a magnitude and direction.

Heat transfer to a system and work done by a system are positive; heat transfer from a system and work done on a system are negative.

Heat and work are energy transfer mechanisms between a system and its surroundings, and there are several similarities between them:

- Both are recognized at the boundaries of a system as they cross the boundaries. That is, both heat and work are boundary phenomena.
- Systems possess energy, but not heat or work.
- Both are associated with a process, not a state. Unlike properties, heat or work have no meaning at a state.
- Both are path functions (their magnitudes depend on the path followed during a process as well as the end results).

Path functions have inexact differentials (δ). Properties, however, are point functions (they depend on the state only, and not on how a system reaches that state) and have exact differentials (d).

2.5 Mechanical Forms of Work

The work done by a constant force on a body displaced by a distance in the direction of the force:

$$W = Fs \text{ Units: kJ}$$

If the force is not constant:

$$W = \int F ds$$

There are two requirements for a work interaction between a system and its surroundings to exist:

- There must be a force acting on the boundary.
- The boundary must move.

Shaft work:

$$T = Fr$$

Spring work:

$$F = kx$$

Work done on elastic solid bars:

$$W_{elastic} = \int F dx = \int \sigma_n A dx$$

Work associated with the stretching of a liquid film:

$$W_{surface} = \int \sigma_s dA$$

2.6 The First Law of Thermodynamics

The First Law of Thermodynamics states that energy can be neither created nor destroyed during a process; it can only change forms.

For all adiabatic processes between two specified states of a closed system, the net work done is the same regardless of the nature of the closed system and the details of the process.

Energy balance:

$$E_{in} - E_{out} = \Delta E_{system}$$
$$\Delta E = \Delta U + \Delta KE + \Delta PE$$

For stationary systems, the changes in kinetic and potential energies are zero.

Mechanisms of energy transfer:

- Heat transfer (Q)
- Work transfer (W)
- Mass flow (m)

2.7 Energy Conversion Efficiencies

Efficiency can be expressed in terms of desired output over the required input.

The efficiency of a water heater is defined as the ratio of the energy delivered to the house by hot water to the energy supplied to the water heater.

The heating value (HV) of fuel is the amount of heat released when a unit amount of fuel at room temperature is completely burned and the combustion products are cooled to the room temperature.

Combustion equipment efficiency ($\eta_{comb. equip}$):

$$\eta_{comb. equip} = \frac{Q_{useful}}{HV}$$

Generator efficiency is the ratio of the electrical power output to the mechanical power input.

Overall efficiency is the net electrical power output to the rate of fuel energy input ($\eta_{overall}$):

$$\eta_{overall} = \frac{W_{dot_{net, electric}}}{HHV \cdot m_{dot_{fuel}}}$$

Mechanical efficiency (η_{mech}):

$$\eta_{mech} = \frac{E_{mech, out}}{E_{mech, in}} = 1 - \frac{E_{mech, loss}}{E_{mech, in}}$$

Pump efficiency (η_{pump}):

$$\eta_{pump} = \frac{\Delta E_{dot_{mech, fluid}}}{W_{dot_{shaft, in}}} = \frac{W_{dot_u}}{W_{dot_{pump}}}$$

Turbine efficiency ($\eta_{turbine}$):

$$\eta_{turbine} = \frac{W_{dot_{shaft, out}}}{|\Delta E_{dot_{mech, fluid}}|} = \frac{W_{dot_{turbine}}}{W_{dot_{turbine, e}}}$$

Chapter 3

3.1 Pure Substance

A pure substance is a substance that has a fixed chemical composition throughout. Ex: Water, nitrogen, helium, and carbon dioxide.

3.2 Phases of a Pure Substance

The molecules of a solid are arranged in a three-dimensional lattice that is repeated throughout.

The molecular spacing in the liquid phase is not much different from that of the solid phase, except the molecules are no longer at fixed positions relative to each other and they can rotate and translate freely.

In the gas phase, molecules are far apart from each other, and a molecular order is nonexistent. Gas molecules move about at random, continually colliding with each other and the walls of the container they are in.

3.3 Phase-Change Processes of Pure Substances

A compressed or subcooled liquid is a liquid that is not about to vaporize.

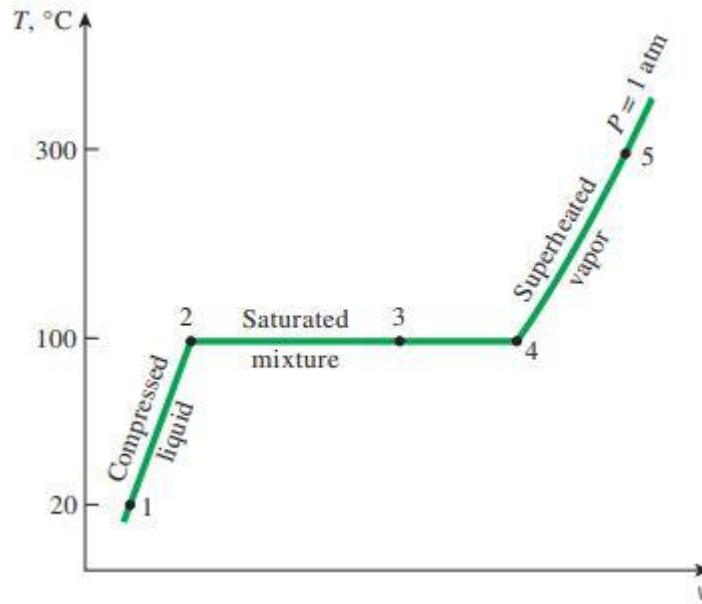
A liquid that is about to vaporize is called a saturated liquid.

A vapor that is about to condense is called a saturated vapor.

A saturated liquid-vapor mixture is when the liquid and vapor phases coexist in equilibrium.

A vapor that is not about to condense is called a superheated vapor.

The saturation temperature (T_{sat}) is the temperature at which a pure substance changes phase, and the saturation pressure (P_{sat}) is the pressure at which a pure substance changes phase.

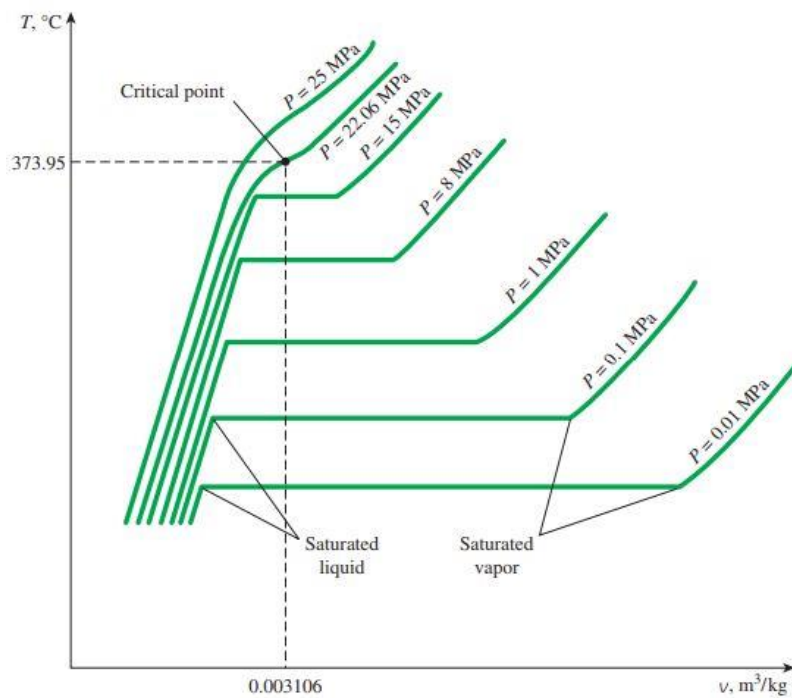


T-V Diagram

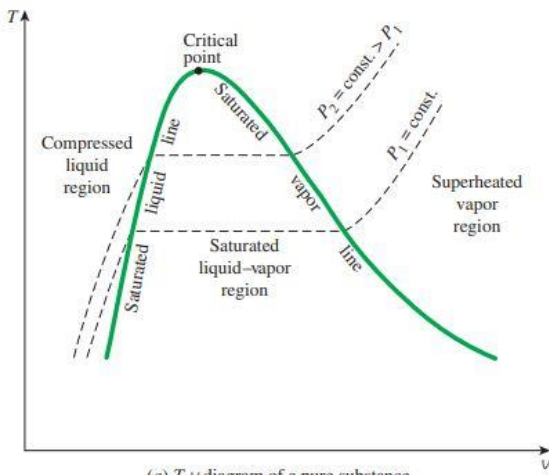
The latent heat is the amount of energy absorbed or released during a phase-change process.

3.4 Property Diagrams for Phase-Change Processes

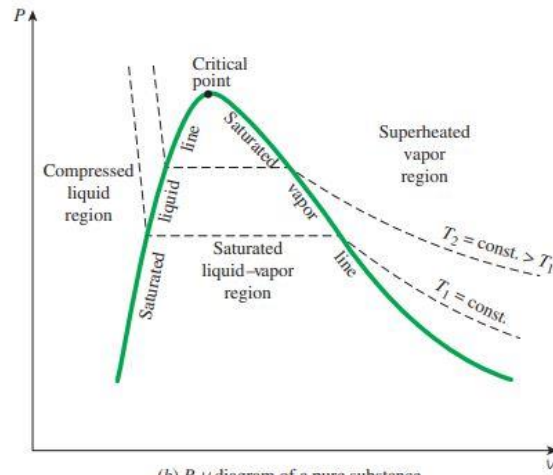
The critical point is defined as the point at which the saturated liquid and saturated vapor states are identical.



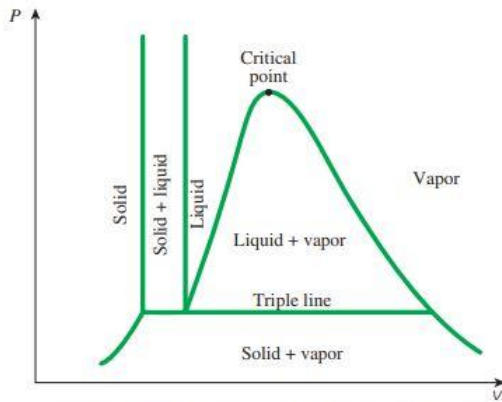
T-V Diagram



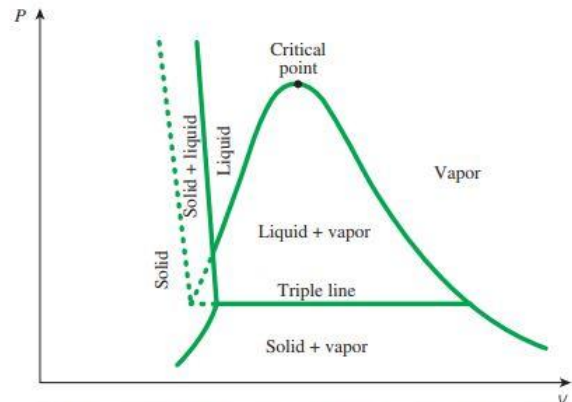
(a) T-v diagram of a pure substance



(b) P-v diagram of a pure substance

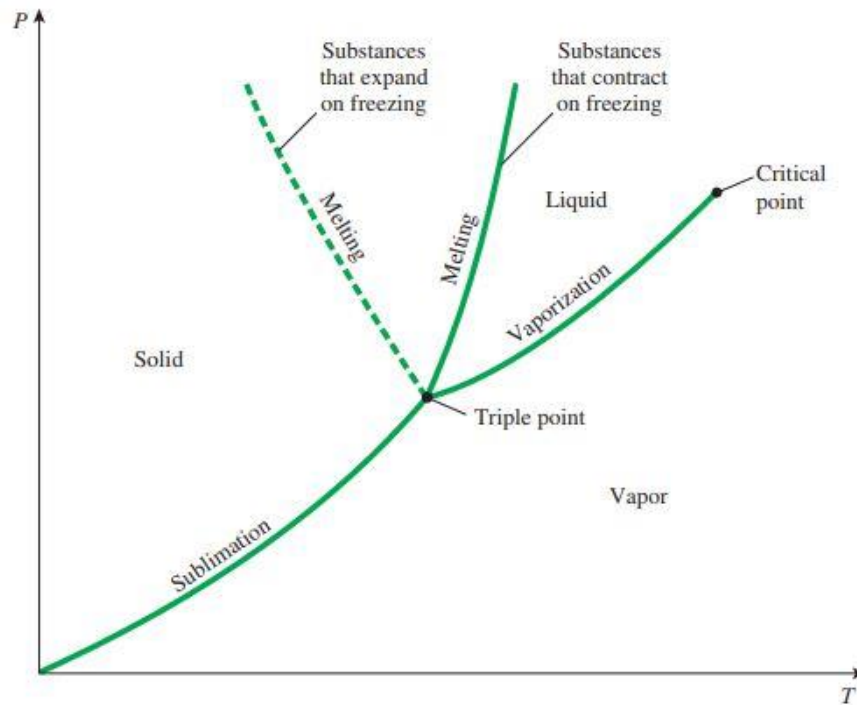


(a) P-v diagram of a substance that contracts on freezing



(b) P-v diagram of a substance that expands on freezing (such as water)

On P-V or T-V diagrams, the triple-phase states form a line called the triple line.



P-T Diagram

The triple line appears as a point on the P-T diagrams, and therefore is called the triple point.

Passing from the solid phase directly into the vapor phase is called sublimation.

3.5 Property Tables

Enthalpy (h):

$$h = u + PV \quad \text{Units: kJ/kg}$$

Total Enthalpy (H):

$$H = U + PV \quad \text{Units: kJ}$$

Enthalpy of vaporization (h_{fg}), also known as the latent heat of vaporization, represents the amount of energy needed to vaporize a unit mass of saturated liquid at a given temperature or pressure.

Quality is the ratio of the mass of vapor to the total mass of the mixture:

$$x = \frac{m_{\text{vapor}}}{m_{\text{total}}} = \frac{V_{\text{avg}} - V_f}{V_{fg}}$$

$$m_{\text{total}} = m_{\text{liquid}} + m_{\text{vapor}} = m_f + m_g$$

$$V = V_f + V_g$$

$$V_{avg} = V_f + xV_{fg}$$

$$u_{avg} = u_f + xu_{fg}$$

$$h_{avg} = h_f + xh_{fg}$$

3.6 The Ideal-Gas Equation of State

Equation of state refers to any equation that relates the pressure, temperature, and specific volume of a substance.

$$PV = RT$$

$$R = \frac{R_u}{M}$$

The molar mass (M) can be simply defined as the mass of one mole of a substance in grams, or the mass of one kmol in kilograms.

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

3.7 Compressibility Factor – A Measure of Deviation From Ideal-Gas Behavior

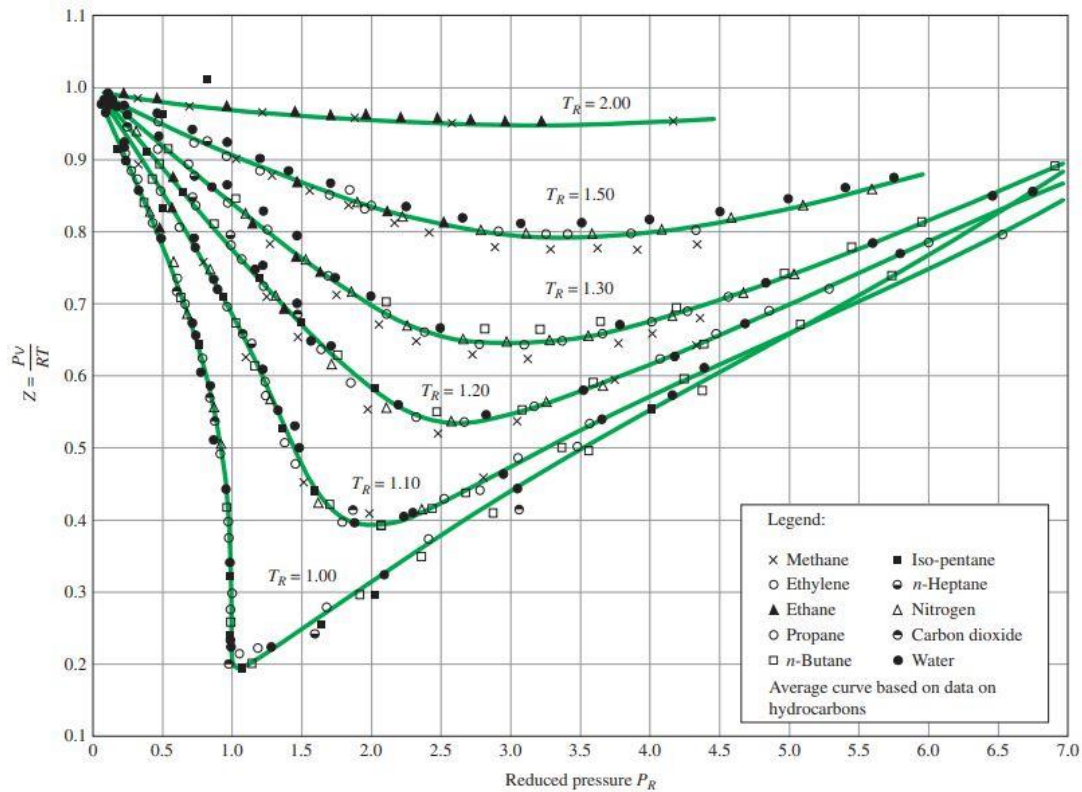
The compressibility factor (Z) is a correction factor that can help measure the deviation from ideal-gas behavior at a given temperature and pressure.

$$Z = \frac{PV}{RT} = \frac{V_{actual}}{V_{ideal}}$$

Gases behave differently at a given temperature or pressure, but they behave very much the same at temperatures and pressures normalized with respect to the critical temperatures and pressures (we call these reduced temperature and pressures (P_R and T_R)).

$$P_R = \frac{P}{P_{cr}}$$

$$T_R = \frac{T}{T_{cr}}$$



Comparison of Z factors for various gases

The following observations can be made from the generalized compressibility chart:

- At very low pressures, gases behave as ideal gases regardless of temperature.
- At high temperatures, ideal-gas behavior can be assumed with good accuracy regardless of pressure.
- The deviation of gas from ideal-gas behavior is greatest in the vicinity of the critical point.

3.8 Other Equations of State

van der Waals Equation of State:

$$\left(P + \frac{a}{V^2}\right)(V - b) = RT$$

Beattie-Bridgeman Equation of State:

$$P = \frac{R_u T}{V_{bar}^2} \left(1 - \frac{c}{V_{bar} T^3}\right) (V_{bar} + B) - \frac{A}{V_{bar}^2}$$

Chapter 4

4.1 Moving Boundary Work

Moving Boundary Work (Boundary Work): the work associated with the expansion or compression of a gas generally in a piston-cylinder device

For this section, it is a quasi-equilibrium process

$$W_b = \int_1^2 P d\mathcal{V}$$

- \therefore Boundary work is negative for compression and positive for expansion
- This equation also proves that the area under the process curve on a P - \mathcal{V} diagram is equal, in magnitude, to the work done during a quasi-equilibrium expansion or compression of a closed system
- In a more realistic system the equation expands to:

$$W_b = W_{\text{friction}} + W_{\text{atm}} + W_{\text{crank}} = \int_1^2 (F_{\text{friction}} + P_{\text{atm}}A + F_{\text{crank}})dx$$

Polytropic Process: during actual expansion and compression process P and \mathcal{V} are related by

$$P = C\mathcal{V}^{-n} \text{ (where } C \text{ and } n \text{ are constants)}$$

This is called a polytropic process and can be used to find boundary work with,

$$W_b = \int_1^2 P d\mathcal{V} = \int_1^2 C\mathcal{V}^{-1} d\mathcal{V} = P\mathcal{V} \ln\left(\frac{\mathcal{V}_2}{\mathcal{V}_1}\right)$$

4.2 Energy Balance for Closed Systems

Energy Balance:

$$E_{\text{in}} - E_{\text{out}} = \Delta E_{\text{system}}$$

- Per unit mass

$$e_{\text{in}} - e_{\text{out}} = \Delta e_{\text{system}}$$

- For a cycle

$$W_{\text{net,out}} = Q_{\text{net,in}}$$

- Therefore, for a closed system

$$Q_{\text{net,in}} - W_{\text{net,out}} = \Delta E_{\text{system}}$$

- Note: Q_{in} and W_{out} are positive and Q_{out} and W_{in} are negative

4.3 Specific Heats

Specific Heat: the energy required to raise the temperature of the unit mass of a substance by one degree

- Specific Heat at Constant Volume: the energy required to raise the temperature of the unit mass of a substance by one degree as the volume is maintained constant
 - Related to changes in the internal energy

$$c_v = \left(\frac{\partial u}{\partial T} \right)_v$$

- Specific Heat at Constant Pressure: the energy required to raise the temperature of the unit mass of a substance by one degree as the pressure is maintained constant
 - Related to changes in the enthalpy

$$c_p = \left(\frac{\partial h}{\partial T} \right)_p$$

4.4 Internal Energy, Enthalpy, and Specific Heats of Ideal Gases

Using ideal gas law, definition of enthalpy, and the previous equations:

$$du = c_v(T) dT$$

$$dh = c_p(T) dT$$

Which lead to:

$$\Delta u = u_2 - u_1 = \int_1^2 c_v(T) dT$$

$$\Delta h = h_2 - h_1 = \int_1^2 c_p(T) dT$$

Which can't be done easily by hand but can be approximated by:

$$u_2 - u_1 = c_{v,avg}(T_2 - T_1)$$

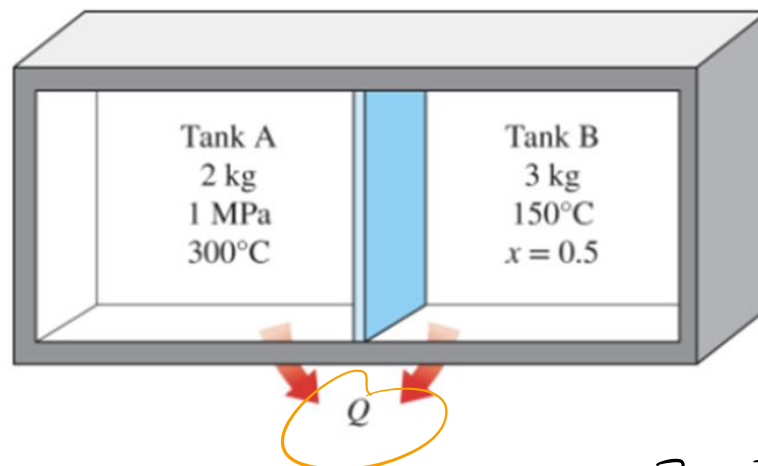
$$h_2 - h_1 = c_{p,avg}(T_2 - T_1)$$

Summary, one can determine the internal energy and enthalpy of ideal gases:

1. By using the tabulated u and h data
2. By using the c_v or c_p relations as a function of temperature and performing the integrations
3. By using average specific heats

Problem 1

Two tanks (Tank A and Tank B) are separated by a partition. Initially Tank A contains 2 kg of steam at 1 MPa and 300°C while Tank B contains 3 kg of saturated liquid-vapor mixture at 150°C with a vapor mass fraction of 50 percent. The partition is now removed and the two sides are allowed to mix until mechanical and thermal equilibrium are established. If the pressure at the final state is 300 kPa, determine (a) the temperature and quality of the steam (if mixture) at the final state and (b) the amount of heat lost from the tanks.



Given

$$m_{1A} = 2 \text{ kg}$$

$$P_{1A} = 1 \text{ MPa}$$

$$T_{1A} = 300^\circ\text{C}$$

$$m_{1B} = 3 \text{ kg}$$

$$T_{1B} = 150^\circ\text{C}$$

$$x_1 = 0.5$$

$$P_2 = 300 \text{ kPa}$$

Find

a) T_2, x_2 b) Q_{out}

Eqs

$$\cancel{E_{in}} - E_{out} = \Delta E_{sys}$$

$$-Q_{out} = [m(u_2 - u_1)]_A + [m(u_2 - u_1)]_B$$

$$x_2 = \frac{v_2 - v_f}{v_g - v_f}$$

$$u = u_f + x u_{fg}$$

Calcs

$$v_{1A} = 0.258 \text{ m}^3/\text{kg}$$

$$u_{1A} = 2793.7 \frac{\text{kJ}}{\text{kg}}$$

} tank A
superheated vapor

$$v_f = 0.001091 \text{ m}^3/\text{kg}$$

$$v_g = 0.39248 \text{ m}^3/\text{kg}$$

$$u_f = 631.66 \frac{\text{kJ}}{\text{kg}}$$

$$u_{fg} = 1927.4 \frac{\text{kJ}}{\text{kg}}$$

} tank B
Saturated water

$$\begin{aligned} v_{1B} &= v_f + x_1 \cdot v_{fg} \\ &= 0.001091 + (0.5)(0.3925 - 0.001091) \end{aligned}$$

$$v_{1B} = 0.1968 \text{ m}^3/\text{kg}$$

$$u_{1B} = 1595.36 \text{ kJ/kg}$$

$$v_2 = \frac{V_2}{m_2}$$

$$m_2 = m_A + m_B = 2 + 3 = 5 \text{ kg}$$

$$\begin{aligned} V_2 &= V_A + V_B = m_A v_{1A} + m_B v_{1B} \\ &= (2)(0.258) + (3)(0.1968) \end{aligned}$$

$$V_2 = 1.106 \text{ m}^3$$

$$v_2 = \frac{1.106}{5} = 0.2212 \text{ m}^3/\text{kg}$$

$$P_2 = 300 \text{ kPa} \rightarrow \text{sat water for Pressure}$$

$$T_2 = 133.5^\circ\text{C} \quad \text{①}$$

x_2

$$v_f = 0.001073 \text{ m}^3/\text{kg}$$

$$v_g = 0.60582 \text{ m}^3/\text{kg}$$

$$u_{fg} = 1982.1 \frac{\text{kJ}}{\text{kg}}$$

$$u_f = 561.11 \frac{\text{kJ}}{\text{kg}}$$

$$X_2 = \frac{v_2 - v_f}{v_g - v_f} = \frac{0.2212 - 0.001073}{0.60582 - 0.001073}$$

$$\boxed{X_2 = 0.364} \quad \textcircled{a}$$

$$u_2 = u_f + X_2 u_{fg}$$

$$= 561.11 + (0.364)(1982.1)$$

$$u_2 = 1282.78 \frac{\text{kJ}}{\text{kg}}$$

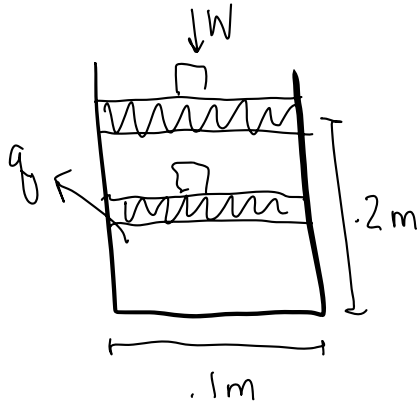
$$-Q_{out} = [m(u_2 - u_1)]_A + [m(u_2 - u_1)]_B$$

$$= [2(1282.78 - 2793.7)] + [3(1282.78 - 1595.4)]$$

$$\boxed{Q_{out} = 3959.6 \text{ kJ}} \quad \textcircled{b}$$

Problem 2

A vertical 10-cm-diameter piston-cylinder device contains an ideal gas at the ambient conditions of 1 bar and 24°C. Initially, the inner face of the piston is 20 cm from the base of the cylinder. Now an external shaft connected to the piston exerts a force corresponding to a boundary work input of 0.1 kJ. The temperature of the gas remains constant during the process. Determine (a) the amount of heat transfer, (b) the final pressure in the cylinder, and (c) the distance that the piston is displaced.



Given

$$T = 24^\circ\text{C}$$

$$P = 1 \text{ bar} = 100 \text{ kPa}$$

$$L_1 = 0.2 \text{ m}$$

$$W_b = 0.1 \text{ kJ}$$

$$D = 0.1 \text{ m}$$

Find

$$Q_{\text{out}}$$

$$P_2$$

$$\Delta L$$

Assumptions: kinetic + potential energy Δ 's
are negligible

a) Q_{out}

$$E_{\text{in}} - E_{\text{out}} = \Delta E_{\text{sys}}$$

$$W_b - Q_{\text{out}} = \Delta U = 0$$

$$W_b = Q_{\text{out}}$$

$$0.1 \text{ kJ} = Q_{\text{out}}$$

c) ΔL

$$\Delta L = L_1 - L_2$$

$$V_2 = \pi \frac{D^2}{4} L_2$$

$$8.308 \cdot 10^{-4} = \pi \frac{(0.1)^2}{4} L_2$$

$$L_2 = 0.1058 \text{ m}$$

$$\Delta L = L_1 - L_2$$

$$0.2 - 0.1058$$

$$\Delta L = 9.42 \text{ cm}$$

b) P_2

$$W_b = -P_1 V_1 \ln \left(\frac{V_2}{V_1} \right) \left. \vphantom{W_b} \right\} \text{isothermal}$$

$$P_1 V_1 = P_2 V_2$$

$$V_1 = \pi \frac{D^2}{4} L_1$$

$$= \pi \frac{(0.1)^2}{4} (0.2)$$

$$V_1 = 0.00157 \text{ m}^3$$

$$0.1 = -(100)(0.00157) \ln \left(\frac{V_2}{0.00157} \right)$$

$$V_2 = 8.308 \cdot 10^{-4} \text{ m}^3$$

$$P_1 V_1 = P_2 V_2$$

$$(100)(0.00157) = P_2 (8.308 \cdot 10^{-4})$$

$$P_2 = 189.069 \text{ kPa}$$

Problem 3

Ethane at 10 MPa and 100°C is heated at constant pressure until its volume has increased by 60 percent. Determine the final temperature using (a) the ideal-gas equation of state and (b) the compressibility factor. Which of these two results is the more accurate?

G:

$$P = 10 \text{ MPa}$$

$$T_2 = 100^\circ\text{C} = 373.15 \text{ K}$$

$$\frac{V_2}{V_1} = 1.6$$

using table A-1

E)

$$PV = ZRT$$

$$R = 0.2765 \frac{\text{kJ}}{\text{kg} \cdot \text{K}}$$

$$T_{\text{cp}} = 305.5 \text{ K}$$

$$P_{\text{cp}} = 4.48 \text{ MPa}$$

$$\text{A) } \cancel{P_1} \cancel{V_1} = \cancel{Z} \cancel{R} \cancel{T_1} \quad P_1 Z_1 R_1 = P_2 Z_2 R_2$$

$$\cancel{P_2} V = \cancel{Z_2} \cancel{R} T_2$$

$$T_2 = T_1 \frac{V_2}{V_1} = 373.15 \text{ K} (1.6) = 597.04 \text{ K}$$

$$B) \quad E) \quad P_R = \frac{P}{P_{cp}} \quad T_R = \frac{T}{T_{cp}}$$

$$T_{R,1} = \frac{T_1}{T_{cp}} = \frac{373.15}{305.5} = 1.22$$

$$P_{R,1} = \frac{P_1}{P_{cp}} = \frac{10}{4.48} = 2.23$$

Using A-15

$$Z_1 = 0.61 \quad V_{R,1} = 0.35$$

$$P_{R,1} = P_{R,2} = 2.23$$

$$V_{R,2} = 1.6 V_{R,1} = 1.6(0.35) = 0.56$$

$$Z_2 = 0.83$$

$$T_2 = \frac{P_2 V_2}{Z_2 R} = \frac{P_2 V_{R,2} T_{cp}}{Z_2 P_{cp}} = \frac{(10^7)(0.56)(305.5)}{(0.83)(4.48 \times 10^6)}$$

$$T_2 = 460.09 \text{ K}$$