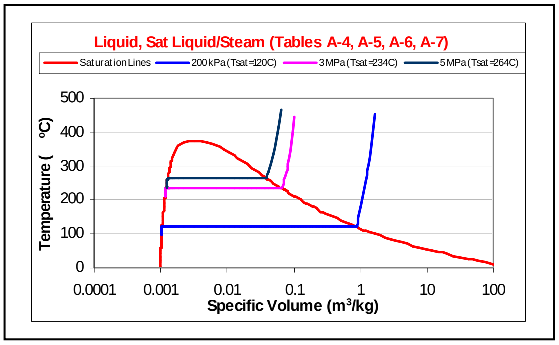
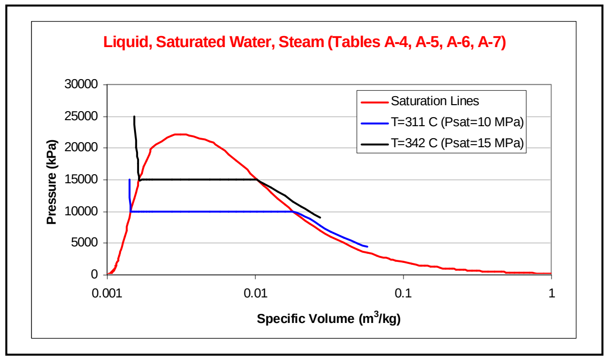
Thermodynamics FE review

Subjects

1. Properties of Materials, Property Relations for Ideal Gases/Liquids/Solids and Liquid-Vapor Phases
2. First Law in closed and Open Systems
3. Second Law, Entropy, Heat Engine and Refrigeration Cycles

Material Properties
State postulate
P-v and T-v diagrams for two-phase systems, saturated substances, mixtures and quality





<u>Ideal Gas Law Property Relations</u>
$PV = mRT$
$Pv = RT$
$P = \rho RT$
$PV = NR_UT$
$R_U = R(MW)$ and $N(MW) = m$
Isothermal: $P_1V_1 = P_2V_2$
Isobaric: $T_1V_2 = T_2V_1$
Isochoric: $P_1T_2 = P_2T_1$

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

<u>Specific Heat, Internal Energy and Enthalpy Relations</u>
Ideal gases
$\Delta u = C_V\Delta T$ for specific heat constant
$\Delta h = C_P\Delta T$ for specific heat constant
$C_P = C_V + R$
Incompressible liquids and solids where ΔP is negligible: $\Delta h = \Delta u = C_P\Delta T$
Incompressible liquids where Δu is negligible (ΔT negligible) - pumps: $\Delta h = v\Delta P$

1. Steam at 2.0 kPa has Tsat = 17.5 C. At 40 C, the steam will be
    a. superheated
    b. subcooled
    c. saturated
    d. supersaturated

2. All real gases deviate somewhat from ideal gas behavior: PV = mRT. For which of the following conditions is the deviation the smallest?
    a. High temperature and low volume
    b. High temperature and low pressures
    c. High pressures and low volumes
    d. High pressure and low temperatures

An 0.5 m^3 rigid tank contains equal volumes of Freon-12 vapor and Freon-12 liquid at 312K. Additional Freon-12 is added to the tank until the total mass of Freon-12 (liquid + vapor) is 400 kg. (Some vapor is led off to maintain the original temperature and pressure with a final mass of 400 kg.) At 312K, P_{sat} for Freon-12 is 0.9334 MPa. Under these saturation conditions, v_f = 0.000795 m^3/kg and v_g = 0.01872 m^3/kg.

3. What is the final mass of Freon-12 vapor?
    a. 10 kg
    b. 39 kg
    c. 100 kg
    d. 300 kg

4. What is the final volume of the Freon-12 liquid?
    a. 0.16 m^3
    b. 0.18 m^3
    c. 0.31 m^3
    d. 0.39 m^3

5. What was the mass of Freon-12 added to the tank?
    a. 14 kg
    b. 22 kg
    c. 46 kg
    d. 72 kg

6. What is the change in internal energy of air (an ideal gas) cooled from 550 C to 100 C?
    a. 320 kJ/kg
    b. 390 kJ/kg
    c. 450 kJ/kg
    d. 550 kJ/kg

7. When the volume of an ideal gas is doubled while the temperature is halved, what happens to the pressure?
    a. Pressure is doubled
    b. Pressure is halved
    c. Pressure is quartered
    d. Pressure is quadrupled

8. Assuming air is an ideal gas with a molecular weight of 28.97, what is the density of air at 1 atm and 600 C?
    a. 0.12 kg/m^3
    b. 0.40 kg/m^3
    c. 0.59 kg/m^3
    d. 0.68 kg/m^3

9. What the thermodynamic property is the best measure of the molecular activity of a substance?
    a. Enthalpy
    b. Internal energy
    c. Entropy
    d. External energy

10. A liquid boils when the vapor pressure is equal to
    a. One atmosphere
    b. The gage pressure
    c. The absolute pressure
    d. The surrounding pressure

11. A substance whose properties are uniform throughout is referred to as
    a. A solid
    b. An ideal substance
    c. A pure substance
    d. A standard substance

12. For every gas there is a particular temperature above which the properties of the gas cannot be distinguished from the properties of the liquid no matter how great the pressure. The temperature is known as the
    a. Absolute temperature
    b. Saturation temperature
    c. Standard temperature
    d. Critical temperature

13. Steam initially at 1 MPa and 200 C expands in a turbine to 40 C and 83% quality. What is the change in entropy?
    a. –0.35 kJ/kgK
    b. 0.00 kJ/kgK
    c. 0.26 kJ/kgK
    d. 0.73 kJ/kgK

14. A 3-kg mixture of water and water vapor at 70 C is held at constant pressure while heat is added. The enthalpy of the water increases by 50 kJ/kg. What is the change in entropy?
    a. 0.111 kJ/kgK
    b. 0.146 kJ/kgK
    c. 0.158 kJ/kgK
    d. 0.177 kJ/kgK

15. The ratio C_p:C_v for an ideal gas = 1.4 and the specific heat measured at constant pressure is 1100 kJ/kgK. The gas flows through an adiabatic throttling valve and the pressure drops from 700 kPa to 150 kPa. The temperature before the valve is 100 C. What is the temperature after the valve?
    a. –193 C
    b. –33 C
    c. 64 C
    d. 100 C

16. What is the specific volume of refrigerant HFC-134a (R-134a) with an enthalpy of 570 kJ/kg and a pressure of 0.6 MPa?
    a. 0.006 m^3/kg
    b. 0.06 m^3/kg
    c. 0.6 m^3/kg
    d. 180 m^3/kg

17. HFC-134a is ideally throttled from a pressure of 0.2 MPa to a pressure of 0.02 MPa. The enthalpy at the throttling valve inlet is 480 kJ/kg. What is the final enthalpy?
    a. 370 kJ/kg
    b. 410 kJ/kg
    c. 450 kJ/kg
    d. 480 kJ/kg

18. The enthalpy of refrigerant HFC-134a is reduced from 440 kJ/kg at 0.8 MPa to 300 kJ/kg in a condenser at constant pressure. What is the approximate final quality of the refrigerant?
    a. 32%
    b. 37%
    c. 63%
    d. 71%

19. Which property of state is not an extensive property?
   a. Temperature
   b. Volume
   c. Number of molecules
   d. Mass

II. First Law and Work

CLOSED systems:

$Q - W = \Delta U$

Work = W = $\int PdV$

Special cases:

Isobaric: $w = P(v_2 - v_1)$
Isochoric: $w = 0$

Isothermal, ideal gas ($Pv = C$): $w = RT\ln\left(\frac{v_2}{v_1}\right) = RT\ln\left(\frac{P_1}{P_2}\right) = P_1V_1\ln\left(\frac{v_2}{v_1}\right)$

Isentropic, ideal gas ($Pv^k = C$ where $k = C_P/C_V$): $w = \frac{P_2v_2 - P_1v_1}{(1-k)} = \frac{R(T_2 - T_1)}{(1-k)}$

Polytropic ($Pv^n = C$): $w = \frac{P_2v_2 - P_1v_1}{(1-n)}$

OPEN systems at STEADY STATE

$$\dot{Q} - \dot{W} = \sum_e \dot{m}_e\left(h_e + \frac{V_e^2}{2} + gz_e\right) - \sum_i \dot{m}_i\left(h_i + \frac{V_i^2}{2} + gz_i\right)$$

one inlet (1) and one outlet (2)

$$\dot{Q} - \dot{W} = \dot{m}\left(h_2 - h_1 + \frac{(V_2^2 - V_1^2)}{2000} + g(z_2 - z_1)\right)\frac{(kJ)}{kg}$$

where units of h are kJ/kg, V are m/s and z is km

Stationary (ke and pe changes can be neglected): often turbines, compressors, pumps.

$$\dot{Q} - \dot{W} = \dot{m}(h_2 - h_1)\frac{(kJ)}{kg}$$

where $\dot{m} = \rho vA = \rho\dot{V}$

Isentropic work: $w = -\int vdP$ for incompressible fluid device (pump) $w = v(P_1 - P_2)$

1. Air is compressed in a piston cylinder device to 1/10 of its initial volume. If the initial temperature is 35 C and the process is reversible and adiabatic, what is the final temperature?
    a. A. 350K
    b. 360K
    c. 620K
    d. 770K

2. 7.2 MJ of work is put into a gas at 1 MPa and 150 C while heat is removed at the rate of 1.5 kw. What is the change in internal energy of the gas after one hour?
    a. –5.7 MJ
    b. 1.8 MJ
    c. 8.7 MJ
    d. 13 MJ

3. One kg air is compressed from a volume of 1.0 m^3 and a pressure of 100 kPa to a volume of 0.147 m^3 and a pressure of 1000 kPa. Assuming the compression follows the relation Pv^n = constant, find the work done on the gas during the compression process.
    a. -70 kJ
    b. -100 kJ
    c. -118 kJ
    d. -235 kJ

4. Steam enters an adiabatic nozzle at 1 MPa, 30 m/s, and 250 C. At a point down stream in the nozzle, the enthalpy of the steam has decrease by 40 kJ/kg from the inlet value. What is the velocity at that point?
    a. 31 m/s
    b. 110 m/s
    c. 250 m/s
    d. 280 m/s

5. A boiler feedwater pump receives saturated liquid water at 50 C and compresses it isentropically to 1 MPa. For a water flow rate of 100 Mg/hr, estimate the pump power.
    a. -20 kw
    b. -28 kw
    c. -35 kw
    d. -39 kw

6. Calculate the power required to compress 10 kg/s air flow from 1 atm and 37 C to 2 atm and 707 C. For air at the average process temp., C_p = 1.094 and C_v = 0.810 kJ/kg-K.
    a. –5430 kw
    b. –7020 kw
    c. –7260 kw
    d. –7330 kw

7. Which of the following is true for an isentropic steady-flow process?
   a. $\frac{P_2}{P_1} = \left(\frac{v_1}{v_2}\right)^k \ldots$
   b. w = - v($P_2 - P_1$)
   c. $P_1V_1 = P_2V_2$
   d. $P_1T_2 = P_2T_1$

8. Air is compressed from 100 kPa and 40 C to 1500 kPa and 130 C in a steady flow process. During the compression, each kilogram of air loses 90 kJ as heat to the surroundings. Air leaves the compressor at a rate of 10 m^3/min. What is the power requirement for the compressor?
   a. –126 kw
   b. –180 kw
   c. –195 kw
   d. –391 kw

9. Which of the following statements is the best expression of the first law of thermodynamics?
   a. The mass within a closed system does not change.
   b. The net energy crossing the system boundary equals the change in energy inside the system.
   c. The change of total energy is equal to the rate of work performed.
   d. All real process tent toward increased entropy.

Second Law, Entropy, Power and Refrigeration Cycles

Heat Engine Cycle:

$$\eta = \frac{W_{net}}{Q_{in}} = \frac{Q_{net}}{Q_{in}} = 1 - \frac{Q_{out}}{Q_{in}}$$

$$\eta_{carnot} = 1 - \frac{T_L}{T_H} (Kelvin)$$

Refrigeration Cycle:

$$COP_R = \frac{Q_L}{W} = \frac{1}{\left(\frac{Q_H}{Q_L} - 1\right)}$$

$$COP_{carnotR} = \frac{1}{\left(\frac{T_H}{T_L} - 1\right)} (Kelvin)$$

$$COP_{HP} = \frac{Q_H}{W} = \frac{1}{\left(1 - \frac{Q_L}{Q_H}\right)}$$

$$COP_{carnotHP} = \frac{1}{\left(1 - \frac{T_L}{T_H}\right)} (Kelvin)$$

$$COP_{HP} = COP_R + 1$$

Entropy

$S_2 - S_1 = \int dS = \int \frac{dQ_{reversible}}{T} (Kelvin)$

$S_2 - S_1 \geq \sum_k \left(\frac{Q}{T}\right)_k (Kelvin)$ (> or real, = for reversible) SECOND LAW of Thermodynamics

Isentropic processes (Reversible and Adiabatic):

$S_2 - S_1 = 0$

Reversible Processes

$S_2 - S_1 = \sum_k \left(\frac{Q}{T}\right)_k (Kelvin)$

Adiabatic and Irreversible (Real) Processes

$S_2 - S_1 > 0$

SECOND LAW statements

Kelvin Planck: it is impossible to operate a heat engine in a cycle that will have no other effect than to extract heat from a reservoir and produce an equivalent amount of work. (Must reject a portion of the heat to a low temperature reservoir.) Corollary: Carnot heat engine has highest η for given reservoir temperatures.

Clausius: It is impossible to devise a cycle that has as its only effect the transfer of heat from a low temperature body to a high-temperature body. (Input of work is required.) Corollary: Carnot refrigerator and Carnot heat pumps have highest possible COP's for given reservoir temperatures.

1. A Carnot heat engine receives 100 kJ of heat from a high temperature reservoir at 370 C and rejects 37 kJ heat. Determine the temperature of the low temperature reservoir.
   a. –35 C
   b. 100 C
   c. 130 C
   d. 230 C

2. What is the maximum thermal efficiency possible in a power cycle operating between 600 C and 110 C?
   a. 47%
   b. 56%
   c. 63%
   d. 74%

3. An ideal Rankine cycle consists of which of the following?
   a. Two constant volume and two isentropic processes
   b. Two constant pressure and two isentropic processes
   c. Two constant volume and two constant temperature processes
   d. Two constant pressure and two constant temperature processes

4. What cycle or process does the T-s diagram below represent?
   a. Rankine cycle with superheated steam
   b. Carnot cycle
   c. Diesel Cycle
   d. Refrigeration Cycle

5. A Rankine cycle operates between 600 kPa (boiler) and 10 kPa (condenser). Water leaving the condenser is saturated liquid and the turbine inlet temperature is 300 C. Determine the efficiency of the cycle.
   a. 13%
   b. 25%
   c. 37%
   d. 52%

6. A refrigeration cycle has a coefficient of performance of 80% of the COP for a Carnot refrigerator operating between the reservoir temperatures of 50 C and –5 C. For 3 kw of cooling, what is the required power input?
   a. 0.53 kw
   b. 0.62 kw
   c. 0.77 kw
   d. 0.89 kw

7. A heat pump takes heat from groundwater at 7 C and maintains a room at 21 C. What is the maximum COP possible for the heat pump?
   a. 1.4
   b. 2.8
   c. 5.6
   d. 21

8. An inventor claims that an engine produces 130 kw with a fuel consumption of 20 kg/h. The energy content of the fuel is 40,000 kJ/kg. The energy is received at a mean temperature of 500 C and rejected at a mean temperature of 50 C. Which laws of thermodynamics are violated?
   a. First law only
   b. Second law only
   c. Both first and second laws
   d. Neither first nor second laws

9. A Carnot cycle operates between the temperature limits of 800 K and 300 K. If the entropy of the low temperature reservoir increases 2.34 kJ/K, the cycle work is?
   a. 230 kJ
   b. 440 kJ
   c. 670 kJ
   d. 1200 kJ

10. A ball is dropped onto a smooth floor. It deforms elastically, and then returns to its original shape as it rebounds to its original height. Air friction is negligible. Which of the following statements best describes the thermodynamic change in the ball?
    a. The entropy of the ball increases
    b. The entropy of the ball is unchanged
    c. The temperature of the ball decreases
    d. The enthalpy of the ball decreases

11. A 10 m^3 uninsulated tank contains nitrogen at 2 MPa and 250 C. The temperature of the surroundings is 35 C. After the nitrogen comes to equilibrium with the surroundings, the entropy change in the surroundings is:
    a. –600 kJ/K
    b. –76 kJ/K
    c. 67 kJ/K
    d. 120 kJ/K

12. A Rankine steam cycle operates between 600 kPa and 10 kPa. The turbine inlet temperature is 300 C. The water leaving the condenser is saturated liquid. The enthalpy changes of the water/steam in processes in the cycle are: Δh_{pump} = 0.6 kJ/kg; Δh_{boiler} = 2868.77 kJ/kg; $\Delta h_{turbine}$ = -725.2 kJ/kg; $\Delta h_{condener}$ = -2144.17 kJ/kg. What is the thermal efficiency of the cycle?
    a. 19%   b. 25%   c) 32%   d) 48%

A power plant operates on an ideal Rankine steam cycle between the pressures of 1 MPa (boiler) and 35 C (condenser). The temperature of the steam at the turbine inlet is 500 C. The power generated by the turbines is 300 MW.

13. What is the quality of the steam after it has expanded in the turbines?
    a. 78%
    b. 92%
    c. 97%
    d. 100%

14. What is the enthalpy of the steam as it enters the condenser?
    a. 2380 kJ/kg
    b. 2420 kJ/kg
    c. 2560 kJ/kg
    d. 2600 kJ/kg

15. What is the mass flow rate of steam through the turbine?
    a. 10 kg/s
    b. 110 kg/s
    c. 200 kg/s
    d. 270 kg/s

16. 1 kg steam is initially at 400 C and 800 kPa (state 1). The steam expands adiabatically to 200 C and 400 kPa (state 2) in a closed process, performing 450 kJ work. The properties of the steam at the two states are: state 1, u_1 = 2959 kJ/kg, h_1 = 3267.1 kJ/kg, s_1 = 7.5716 kJ/kgK; state 2, u_2 = 2646.8 kJ/kg, h_2 = 2860.5 kJ/kg, s_2 = 7.1706 kJ/kgK. Which law(s) of thermodynamics does this process violate?
    a. Zeroth law
    b. First law
    c. Second law
    d. First and second laws

17. In a particular power cycle, 350 MJ of heat is transferred to the system each cycle. The heat rejected from the system is 297.5 MJ per cycle. What is the thermal efficiency of the cycle?
    a. 1% b. 5% c. 7.5% d. 15%