King Saud University
Mechanical engineering Department
ME 374 final exam, Thermodynamics tables are allowed, three hour exam, 5-3-1435H, 6-1-2014 G.
Solve questions 1, 2, 3 and 4 then solve only one question, either number 5 or 6.

Question # 1

One kg-mole of n-octane C_8H_{18} (g) at 25 ^oC is burned with 100 percent excess air at 400 K in a constant pressure steady flow process as seen in Fig. 1. If the products of combustion leave at 700 K,

(a) Write the balanced stoichiometric combustion equation of the fuel,
(b) Write the balanced actual combustion equation of the fuel
(c) Determine the air to fuel ratio of the equation in part (b),
(d) Determine the amount of heat transferred in part (b)
(e) If the total pressure of the products is 101 kPa, determine the dew point temperature of the combustion equation in part (b).

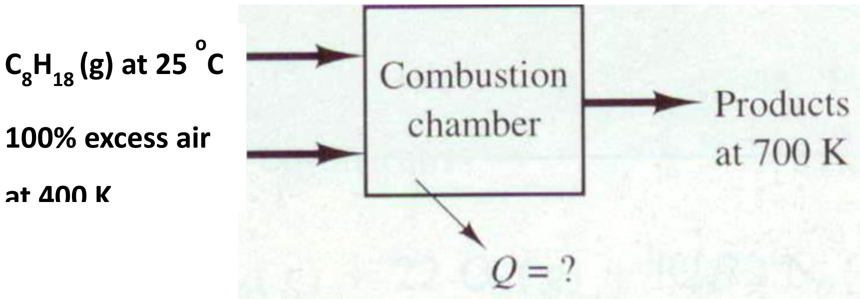


Fig. 1

Question # 2

(a) How does useful work differ from actual work? For what kind of systems are these two identical?
(b) Is the exergy of a system different in different environment?
(c) A 1.2-m3 insulated rigid tank contains 2.13 kg of carbon dioxide at 100 kPa. Now paddle-wheel work is done on the system until the pressure in the tank rises to 120 kPa. Determine:
(1) the actual paddle-wheel work done during this process,
(2) the minimum paddle-wheel work with which this process (between the same end states) could be accomplished,
(3) the entropy generation, and
(4) the surrounding work, and
(5) destroyed exergy. Take T_0 = 298 K.

Question # 3

(a) Show that the thermal efficiency of the ideal Brayton cycle under the cold air standard assumptions can be written as:

$$\eta_{\text{th,Brayton}} = 1 - \frac{1}{r_p^{(k-1)/k}}$$

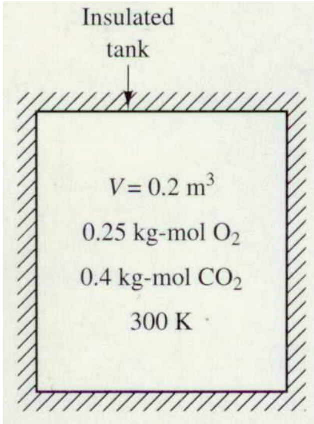
Where r_p and k are the pressure ratio and the specific heat ratio respectively.

(b) An ideal diesel engine has a compression ratio of 20 and uses air as the working fluid. The state of air at the beginning of the **isentropic** compression process is 95 kPa and 20°C. The expansion process is **polytropic** with the polytropic exponent *n* =1.35. If the maximum temperature in the cycle is not to exceed 2200 K. Assume constant specific heats for air at room temperature, determine.
(1) the thermal efficiency,
(2) the mean effective pressure,and
(3) draw the cycle on a P-V and T-S diagrams.

Question # 4

(a) Prove that for ideal gas mixture; the pressure fraction = the volume fraction = the mole fraction.

$$\frac{P_i}{P_m} = \frac{V_i}{V_m} = \frac{N_i}{N_m} = y_i$$



(b) An insulated rigid tank of volume 0.2 m^3 contains 0.25 kg-mole of O_2 and 0.4 kg-mole of CO_2 at 300 K as shown in the figure. Determine the pressure of the mixture using:

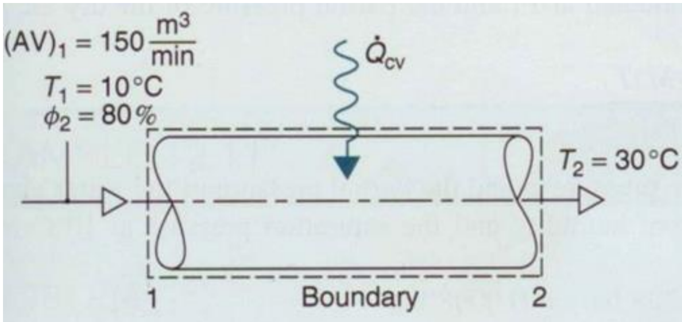
(1) The ideal gas equation of state
(2) The compressibility factors based on Amagat's model
(3) Kay's rule

<u>SOLVE ONLY ONE QUESTION OF THE FOLLOWING</u>

Question # 5

(a) Show that the relative humidity of the air can be given by $\varphi = P_v/P_g$ where P_v and P_g are the vapor pressure of unsaturated and saturated air respectively.

(b) Moist air enters a duct at 10°C, 80% relative humidity, and a volumetric flow rate of 150 m^3/min. The mixture is heated as it flows through the duct and exits at 30°C. No moisture is added or removed, and the mixture pressure remains approximately constant at 100kPa. For steady state operation, determine: (Changes in kinetic and potential energy can be ignored)



(1) The rate of heat transfer, in kJ/min, and
(2) The relative humidity at the exit.
(3) Show the process on T-v diagram

Question # 6

Nitrogen gas is compressed from 80 kPa and 27°C to 480 kPa by a 10-kW compressor. Determine the mass flow rate of nitrogen through the compressor, assuming the compression process to be (*a*) isentropic, (*b*) polytropic with *n*=1.3, (*c*) isothermal, and (*d*) ideal two-stage polytropic with *n*=1.3. Draw a P-V diagram showing all processes from (*a*) to (*d*). What is the most desirable process?

Some Relations you may need

$$\underbrace{S_{in} - S_{out}}_{\substack{\text{Net entropy transfer}\\ \text{by heat and mass}}} + \underbrace{S_{gen}}_{\substack{\text{Entropy}\\ \text{generation}}} = \underbrace{\Delta S_{system}}_{\substack{\text{Change}\\ \text{in entropy}}}$$

$$\underbrace{X_{in} - X_{out}}_{\substack{\text{Net exergy transfer}\\ \text{by heat, work, and mass}}} - \underbrace{X_{destroyed}}_{\substack{\text{Exergy}\\ \text{destruction}}} = \underbrace{\Delta X_{system}}_{\substack{\text{Change}\\ \text{in exergy}}}$$

$$\Delta X = X_2 - X_1 = m(\phi_2 - \phi_1) = (E_2 - E_1) + P_0(V_2 - V_1) - T_0(S_2 - S_1)$$

$$= (U_2 - U_1) + P_0(V_2 - V_1) - T_0(S_2 - S_1) + m\frac{V_2^2 - V_1^2}{2} + mg(z_2 - z_1)$$

$$\psi_1 - \psi_2 = (h_1 - h_2) - T_0(s_1 - s_2) + \frac{V_1^2 - V_2^2}{2} + g(z_1 - z_2)$$

$$\text{MEP} = \frac{W_{net}}{V_{max} - V_{min}} = \frac{w_{net}}{v_{max} - v_{min}} \qquad \text{(kPa)}$$

Isentropic compression with $k = 1.4$:

$$w_{comp,in} = \frac{kRT_1}{k-1}\left[\left(\frac{P_2}{P_1}\right)^{(k-1)/k} - 1\right]$$

For ideal gases isentropic process between states 1 and 2 we have:

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

$$s_2 - s_1 = \int_1^2 c_v(T)\frac{dT}{T} + R\ln\frac{v_2}{v_1}$$

$$s_2 - s_1 = \int_1^2 c_p(T)\frac{dT}{T} - R\ln\frac{P_2}{P_1}$$

$$\phi = \frac{m_v}{m_g} = \frac{P_v}{P_g}$$

$$\omega = \frac{m_v}{m_a} = \frac{0.622P_v}{P - P_v} \qquad (\text{kg } H_2O/\text{kg dry air})$$

$$h = h_a + \omega h_g \qquad (\text{kJ/kg dry air})$$