IZMIR UNIVERSITY OF ECONOMICS
Faculty of Engineering

FE 251 – Thermodynamics
ME 201 – Engineering Thermodynamics

2021-22 Fall Semester / Midterm Examination

Date: 09.12.2021

Full Name: ....

Student ID: .... **Signature:** ....

Time Allowed: 90 minutes.

ATTENTION: During the examination, please do not attempt for cheating. Suspected cheating will result in a ZERO on your exam and all students who were caught cheating will face disciplinary sanctions.

Question	Score
1	
2	
3	
4	
Total	

Question 1 (25 pts)

A 4-m × 5-m × 7-m room is heated by the radiator of a steam-heating system. The steam radiator transfers heat at a rate of 10,000 kJ/h, and a 100-W fan is used to distribute the warm air in the room. The rate of heat loss from the room is estimated to be about 5000 kJ/h. If the initial temperature of the room air is 10°C, determine how long it will take for the air temperature to rise to 20°C. Assume constant specific heats at room temperature.

Assumptions 1 Air is an ideal gas since it is at a high temperature and low pressure relative to its critical point values of -141°C and 3.77 MPa. 2 The kinetic and potential energy changes are negligible, $\Delta ke \cong \Delta pe \cong 0$. 3 Constant specific heats at room temperature can be used for air. This assumption results in negligible error in heating and air-conditioning applications. 4 The local atmospheric pressure is 100 kPa. 5 The room is air-tight so that no air leaks in and out during the process.

Properties The gas constant of air is $R = 0.287$ kPa.m^3/kg.K (Table A-1). Also, $c_v = 0.718$ kJ/kg.K for air at room temperature (Table A-2).

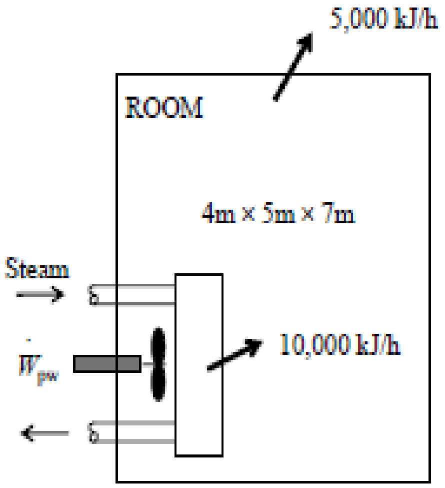
Analysis We take the air in the room to be the system. This is a closed system since no mass crosses the system boundary. The energy balance for this stationary constant-volume closed system can be expressed as

$$\underbrace{E_{in}-E_{out}}_{\substack{\text{Net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{system}}_{\substack{\text{Change in internal, kinetic,}\\ \text{potential, etc. energies}}}$$

$$Q_{in}+W_{fan,in}-Q_{out}=\Delta U \cong mc_{v,avg}(T_2-T_1) \quad (\text{since } KE = PE = 0)$$

or,

$$(\dot{Q}_{in}+\dot{W}_{fan,in}-\dot{Q}_{out})\Delta t = mc_{v,avg}(T_2-T_1)$$



The mass of air is

$$V = 4\times5\times7 = 140 \text{ m}^3$$

$$m = \frac{PV}{RT_1} = \frac{(100 \text{ kPa})(140 \text{ m}^3)}{(0.287 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(283 \text{ K})} = 172.4 \text{ kg}$$

Using the c_v value at room temperature,

$$\left[(10{,}000-5{,}000)/3600 \text{ kJ/s}+0.1\text{kJ/s}\right]\Delta t = (172.4 \text{ kg})(0.718 \text{ kJ/kg}\cdot{}^\circ\text{C})(20-10)^\circ\text{C}$$

It yields

$$\Delta t = 831 \text{ s}$$

Question 2 (25 pts)

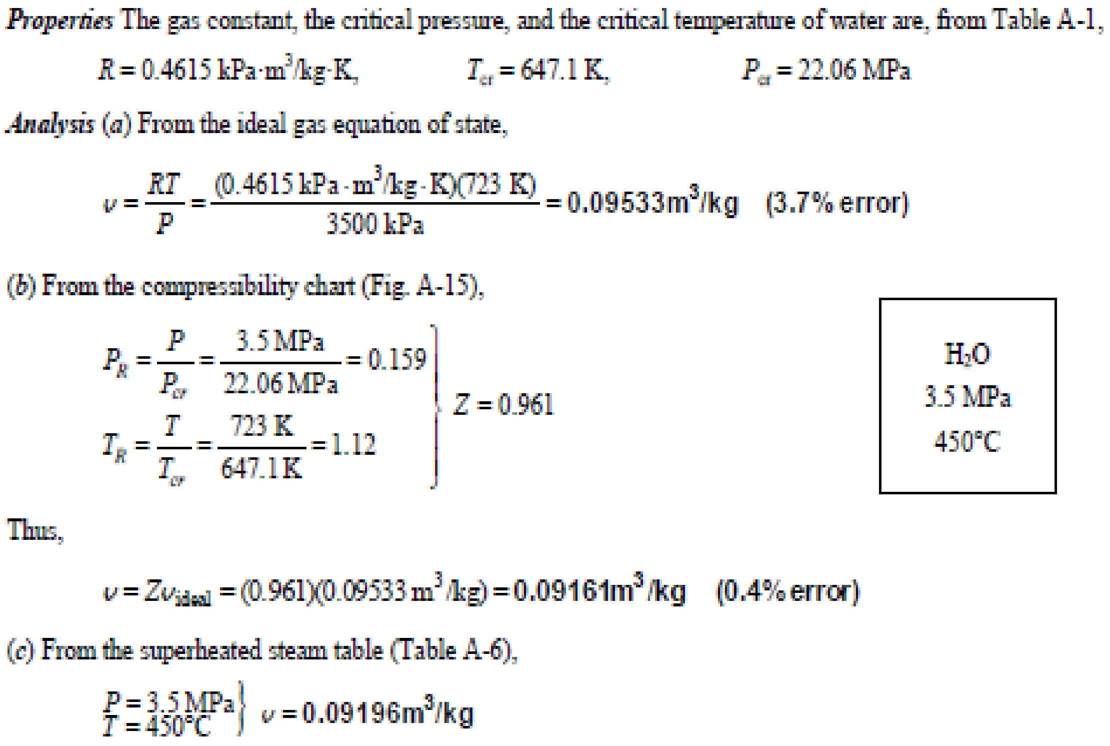
Determine the specific volume of superheated water vapor at 3.5 MPa and 450°C based on

(a) the ideal-gas equation, (7 points)

(b) the generalized compressibility chart, (7 points)

(c) the steam tables. (7 points)

Determine the error involved in the first two cases. (4 points)



Properties The gas constant, the critical pressure, and the critical temperature of water are, from Table A-1,

$$R = 0.4615\ \text{kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K}, \qquad T_{cr} = 647.1\ \text{K}, \qquad P_{cr} = 22.06\ \text{MPa}$$

Analysis (*a*) From the ideal gas equation of state,

$$v = \frac{RT}{P} = \frac{(0.4615\ \text{kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(723\ \text{K})}{3500\ \text{kPa}} = \mathbf{0.09533\ m^3/kg} \quad \mathbf{(3.7\%\ error)}$$

(*b*) From the compressibility chart (Fig. A-15),

$$\left.\begin{array}{l} P_R = \dfrac{P}{P_{cr}} = \dfrac{3.5\ \text{MPa}}{22.06\ \text{MPa}} = 0.159 \\ T_R = \dfrac{T}{T_{cr}} = \dfrac{723\ \text{K}}{647.1\ \text{K}} = 1.12 \end{array}\right\} Z = 0.961$$

H$_2$O
3.5 MPa
450°C

Thus,

$$v = Zv_{\text{ideal}} = (0.961)(0.09533\ \text{m}^3/\text{kg}) = \mathbf{0.09161\ m^3/kg} \quad \mathbf{(0.4\%\ error)}$$

(*c*) From the superheated steam table (Table A-6),

$$\left.\begin{array}{l} P = 3.5\ \text{MPa} \\ T = 450^\circ\text{C} \end{array}\right\} v = \mathbf{0.09196\ m^3/kg}$$

Question 3 (20 pts)

A pump can be used to increase the speed and/or height of a fluid. In a practical application, liquid water which is initially stagnant at sea level is pumped up to a height of 20 m and at the peak, its velocity is measured as 7 m/s. If the volumetric flow rate of water in this process is 600 liters per minute and if the pump has a power consumption of 5 kW, calculate the efficiency of the pump. The density of liquid water can be taken as 1000 kg/m^3 and the gravitational acceleration (g) can be taken as 9.8 m/s^2. Please be careful with the units throughout the question.

We need to determine the power consumption as a result of the change in the height and velocity of the water. Since this is an open system, we need to work with the mass flow rate. By using the volumetric flow rate and the density, the mass flow rate of the water can be found as:

$600\ \text{lt/min} \times 1\ \text{m}^3/1000\ \text{lt} \times 1\ \text{min}/60\ \text{s} \times 1000\ \text{kg/m}^3 = 10\ \text{kg/s}$

The change in the mechanical energy (kinetic + potential) can be found as:

$E_{mech} = m\,[(1/2\,(V_f^2 - V_i^2) + g(z_f - z_i)] = 10\,[1/2(49 - 0) + 9.8(20 - 0)] = 2205\ \text{W} = 2.205\ \text{kW}$

The efficiency of the pump can be found as

$2.205 / 5 = 0.441 = \boxed{\textbf{44.1\%}}$

Question 4 (30 pts – 2 points for each box)

Complete the following table for water.

	Temperature (°C)	Pressure (kPa)	Specific enthalpy, h (kJ/kg)	Quality, x	Phase Description
a)	200	1554.9	2210.08	0.7	Saturated mixture
b)	≅ 262.8	100	3000	undefined	Superheated vapor
c)	50	120	209.34	undefined	Compressed liquid
d)	200	1554.9	2792.0	1.0	Saturated vapor
e)	150	476.16	2000	0.647	Saturated mixture

Please show all your calculations and comments regarding the filling of the table above on the answer sheets in detail.

a) Since $0 < x < 1$, we can conclude that we have a saturated mixture. Accordingly, the pressure must be equal to the saturation pressure of water at 200°C, which can be obtained as 1554.9 kPa from Table A4. Finally, the mixture enthalpy can be calculated as follows:

$h_{mix} = x\, h_g + (1-x)\, h_f = (0.7)(2792.0) + (0.3)(852.26) = 2210.08$ kJ/kg

b) At 100 kPa, the saturated liquid enthalpy and the saturated gas enthalpy of water can be obtained as 417.51 kJ/kg and 2675.0 kJ/kg from Table A5, respectively. Since $h > h_g$ (3000 > 2675), we conclude that we have a superheated gas. Mixture quality would be undefined. In order to determine the temperature, we must use Table A6. According to the mini-table for a pressure of 100 kPa (0.1 MPa) in Table A6, the enthalpy at 250°C is 2974.5 kJ/kg and the enthalpy at 300°C is 3074.5 kJ/kg. Therefore we conclude that the temperature is between 250°C and 300°C, and the approximate value can be found via interpolation as follows:

$$\frac{T - 250}{300 - 250} = \frac{3000 - 2974.5}{3074.5 - 2974.5}$$

From here, the temperature can be approximated as 262.8°C.

c) According to Table A-5, the saturation temperature of water at 120 kPa is between 100°C and 105.97°C. Since the temperature is lower than the saturation temperature, we have a compressed liquid. The mixture quality would be undefined. When we go to the compressed liquid data table for water (Table A-7), we can see that the smallest value of pressure is 5 MPa whereas the pressure in this question is 0.125 MPa. Hence, we can safely assume that water in this state behaves like a saturated liquid. Therefore the enthalpy of saturated liquid water at 50°C can be obtained as 209.34 kJ/kg from Table A-4.

d) If we have a saturated vapor, the pressure would be equal to the saturation pressure at 200°C, which can be obtained as 1554.9 kPa from Table A-4. Mixture quality would simply be equal to 1, and the enthalpy value would be equal to the h_g value at 200°C, which is equal to 2792.0 kJ/kg.

e) At a temperature of 150°C, the saturated liquid enthalpy and the saturated gas enthalpy of water can be obtained as 632.18 kJ/kg and 2745.9 kJ/kg from Table A4, respectively. Since $h_f < h < h_g$, we can conclude that we have a saturated mixture. Therefore, the pressure must be equal to the saturation pressure of water at 150°C, which can be obtained as 476.16 kPa from Table A4. The mixture quality can be calculated as follows:

$h_{mix} = x\, h_g + (1-x)\, h_f$

$2000 = 2745.9\, x + 632.18\, (1-x)$ From here, x can be found as 0.647