IZMIR UNIVERSITY OF ECONOMICS
Faculty of Engineering

ME 201 – Engineering Thermodynamics

2021-22 Spring Semester / Midterm Examination

Date: 12.05.2022

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	
5	
Total	

Question 1 (25 points)

Complete the following table for water.

	Temperature (°C)	Pressure (kPa)	Specific internal energy, u (kJ/kg)	Quality, x	Phase Description
a)	220	**2319.6**	**1605**	0.4	**Saturated liquid – vapor mixture**
b)	**308.5**	1400	2800	**undefined**	**Superheated vapor**
c)	200	**1554.9**	**850.46**	**0**	Saturated liquid
d)	**143.61**	400	1000	**0.203**	**Saturated liquid – vapor mixture**
e)	120	**> 50 MPa**	400	**undefined**	**Compressed liquid**

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

Solution:

a) We have an "x" value, which shows that we have a sat'd liquid – vapor mixture. Then, pressure is equal to the saturation pressure of water at 220°C = 2319.6 kPa. Similarly, the specific internal energy is equal to liquid phase saturation specific internal energy (u_f) of water at 220°C, which is equal to 1604.99 kJ/kg ≈ 1605 kJ/kg. (From Table A4)

b) At 1400 kPa, the vapor phase saturation internal energy of water is as follows:

u_g (H_2O, 1400 kPa) = 2591.8 kJ/kg (From Table A5)

Since u > u_g, then we have superheated steam and therefore the quality (x) is undefined. At this stage, we need to go to Table A6 and find the interval in which the specific internal energy of water can be 2800 kJ /kg.

u(1.4 MPa, 300°C) = 2785.7 kJ/kg

u(1.4 MPa, 350°C) = 2869.7 kJ/kg

Now we know that our final temperature is between 300 and 350°C. By interpolation:

$$\frac{T-300}{350-300} = \frac{2800-2785.7}{2869.7-2785.7}$$ then, T can be found as 308.5°C

c) When we have saturated liquid, $P = P^{sat} = P_{sat,H2O}(200°C) = 1554.9$ kPa

$x = 0$ $u = u_f\ (200°C) = 850.46$ kJ/kg

d) At 400 kPa, the saturation internal energies of liquid and vapor phases are as follows:

$u_f\ (H_2O, 400\ kPa) = 604.22$ kJ/kg

$u_g\ (H_2O, 400\ kPa) = 2553.1$ kJ/kg

Since $u_f < u < u_g$, then we have saturated liquid-vapor mixture. Thus, $T = T_{sat} = 143.61°C$. We have to find the quality (x). We know that for any substance property, the equation below applies:

$$u_{mix} = u_g\ (x) + u_f\ (1-x)$$

Then, $1000 = 2553.1\ (x) + 604.22\ (1-x)$ $\rightarrow$ x can be found to be 0.203.

e) At 120°C, the liquid phase saturation internal energy of water is as follows:

$u_f\ (H_2O, 120°C) = 503.6$ kJ/kg (From Table A4)

Since $u < u_f$, then we have compressed liquid and therefore the quality (x) is undefined. Normally, we can neglect the effect of pressure on compressed liquids so we can assume that the pressure is equal to the saturation pressure at 120°C, which is 198.67 kPa. But we can always check Table A-7 to have an idea.

According to Table A-7, for a constant temperature of 120°C, u values keep decreasing as pressure increases and even when P = 50 MPa (the last entry on the table), u = 487.69 kJ/kg, which is still much higher than 400 kJ/kg. Therefore we must say that the final pressure is definitely greater than 50 MPa.

Question 2 (15 pts)

Consider a 90-kg man who has a total foot imprint area of 450 cm^2. He wishes to walk on the snow, but the snow can not withstand pressures greater than 20 kPa. Determine whether this man can walk on the snow without sinking. (gravitational acceleration, g, can be taken as 9.8 m/s^2)

Solution:

In this problem, we need to calculate the pressure exerted by the man onto the snow. If this pressure is found to be greater than 20 kPa, the man would sink. If not, the man would be able to walk on the snow. This question is quite easy, the only thing that we need to be careful about is the unit consistency.

$$P = \frac{F}{A} = \frac{m\,g}{A} = \frac{(90\,kg) \times (9.8\,{}^{m}\!/\!{}_{s^2})}{450\,cm^2} \times \frac{10^4\ cm^2}{1\,m^2} = 19600\frac{N}{m^2} = 19600\,Pa = 19.6\,kPa$$

(12 pts)

Since the pressure exerted by the man, which was found to be 19.6 kPa, is less the withstandable pressure for the snow (20 kPa), it means that the man can walk on the snow. (3 pts)

Question 3 (15 pts)

Water at 20°C and atmospheric pressure is adiabatically and isothermally pumped from a lake to a storage unit 30 m above at a rate of 50 L/s. During the process, the motor of the pump consumes 20 hp of electric power. If the kinetic energy changes and frictional losses in the system are negligible, determine the overall efficiency of the pump-motor unit.

Solution:

This is a simple energy balance problem. The water is being pumped to a certain height by using a electric-powered pump. Obviously, the pump does work on the water. While solving this problem, we have two different choices for the selected system. We can either select the pump as the system, or the water. Generally, it is much easier to select the component on which work is done as the system. In this case, water should be our system. Let's write the general energy balance and eliminate the terms that do not exist.

$$Q_{in} + W_{in} - Q_{out} - W_{out} = \Delta U + \Delta KE + \Delta PE \text{ (2 pts)}$$

The problem statement tells that the process is adiabatic, meaning $Q_{in} = Q_{out} = 0$. Pump does work on the water by pushing it, but water does not do any sort of work on its surroundings. So, the left-hand side of the equation simply becomes W_{in}. Let's also check the right-hand side. The problem statement says the process is isothermal. Since we would not expect any phase change during pumping, we can conclude that $\Delta U = 0$. The problem statement directly says the kinetic energy changes are negligible, meaning $\Delta KE = 0$. However, there has been a potential energy change, as the water's elevation has been increased by 30 m. Therefore, the final form of the energy balance becomes:

$$W_{in} = \Delta PE \text{ (3 pts)}$$

In this question, we should first calculate the change in the potential energy of the water. Since this value would be equal to the amount of work done by the pump on the water, we can calculate pump efficiency by dividing this amount by the total electric power consumption of the pump, which is given as 20 hp. We know that $\Delta PE = m\,g\,(z_2 - z_1)$. Yet, we don't know the mass of water. All we know is the volumetric flow rate. Simply, this is an energy balance, yet we are asked to find the power consumption of the pump. To eliminate this confusion, we should divide each side of the final energy balance equation by time, thus converting the equation into power balance.

$$\frac{W_{in}}{t} = \frac{m}{t}\, g\, (z_2 - z_1)$$

Since $\frac{m}{t} = \dot{m}$ = mass flow rate (kg/s), we need to first calculate the mass flow rate of water. In order to obtain the mass flow rate by using the volumetric flow rate, we need to first find out the specific volume of the water. We have been given the information that water is at atmospheric pressure, which is approximately 100 kPa. From Table A-5, we can read that the saturation temperature at this pressure is 100°C. Since $T < T_{sat}$, we have compressed liquid. As a rule, we can approximate compressed liquids to saturated liquids at the same temperature. The reasoning behind this approximation is the fact that the change in the physical properties of liquids as a function of pressure is negligible. Hence

$$v \approx v_f\ (@20^oC) = 0.001002 \frac{m^3}{kg} \text{ (2 pts)}$$

Then, mass flow rate can be calculated as follows:

$$\dot{m} = \frac{\dot{V}}{v} = \frac{50\frac{L}{s} \times \frac{1\,m^3}{1000\,L}}{0.001002\frac{m^3}{kg}} = 49.9 \text{ kg/s (2 pts)}$$

If we insert this value into the power balance:

$$\dot{W} = \dot{m}\, g\, (z_2 - z_1) \quad = \quad 49.9\frac{kg}{s} \times 9.8\frac{m}{s^2} \times 30\,m = \text{ 14670.7 W} \approx \text{14.671 kW (5 pts)}$$

The final step is to divide the power transferred to the water by the electrical power consumption of the pump, which would yield efficiency. There is one more trick, however, and that is converting the electrical power value into SI units (kW).

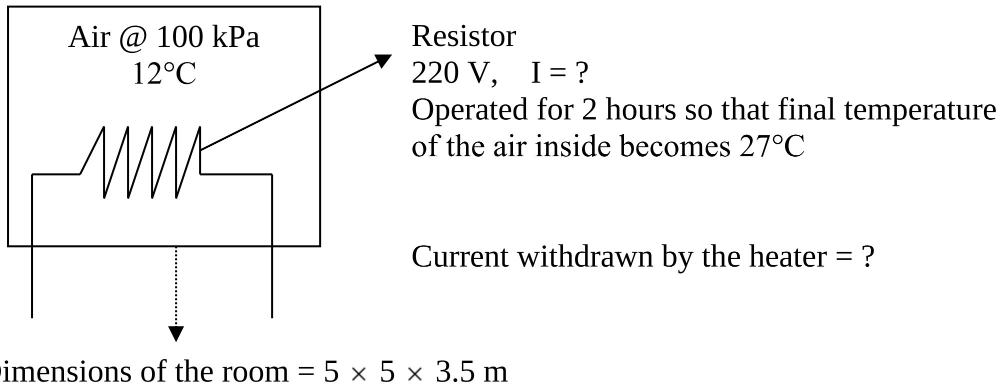
$$\text{Pump efficiency (\%)} = \frac{\textit{power transferred}}{\textit{power consumed}} = \frac{14.671\,kW}{20\,hp} \times \frac{1\,hp}{0.7457\,kW} \times 100$$

$$= \boxed{\textbf{98.4 \%}} \qquad \text{(3 pts)}$$

Question 4 (20 points)

A room with dimensions of 5 m × 5 m × 3.5 m is to be heated by an electrical heater. It is desired that the heater be able to raise the air temperature in the room from 12°C to 27°C within two hours. Assuming no heat losses from the room and an atmospheric pressure of 100 kPa, determine the electrical current requirement of the resistance heater in amperes. Assume constant specific heats at room temperature and regular city voltage (220 V) to operate the heater. The specific gas constant of air can be taken as 0.287 kJ/kg.K.

***Solution*:** Let's make a drawing first.



This is a closed system. Let's write the energy balance for a closed system:

$Q_{in} + W_{in} + m\,(u_1 + ke_1 + pe_1) = Q_{out} + W_{out} + m\,(u_2 + ke_2 + pe_2)$

Problem statement tells that the heat losses can be neglected → $Q_{in} = Q_{out} = 0$

System is not moving horizontally or vertically, then $ke_1 = ke_2$ & $pe_1 = pe_2$

Work enters the system in the form of electricity ($W_{in} = V.I.t$)

A room by definition is a rigid system, which means its volume is constant and there is no boundary work ($W_{out} = 0$)

Then, the final form of the energy balance is:

$W_{in} = m\,(u_2 - u_1)$ (5 pts)

We need to calculate the initial and final internal energy values for the air. Table A-17 contains data for air under ideal conditions. Hence, the first thing we should do is to check if air can be assumed to be ideal at the given conditions.

From Table A1, T_{CR} (air) = 132.5 K & P_{CR} (air) = 3.77 MPa

Then, $T_R = (12+273) / 132.5 = 285 / 132.5 = 2.15 > 2$

P_R = 0.1 MPa / 3.77 MPa = 0.027 < 0.1

Since the reduced temperature is greater than 2 and the reduced pressure is less than 0.1, we can use Ideal Gas approximation; hence the data given in Table A-17 is valid (3 pts)

$u_1 = u_{air}$ (@ 285 K) = 203.33 kJ/kg

$u_2 = u_{air}$ (@ 300 K) = 214.07 kJ/kg (2 pts)

We also need to know the mass of the air inside the room. By using the specific form of the ideal gas law, we can calculate the specific volume of air as follows:

$$P\,\vartheta = R_{sp}\,T \quad \Rightarrow \quad \vartheta = \frac{R_{sp}\,T}{P} = \frac{\left(0.287\,\frac{kJ}{kg\,K}\right)(285\,K)}{100\,kPa} = 0.818\,{}^{m^3}\!/_{kg}$$ (2 pts)

Then, the mass of the air can be found by dividing the volume of the room by the specific volume:

$$m_{air} = \frac{V}{\vartheta} = \frac{(5\times5\times3.5)\,m^3}{0.818\,{}^{m^3}\!/_{kg}} \approx 107.0\,kg$$ (2 pts)

$W_{in} = m\,(u_2 - u_1)$

W_{in} = 107 (214.07 – 203.33) = 1149.18 kJ = 1149180 J = V I Δt

Then, the current can be found as:

$$I = \frac{W_{in}}{V\times\Delta t} = \frac{1149180}{220\times 2\,h\times\frac{3600\,s}{1\,h}} = 0.725\text{ A}$$ (6 pts)

Answer: 0.725 A

Question 5 (25 points)

Steam flows steadily through a turbine, whose inlet opening has an area of 0.005 m^2, with a velocity of 100 m/s, entering at 6 MPa and 500°C and leaving at 100 kPa as saturated vapor. If the power generated by the turbine is 3 MW, determine the rate of heat loss from the steam. Neglect the possible changes in velocity and elevation.

Solution: Let's make a drawing first.

TURBINE
(inlet area: 0.005 m^2)

Steam
100 m/s
6 MPa, 500°C

100 kPa, sat'd vapor

$\dot{W}_{out}$ = 3 MW

$\dot{Q}_{out}$ = ?
Efficiency = ?

This is an open system. Let's write the energy balance for an open system:

$$\dot{Q}_{in} + \dot{W}_{in} + \dot{m}_{in}(h_{in} + pe_{in} + ke_{in}) = \dot{Q}_{out} + \dot{W}_{out} + \dot{m}_{out}(h_{out} + ke_{out} + pe_{out})$$

A turbine system does not involve heat transfer from the surroundings $\rightarrow$ $\dot{Q}_{in} = 0$

The statement "neglect the possible changes in velocity and elevation" means $ke_{in} = ke_{out}$

$pe_{in} = pe_{out}$

Obviously $\dot{m}_{in} = \dot{m}_{out} = \dot{m}$

$\dot{W}_{out}$ is present and equal to 3 MW = 3000 kW. Then, the final form of the energy balance is:

$$\dot{m}_{in} h_{in} = \dot{Q}_{out} + \dot{W}_{out} + \dot{m}_{out} h_{out} \text{ (6 pts)}$$

Let's analyze the incoming stream:

$T_{sat,\ H2O}$ (@ 7 MPa) = 275.59 °C (from Table A-5)

Since $T_{in} > T_{sat}$ $\rightarrow$ incoming stream is superheated steam. We need to go to Table A-6.

h_{H2O} (6 MPa & 500°C) = 3423.1 kJ/kg (2 pts)

We need to calculate the mass flow rate, $\dot{m}$.

$$\dot{m} = \frac{(Velocity)(Area)}{Specific\ Volume}$$ & the specific volume of the incoming steam can be found as:

ν_{H2O} (6 MPa & 500°C) = 0.05667 m^3/kg

$$\dot{m} = \frac{\left(100\, m/s\right)\left(0.005\, m^2\right)}{0.05667\, m^3/kg} = 8.82 \text{ kg/s} \quad \text{(5 pts)}$$

$h_{out} = h_{H2O}$ (sat'd vapor @ 100 kPa) = 2675 kJ/kg (from Table A-5) (2 pts)

$$\dot{m}_{in}\, h_{in} = \dot{Q}_{out} + \dot{W}_{out} + \dot{m}_{out}\, h_{out}$$

$$\rightarrow \quad 8.82\frac{kg}{s} \times 3423.1\frac{kJ}{kg} = \dot{Q}_{out} + 3000\,kW + 8.82\frac{kg}{s} \times 2675\frac{kJ}{kg}$$

From the equation above, $\dot{Q}_{out}$ can be found as 3598.2 kW, or approximately 3.6 MW (10 pts)

Answer: $\dot{Q}_{out}$ **= 3.6 MW**