Mansoura University **Faculty of Engineering** **Program of Biomedical Engineering.** **Course Title: Thermodynamics** **Course Code: MPE 172**		**Level: 100** **Exam Type: Final** **Date: 22 May 2018** **Time: 2 Hours** **Full Mark: 50**

Answer all the following questions. Use of steam and gas tables are allowed

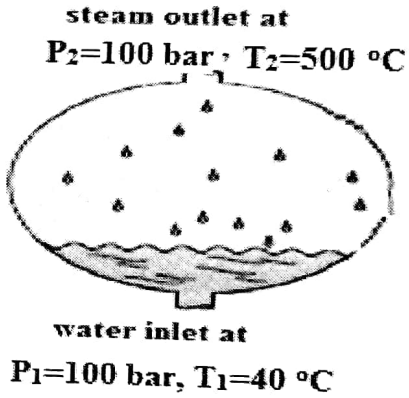
---

Question (1) **[10 Marks]**

A 0.2 m^3 of air at 800 K and 10 bar is expanded polytropic ($pv^{1.2}=c$) to 1 bar. It is then heated at constant volume to initial temperature. Sketch two processes on P-v diagram and determine : (i) Temperature at the end of polytropic expansion. (ii) Pressure at end the constant volume heating. (iii) Heat and work for each process. (iii) Entropy change for each process. Take for air : C_p = 1005 J/kg.K and C_v = 718 J/kg.K.

Question (2) **[10 Marks] (4+6)**

a) Water is supplied to the boiler at 100 bar and 40°C and steam is generated from boiler at the same pressure and 500 °C. Determine the mass flow rate of steam if the rate of heat added to the steam in passing through the boiler is 320 MW. (Neglect the change in potential energy and kinetic energy)



b) *Steam flows steadily through an adiabatic nozzle. The inlet conditions of the steam are 10 bar , 200°C, and 50 m/s, and the exit conditions are 2 bar and dry saturated steam. The mass flow rate of the steam is 2 kg/s. Determine (i) the velocity of the steam leaving the nozzle , (ii) the exit area of the nozzle and (iii) the rate change in entropy.*

Question (3) **[10 Marks]**

In a gas turbine plant working on Brayton cycle, the air at inlet is 300 K, 1 bar . The pressure ratio is 10 and the maximum temperature is 1200 K. The compressor and turbine efficiency are 85% and 90 %, respectively. Sketch the cycle on T-s diagram and determine:

i) The thermal efficiency of the cycle. ii) The back work ratio.

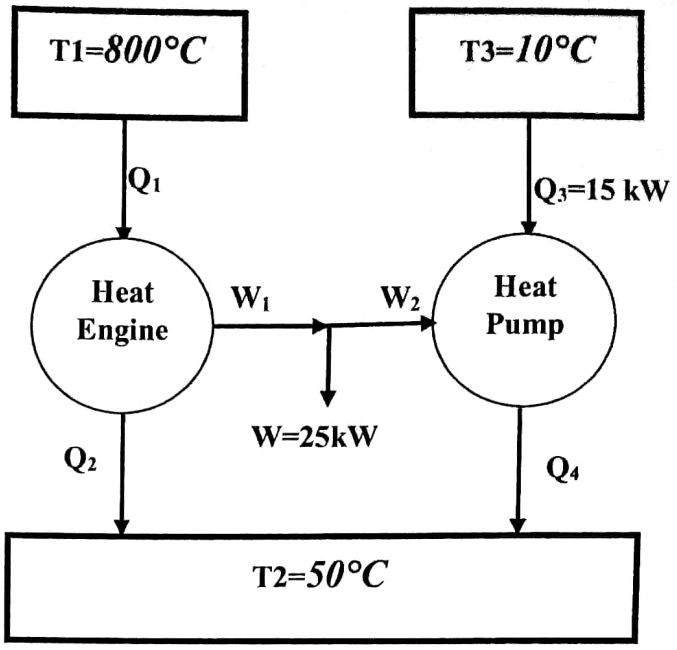
iii) The net output power requrued if the mass flow rate of air 500 kg/s.

Take for air : C_p = 1005 J/kg.K and γ =1.4 .

Scanned by CamScanner

Question (4) **[10 Marks]**

A heat pump is run by a Carnot heat engine operating between reservoirs at 800°C and 50°C. The heat pump working on reversed Carnot cycle picks up 15 kW heat from reservoir at 10°C and delivers it to a reservoir at 50°C. The reversible engine also runs a machine that needs 25 kW. Determine the heat received from highest temperature reservoir and heat rejected to reservoir at 50°C.



Question (5) **[12 Marks] (8+4)**

a) Moist air at the standard atmospheric pressure, has a temperature of 20 °C DBT and a relative humidity 50% . Determine the following:
i)the partial pressure of dry air and the water vapor, ii)the specific humidity,
iii)the degree of saturation, iv)the dew point temperature, and v) the density of moist air.

b)100 kg of air per minute at 20°C DBT and 50% relative humidity is heated to 35 °C DBT maintaining its specific humidity constant. Determine the following :
i) Relative humidity (R.H.) of heated air. ii)Capacity of heating coil in kW.

Change in entropy for ideal gas	
$s_2 - s_1 = c_v ln\left(\frac{T_2}{T_1}\right) + R\ ln\left(\frac{v_2}{v_1}\right)$,	$s_2 - s_1 = c_p ln\left(\frac{T_2}{T_1}\right) - R\ ln\left(\frac{P_2}{P_1}\right)$
$s_2 - s_1 = c_p ln\left(\frac{v_2}{v_1}\right) + c_v ln\left(\frac{P_2}{P_1}\right)$	
Enthalpy of moist air $h = 1.005\ T + \omega(2500.9 + 1.88T\ )\ (\frac{kJ}{kg} dry\ air)$	

Good Luck

Dr. Ahmed Abd-Elsalam

Scanned by CamScanner

Question (1) **[10 Marks]**

A 0.2 m³ of air at 800 K and 10 bar is expanded polytropic ($pv^{1.2}=c$) to 1 bar. It is then heated at constant volume to initial temperature. Sketch two processes on P-v diagram and determine : (i) Temperature at the end of polytropic expansion. (ii) Pressure at end the constant volume heating. (iii) Heat and work for each process. (iii) Entropy change for each process. Take for air : C_p = 1005 J/kg.K and C_v = 718 J/kg.K.

Solution:

$P_1V_1 = m\,R\,T_1$

$m = 0.871\ kg$

process 1-2 : polytropic ($pv^{1.2}=c$)

$$\left(\frac{T_2}{T_1}\right) = \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}$$

$$\left(\frac{T_2}{800}\right) = \left(\frac{1}{10}\right)^{\frac{1.2-1}{1.2}} \quad , T_2 = 545.033K$$

$$W_{1-2} = \frac{mR(T_1 - T_2)}{n-1} = 318683\ J = 318.683\ kJ$$

$$\Delta U_{1-2} = mC_v(T_2 - T_1)$$

$$Q_{1-2} = W_{1-2} + \Delta U_{1-2} = 159\ kJ$$

$$S_{1-2} = m\left(C_p \ln\left(\frac{T_2}{T_1}\right) - R\ln\left(\frac{P_2}{P_1}\right)\right) = 239.66\ J/K$$

process 2-3 : constant volume(V=C)

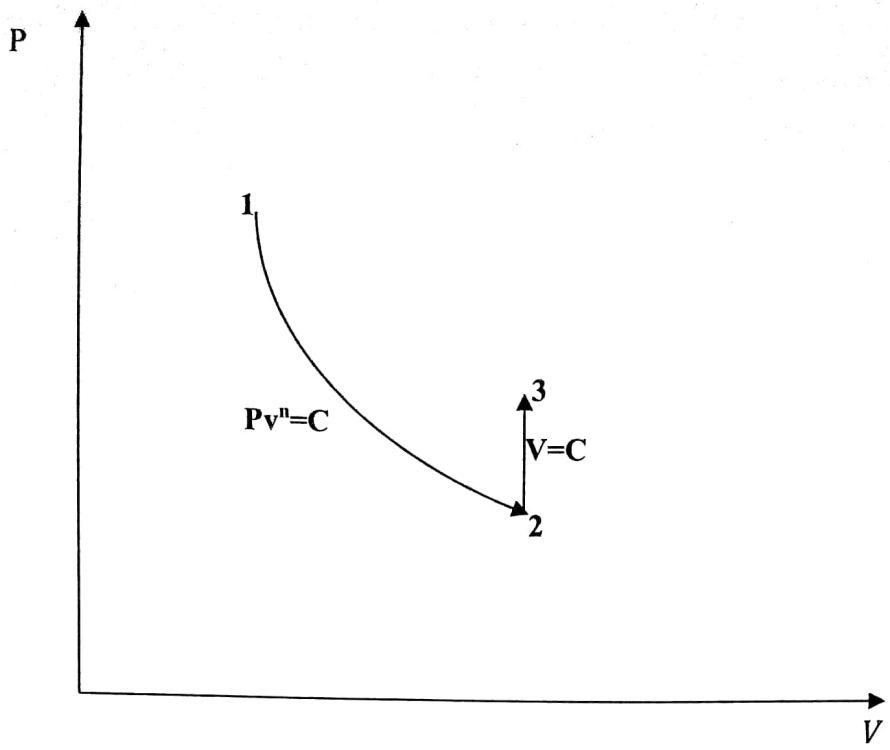
$$\frac{P_3}{P_2} = \frac{T_3}{T_2} \ , \qquad \frac{P_3}{1} = \frac{800}{545.033} \ , \quad P_3 = 1.468\ bar$$

$$W_{2-3} = 0$$

$$Q_{2-3} = mC_p(T_3 - T_2) = 159.4kJ$$

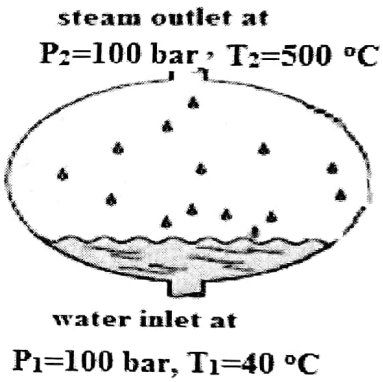
$$\Delta S_{2-3} = m\left(R\ln\left(\frac{V_3}{V_2}\right) + C_v \ln\left(\frac{T_3}{T_2}\right)\right) = mC_v \ln\left(\frac{T_3}{T_2}\right) = 239.998J/K$$

Scanned by CamScanner



Question (2) **[11 Marks] (4+7)**

a) Water is supplied to the boiler at 100 bar and 40°C and steam is generated from boiler at the same pressure and 500 °C. Determine the mass flow rate of steam if the rate of heat added to the steam in passing through the boiler is 320 MW.
(Neglect the change in potential energy and kinetic energy)



Solution:

From steam tables
at P_1= 100 bar and T_1=40 °C. , we get h_1=176.3 kJ/kg
at P_1= 100 bar and T_1=500 °C, we get h_2=3374.5 kJ/kg

$$\dot{Q} = \dot{m}(h_2 - h_1)$$
$$320 \times 10^3 = \dot{m}(3374.5 - 176.3)$$
$$\dot{m} = 100 \ kg/sec$$

b) ***Steam flows steadily through an adiabatic nozzle. The inlet conditions of the steam are 10 bar , 200°C, and 50 m/s, and the exit conditions are 2 bar and dry saturated steam. The mass flow rate of the steam is 2 kg/s. Determine (i) the velocity of the steam leaving the nozzle , (ii) the exit area of the nozzle and (iii) the rate change in entropy.***

Scanned by CamScanner

Solution:

From steam tables No. 3

at P_1= 10 bar and T_1=200 °C, we get h_1=2828.8 kJ/kg , s_1=6.6922 kJ/kgK

From steam tables No. 2

at P_2=2 bar and x_2= 1 , we get $h_2=h_g$=2706.3kJ/kg, $s_2=s_g$=7.126kJ/kgK , $v_2=v_g$=0.885m³/kg.

$$\dot{Q} - \dot{W} = \dot{m}\left[(h_2 - h_1) + \left(\frac{C_2^2 - C_1^2}{2}\right) + g(z_2 - z_1)\right]$$

$$0 - 0 = \left[(2706.3 - 2828.8) \times 10^3 + \left(\frac{C_2^2 - 50^2}{2}\right) + 0\right]$$

C_2=497.5 m/s

$$\dot{m} = \frac{C_2 A_2}{v_2}$$

$$2 = \frac{497.5 \times A_2}{0.885}$$

$$A_2 = 3.557 \times 10^{-3} m^2$$

$$\Delta \dot{S} = \dot{m}(s_2 - s_1) = 2 \times (7.126 - 6.6922) = 0.268 \frac{kW}{K} = 268\ W/K$$

Question (3) **[10 Marks]**

In a gas turbine plant working on Brayton cycle, the air at inlet is 300 K, 1 bar . The pressure ratio is 10 and the maximum temperature is 1200 K. The compressor and turbine efficiency are 85% and 90 %, respectively. Sketch the cycle on T-s diagram and determine:

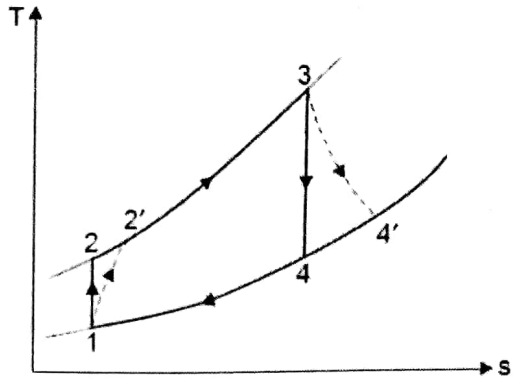
i) The thermal efficiency of the cycle. ii) The back work ratio.

iii) The net output power requrued if the mass flow rate of air 500 kg/s.

Take for air : C_p = 1005 J/kg.K and γ =1.4 .

Solution:

Scanned by CamScanner



T-s diagram

$$T_2 = T_1 r_p^{\frac{\gamma-1}{\gamma}} = 579.3\ K$$

$$\eta_c = 0.85 = \frac{T_2 - T_1}{T_2^{/} - T_1} \quad , \qquad T_2^{/} = 628.59\ K$$

$$T_4 = T_3 (\frac{1}{r_p})^{\frac{\gamma-1}{\gamma}} = 621.54\ K$$

$$\eta_T = 0.9 = \frac{T_3 - T_4^{/}}{T_3 - T_4} \quad , \qquad T_4^{/} = 679.386\ K$$

$$w_c = C_p \times \left(T_2^{/} - T_1\right) = 330.23\ kJ/kg$$

$$w_t = C_p \times \left(T_3 - T_4^{/}\right) = 523.22\ kJ/kg$$

$$w_{net} = w_t - w_c = 193\ kJ/kg$$

Back work ratio $= w_c/W_t = 0.63$

Power $= m \times w_{net} = 96500\ kW = 96.5\ MW$

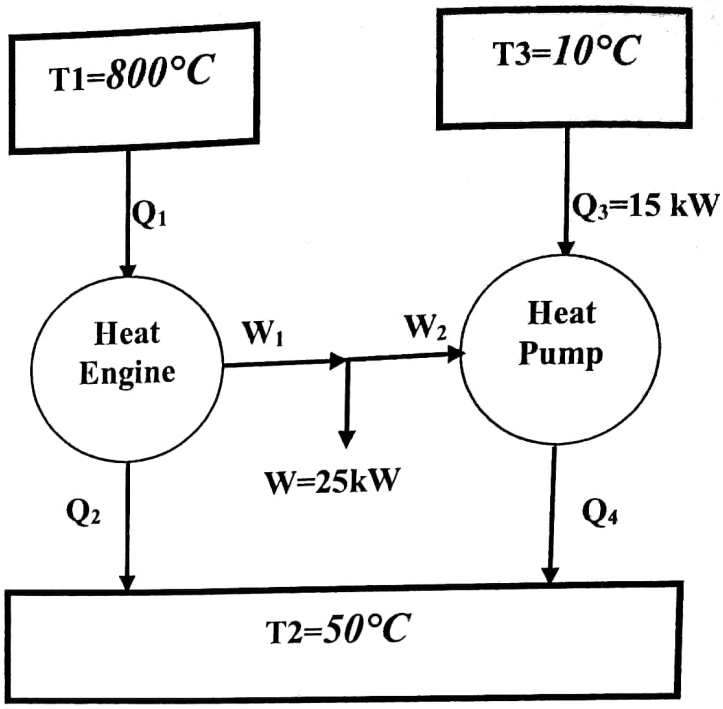
$$Q_{add} = C_p \times \left(T_3 - T_2^{/}\right) = 574.27\ \text{kJ/kg}$$

The thermal efficiency $= \frac{w_{net}}{Q_{add}} \times 100 = 33.61\%$

Scanned by CamScanner

Question (4) **[10 Marks]**

A heat pump is run by a Carnot heat engine operating between reservoirs at 800°C and 50°C. The heat pump working on reversed Carnot cycle picks up 15 kW heat from reservoir at 10°C and delivers it to a reservoir at 50°C. The reversible engine also runs a machine that needs 25 kW. Determine the heat received from highest temperature reservoir and heat rejected to reservoir at 50°C.



Solution:

Heat Pump:

$$COP_{HP,C} = \frac{T_H}{T_H - T_L} = \frac{50+273}{50-10} = 8.075 = \frac{15}{W_2}$$

$$W_2 = 1.857\ kW$$

$$W_1 = W_2 + W = 1.857 + 25 = 26.857kW$$

Heat engine:

$$\eta_{HE,C} = 1 - \frac{T_L}{T_H} = 1 - \frac{50+273}{800+273} = 0.699 = \frac{W_1}{Q_1}$$

$$= \frac{26.857}{Q_1}$$

$$Q_1 = 38.422KW$$

$$Q_2 = Q_1 - W_1 = 11.565kW$$

$$Q_4 = Q_3 + W_2 = 16.857\ kW$$

The heat rejected to reservoir at 50°C $= Q_2 + Q_4 = 28.422\ kW$

Question (5) **[12 Marks] (8+4)**

a) Moist air at the standard atmospheric pressure, has a temperature of 20 °C DBT and a relative humidity 50% . Determine the following:

Scanned by CamScanner

i)the partial pressure of dry air and the water vapor, ii)the specific humidity, iii)the degree of saturation, iv)the dew point temperature, and v) the density of moist air.

b)100 kg of air per minute at 20°C DBT and 50% relative humidity is heated to 35 °C DBT maintaining its specific humidity constant. Determine the following :

i) Relative humidity (R.H.) of heated air. ii)Capacity of heating coil in kW.

Solution:

From steam table

at T=20 °C , P_s= 0.0233 bar

$$\varphi = \frac{P_v}{P_s} = 0.5$$

$$P_v = 0.01165\ bar$$

$$P_a = 1 - P_v = 0.988 bar$$

$$\omega = 0.622\frac{P_v}{1 - P_v} = 0.0117$$

$$\omega_s = 0.622\frac{P_s}{1 - P_s} = 0.0148$$

$$\mu = \frac{\omega}{\omega_s} = 0.791$$

From steam table at P_v= 0.01165 bar , DPT=9.5 °C

$$\rho_a = \frac{P_a}{RT} = 1.175\ \frac{kg}{m^3}$$

$$\rho = \rho_a(\omega + 1) = 1.1887\ \frac{kg}{m^3}$$

$$h_1 = 1.005\ T_1 + \omega_1(2500.9 + 1.88T_1) = 49.8(\frac{kJ}{kg} dry\ air)$$

$$h_2 = 1.005\ T_2 + \omega_2(2500.9 + 1.88T_2) = 65.205(\frac{kJ}{kg} dry\ air)$$

$$Q^{\cdot} = m^{\cdot}(h_2 - h_1) = 1540.5\frac{kJ}{min} = 25.675kW$$

Scanned by CamScanner