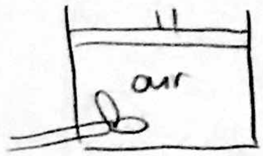
Cankaya University

Faculty of Engineering

Mechanical Engineering Department

Me 211 Thermodynamics I

1- An insulated piston–cylinder device initially contains 400 L of air at 200 kPa and 27°C. Air is now stirred so that work done by the paddle wheel is 50 kJ. The pressure of air is maintained constant during this process. a) Find the final Temperature b) Determine the entropy change of air. c) Find the entropy production.




State 1

$V = 400\,lt = 0{,}4\,m^3$

$P_1 = 200\,kPa$

$T_1 = 300\,K$

$R = 0{,}287\,kJ/kgK$

$$m = \frac{P_1 \cdot V_1}{R \cdot T_1} = \frac{200 \cdot 0{,}4}{0{,}287 \cdot 300}$$

$$\Rightarrow m = 0{,}93\,kg.$$

a) 1st law: ${}_1Q_2 - {}_1W_2 = \Delta U$

$$W_{bd} = \int_{V_1}^{V_2} P\,dV = P(V_2 - V_1)$$

$$\cancel{{}_1Q_2}^{\,0} - W_{sh} - W_{bd} = U_2 - U_1$$

$$-W_{sh} = U_2 - U_1 + W_{bd} = U_2 - U_1 + PV_2 - PV_1$$

$$-W_{sh} = H_2 - H_1 = m \cdot C_p \cdot (T_2 - T_1)$$

$$-(-50) = 0{,}93 \cdot 1{,}005 \cdot (T_2 - 300)$$

$$\Rightarrow \frac{50}{0{,}93 \cdot 1{,}005} = (T_2 - 300) \Rightarrow T_2 = 300 + 53{,}5 = \underline{\underline{353{,}5\,K}}$$

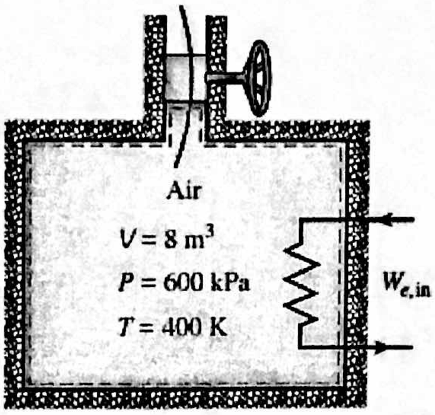
b) $$\Delta S = m(s_2 - s_1) = m\left(C_p \cdot \ln\frac{T_2}{T_1} - \cancel{R \ln\frac{P_2}{P_1}}\right) = m \cdot C_p \cdot \ln\frac{T_2}{T_1}$$

$$\Delta S = 0{,}93 \cdot 1{,}005 \cdot \ln\left(\frac{353{,}5}{300}\right) = \underline{\underline{0{,}1533\,kJ/kgK.}}$$

$$\Delta S = \int_1^2 \left(\cancel{\frac{\delta Q}{T}}\right)_{T_b}^{0} + \sigma \Rightarrow \sigma = \underline{\underline{\Delta S = 0{,}1533\,kJ/kgK}}$$

2)

An insulated 8-m³ rigid tank contains air at 600 kPa and 400 K. A valve connected to the tank is now opened, and air is allowed to escape until the pressure inside drops to 200 kPa. The air temperature during the process is maintained constant by an electric resistance heater placed in the tank. Determine the electrical energy supplied to air during this process.




$R = 0{,}287\ kJ/kg\,K$.

Mass balance:

$m_{cv}(t) - m_{cv}(0) = \sum m_i - \sum m_e$

Energy balance:

$U_{cv}(t) - U_{cv}(0) = Q - W + \sum m_i h_i - \sum m_e h_e$

State 1 (initial state) $u_1 = 286{,}16$ kJ/kg (A.22)

$P_1 \cdot V_1 = m_1 R T_1 \Rightarrow m_1 = \frac{600 \cdot 8}{0{,}287 \cdot 400} = 41{,}81\ kg$

State 2 (final state) $u_2 = 286{,}16$ kJ/kg (A.22)

$P_2 \cdot V_2 = m R T_2 \Rightarrow m_2 = \frac{200 \cdot 8}{0{,}287 \cdot 400} = 13{,}94\ kg$

$m_2 - m_1 = \underbrace{\cancel{m_i}}_{0} - m_e \Rightarrow m_e = m_1 - m_2 = 41{,}81 - 13{,}94$

$\Rightarrow m_e = 27{,}87\ kg$ ($h_e = 400{,}98$ kJ/kg A.22)

energy balance:

$m_2 \cdot u_2 - m_1 \cdot u_1 = \underbrace{\cancel{Q}}_{0} - W_e + \underbrace{\cancel{m_i h_i}}_{0} - m_e \cdot h_e$

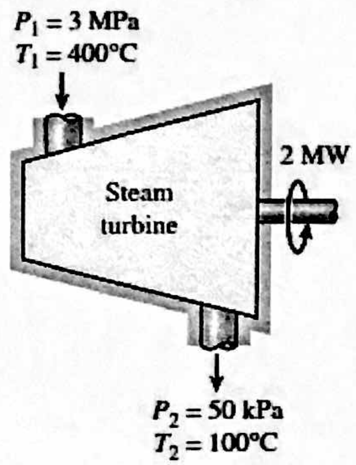
$\Rightarrow 13{,}94 \cdot 286{,}16 - 41{,}81 \cdot 286{,}16 = -W_e - 27{,}87 \cdot 400{,}98$

$\Rightarrow -W_e = 3200\ kJ$

$\Rightarrow W_e = -3200\ kJ$

$\rightarrow$ Electrical work: $W_e = 3200\ kJ = 0{,}889\ kWh$

**3)** Steam enters an adiabatic turbine steadily at 3 MPa and 400 °C and leaves at 70 kPa and 100 °C. If the power output of the turbine is 2 MW, determine a) the isentropic efficiency of the turbine and b) the mass flow rate through the turbine.




State 1 (A.4)

$P_1 = 3\,MPa$, $T_1 = 400°C$ $\Big\}$ $h_1 = 3230{,}9$ kJ/kg, $s_1 = 6.9212$ kJ/kg K.

State 2s (Isentropic)

$P_2 = 70$ kPa (A.3)

$s_{2s} = s_1 = 6.9212$ kJ/kg K

at 70 kPa, $s_f = 1.1919$ kJ/kg K

$s_g = 7.4797$ kJ/kg K.

$h_f = 376.70$ kJ/kg

$h_{fg} = 2283{,}3$ kJ/kg.

$s_{2s} = s_f + x_{2s}(s_g - s_f)$

$\Rightarrow 6.9212 = 1.1919 + x_{2s}(7.4797 - 1.1919)$

$\Rightarrow x_{2s} = 0{,}911$

$h_{2s} = h_f + x_{2s}(h_{fg})$

$\Rightarrow h_{2s} = 376{,}7 + 0{,}911 \cdot 2283{,}3 = 2457{,}19$ kJ/kg

State 2 (actual) (A.4)

$P_2 = 70$ kPa, $T_2 = 100°C$, $h_{2a} = 2680.0$ kJ/kg

a) $\eta_T = \dfrac{w_a}{w_s} = \dfrac{h_1 - h_{2a}}{h_1 - h_{2s}} = \dfrac{3230{,}9 - 2680}{3230{,}9 - 2457{,}19} = \dfrac{550{,}9}{773{,}71}$

$\Rightarrow \eta_T = 0{,}712 \Rightarrow \eta = 71{,}2\,\%$

b) $\dot{W}_T = \dot{m}(h_1 - h_{2a}) \Rightarrow 2000 = \dot{m} \cdot 550{,}9$

$\Rightarrow \dot{m} = 3.63$ kg/s

**4) Water in the amount of 2 kg undergoes a reversible isothermal expansion from a saturated liquid at 80 $^oC$ to a superheated vapor at 80 $^oC$ and 6 kPa. Determine the heat and work transports of energy for this process.**

State 1

$T_1 = 80°C$
sat. liquid ) Table A.2 $\Rightarrow u_1 = 334.86$ kJ/kg $= u_f$
$s_1 = 1.0753$ kJ/kg.K $= s_f$

State 2

$T_2 = 80°C$
$P_2 = 6$ kPa ) Table. A.2 $\Rightarrow u_2 = 2487.3$ kJ/kg
$s_2 = 8.5804$ kJ/kg

$\sigma = 0$ (no s generation)

$$S_2 - S_1 = \int_1^2 \frac{\delta Q}{T} + \cancel{\sigma}_0 \Rightarrow m(s_2 - s_1) = \frac{{}_1Q_2}{T_b}$$

$T_b \downarrow$ 353 K.

$$\Rightarrow {}_1Q_2 = 2\cdot(8.5804 - 1.0753)\cdot 353 = \underline{\underline{5298.6 \text{ kJ}}}$$

1st law:

$${}_1Q_2 - {}_1W_2 = m(u_2 - u_1)$$

$$5298.6 - {}_1W_2 = 2(2487.3 - 334.86)$$

$$\Rightarrow \underline{\underline{{}_1W_2 = 993.77 \text{ kJ}}}$$