Solved Examples 8: Availability

Example 8. 1 In Example 7. 1, calculate the availability loss as well as Second Law efficiency.

Answer:

Availability paid by the hot heat reservoir is $|Q_{res}|\,(1 - T_{amb}/T_{res}) = 240$ J
Availability gain of air is zero since it is at ambient temperature.
Hence total availability loss is 240 J and Second Law efficiency is $\eta_{2nd} = 0$

Example 8. 2 In Example 7. 2, assuming that the cycle was performed on an ideal gas in open system (mass flow rate is 1kg/s), and that heat was added from a reservoir at 300°C and rejected to ambient air at 0°C, find the availability loss as well as Second Law efficiency of each process

Answer:

- **Process 1-2: Reversible isobaric heating**

Availability paid by the hot heat reservoir is $A_{paid} = |Q_{res}|\,(1 - T_{amb}/T_{res})$
$|Q_{res}| = \dot{m}_{air}\,(h_2 - h_1) = 221.1$ W; $T_{amb} = 273$, $T_{res} = 573 \Rightarrow A_{paid} = 115.76$ W
Availability gained by air is $A_{gained} = \dot{m}_{air}\,[(h_2 - h_1) - T_{amb}\,(s_2 - s_1)] = 81.92$ W
Availability loss $A_{loss} = A_{paid} - A_{gained} = 33.84$ W
N.B. You can easily verify that A_{loss} is also $T_{amb}\,\Delta S_{universe} = T_{amb}\,(\Delta S_{res}+\Delta S_{air})$
where $\Delta S_{res} = Q_{res} / T_{res}$
Second Law efficiency is $\eta_{2nd} = A_{gained} / A_{paid} = 70.77$ %

- **Process 2-3: Irreversible expansion**

Availability paid by air is $A_{paid} = \dot{m}_{air}\,[(h_2 - h_3) - T_{amb}\,(s_2 - s_3)] = 303.495$ W
Availability gained is work $A_{gained} = h_2 - h_3 = 276.878$ W
Availability loss $A_{loss} = A_{paid} - A_{gained} = 26.6175$ W
(N.B. you can easily verify that A_{loss} is also $T_{amb}\,\Delta S_{universe} = T_{amb}\,(\Delta S_{air})$
Second Law efficiency is $\eta_{2nd} = A_{gained} / A_{paid} = 91.297$ %

- **Process 3-4: Reversible isothermal cooling**

Availability paid by air is $A_{paid} = \dot{m}_{air}\,[(h_3 - h_4) - T_{amb}\,(s_3 - s_4)] = 4.3246$ W
Availability gained by cold reservoir is $A_{gained} = |Q_{res}|\,(1 - T_{amb}/T_{res}) = 0$ W
Availability loss $A_{loss} = A_{paid} = 4.3246$ W
(N.B. you can easily verify that A_{loss} is also $T_{amb}\,\Delta S_{universe} = T_{amb}\,(\Delta S_{air})$
Second Law efficiency is $\eta_{2nd} = A_{gained} / A_{paid} = 0$ %

- **Process 4-1: Reversible adiabatic compression**

This is a reversible adiabatic process, hence:
Availability loss $A_{loss} = 0$ W
Second Law efficiency is $\eta_{2nd} = 100$ %

- **It appears from cycle availability analysis that the worse process (highest availability loss) requiring to be improved is process 1-2**

Example 8. 3 In example Example 7. 7, assuming ambient conditions are 27°C and 1 bar, find the rate of availability loss as well as Second Law efficiency

Answer:

At ambient conditions: $h_0 = 113.18$ kJ/kg; $s_0 = 0.3946$ kJ/kg K.
Knowing that availability of a flowing fluid due to its enthalpy is $A = \dot{m}\,[h - h_0 - T_0(s - s_0)]$
Availability paid = $A_{s,in} + A_{w,in} = 308$ kW
Availability gained = $A_{s,out} = 302.08$ kW

Rate of availability loss is $\dot{I} = T_{amb}\, dS_{irrev}/dt$ = (273+27) * 0.0229 = 5.93 kW
Second Law efficiency is $\eta_{2nd} = A_{gained} / A_{paid}$ = 98 %

Example 8. 4 A rigid tank of volume 0.2 m^3 initially contains 0.652 kg of H_20 at 2 bar. A heat reservoir at 500°C is used to heat the tank until the pressure inside it reaches 10 bar. Find initial and final temperatures inside the tank, heat and work exchanged by H_2O, entropy change of the universe as well as availability change due to this process (ambient conditions 27°C, 1 bar) and Second Law efficiency. Is it reversible?

Answer

System: 3 systems: 1) Water (all phases) in the tank (closed); 2) The heat reservoir; 3) Universe (sum of all systems)
Conservation: Only energy
Energies: Heat, internal energy. No Work.
Process: Isochoric
Properties: The tank: Initial: m, V ($\Rightarrow$ get v_1), $P_1 \Rightarrow$ complete; Final: P_2, $v_2 = v_1 \Rightarrow$ complete; The Reservoir: T_{res} given
Model: Steam tables
Extensive: yes, 2 values: $m\ V$ in tank $\Rightarrow v$

Ambient conditions:

At ambient conditions: u_0 = 113.176 kJ/kg; s_0 = 0.3946 kJ/kg K, v_0=0.001004 m^3/kg

System 1: Tank

- **Initial state:**
  specific volume $v_1 = V / m$ = 0.2/0.652= 0.306748 m^3/kg, pressure P_1=2 bar.
  From saturation steam tables at 2 bar: v_{f1} = 0.0010605, v_{g1} = 0.8857
  For wet steam; x_1 = (0.306748 - 0.0010605) / (0.8857 - 0.0010605) = 0.346
  u_{f1} = 504.49; u_{g1} = 2529.5; $\Rightarrow u_1 = u_{f1} + x_1 (u_{g1} - u_{f1})$ = 1204.2 kJ / kg
  s_{f1} = 1.5301; s_{g1} = 7.1271; $\Rightarrow s_1 = s_{f1} + x_1 (s_{g1} - s_{f1})$ = 3.4641 kJ / kg K
  availability $\phi_1 = (u_1-u_0)-T_0(s_1-s_0)+P_0(v_1-v_0)$ = 200.75 kJ/kg
- **Final state:**
  Given: $v_2 = v_1$= 0.306748; P_2 = 10 bar
  From saturation steam tables at 10 bar: v_{g2} = 0.1944 < v_2 $\Rightarrow$ superheated
  From superheat tables at P_2, v_2: T_2 = 400°C
  u_2 from steam tables at 10 bar, 400°C: 2957.3 kJ/kg
  s_2 from steam tables at 10 bar, 400°C: 7.4651 kJ/kg K
  availability $\phi_2 = (u_2-u_0)-T_0(s_2-s_0)+P_0(v_2-v_0)$ = 754.78 kJ/kg
  $\Rightarrow Q_{tank} = m (u_2 - u_1)$ = 1143 kJ

System 2: Heat Reservoir

For reservoir $\Delta S_{res} = Q_{res} / T_{res}$ = -1143 / (500+273) = - 1.4787 kJ/K

System 3: Universe

ΔS for Universe = $m(s_2 - s_1)$ – 1.4787 = 1.1272 > 0 $\Rightarrow$ irreversible
Availability paid by the hot heat reservoir is $A_{paid} = |Q_{res}| (1 - T_{amb}/T_{res})$ = 699.4 kJ
Availability gained by steam is $A_{gained} = m (\phi_2 - \phi_1)$ = 361.227 kJ
Availability loss $A_{loss} = A_{paid} - A_{gained}$ = 338.17 kJ
N.B. You can easily verify that A_{loss} is also $T_{amb}\, \Delta S_{universe}$
Second Law efficiency is $\eta_{2nd} = A_{gained} / A_{paid}$ = 51.65 %