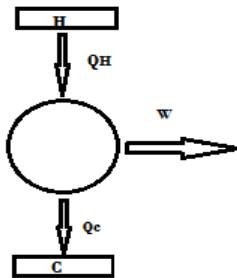


Example 4.1

An inventor claims to have devised a cyclic engine which exchanges heat with reservoirs at 27°C and 327°C, and which produces 0.6 kJ of work for each kJ of heat extracted from the hot reservoir. Is the claim believable? If instead he claimed that the delivered work would be 0.25 kJ / kJ of extracted heat, would the engine be feasible?



$$Q_H = 1 \text{ kJ}, W = 0.6 \text{ kJ}, T_H = 600 \text{ K}, T_c = 300 \text{ K}$$

Efficiency:

$$\eta_{actual} = \frac{|W|}{|Q_H|} = 0.6$$

$$\eta_{ideal(Carnot)} = 1 - \frac{T_c}{T_H} = 0.5$$

Since $\eta_{actual} > \eta_{ideal}$ the engine is not possible.

However for a delivered work of 0.25 kJ / kJ of extracted heat the $\eta_{actual} < \eta_{ideal}$; hence the engine is feasible.

Example 4.2

A rigid vessel of 0.06 m³ volume contains an ideal gas, $C_V = (5/2)R$, at 500 K and 1 bar. (a) If 15 kJ of heat is transferred to the gas, determine its entropy change. (b) If the vessel is fitted with a stirrer that is rotated by a shaft so that work in the amount of 15 kJ is done on the gas, what is the entropy change of the gas if the process is adiabatic? What is ΔS^{total} ?

$$n = P_1 V_1 / RT_1 = 1.443 \text{ mole}$$

$$\Delta U = Q + W = Q = 15000 \text{ J} = n C_V (T_2 - T_1) \quad [W=0]$$

$$\text{Hence } T_2 = 1000 \text{ K}$$

$$\Delta S^t = n [C_P \ln T_2 / T_1 - R \ln P_2 / P_1]; \text{ but } \frac{P_2}{P_1} = \frac{T_2}{T_1}$$

Hence $\Delta S^t = 20.8 J / K$

For second case, the since change of state of the gas is same as in part 'a'

$$\Delta S_{system} = 20.8 J / K ;$$

$$\Delta S_{surr} = 0 \text{ (as there is no heat effect on the surrounding)}$$

$$\Delta S_{universe}^t = \Delta S_{system}^t + \Delta S_{surr}^t = 20.8 J / K , \text{ (Hence stirring process is irreversible)}$$

Example 4.3

An ideal gas, $C_p = (7/2)R$, is heated in a steady-flow heat exchanger from 70°C to 190°C by another stream of the same ideal gas which enters at 320°C . The flow rates of the two streams are the same, and heat losses from the exchanger are negligible. Calculate the molar entropy changes of the two gas streams for both parallel and countercurrent flow in the exchanger. What is ΔS^{total} in each case?

Temperature drop of stream 'B' in either case of flow is the same as the temperature rise of first stream 'A' = 120°C . Thus, exit temperture of stream 'B' = 200°C

Thus in both cases:

$$\Delta S_A = C_p \ln \left(\frac{463}{343} \right) = 8.726 J / molK$$

$$\Delta S_B = C_p \ln \left(\frac{473}{593} \right) = -6.58 J / molK$$

$$\therefore \Delta S^{\text{total}} \text{ (in both types of flow)} = \Delta S_A + \Delta S_B = 2.15 J / molK$$

Example 4.4

Ten kmol per hour of air is throttled from upstream conditions of 25°C and 10 bar to a downstream pressure of 1.2 bar. Assume air to be an ideal gas with $C_p = (7/2)R$. (a) What is the downstream temperature? (b) What is the entropy change of the air in J/molK? (c) What is the rate of entropy generation in W/K?

$$\dot{m} = 10 \text{ kmol / hr.}$$

Since $Q, W_s = 0$, the process is isenthalpic

$$\Delta H_{12} = C_p(T_2 - T_1) = 0; \Rightarrow T_2 = T_1 = 298 K$$

$$\Delta S = C_p \ln(T_2 / T_1) - R \ln(P_2 / P_1) = 17.63 J / molK$$

Rate of entropy generation:

$$\dot{S}_G = \dot{m} \Delta S = 48.97 \text{ W/K}$$

Example 4.5

A steady-flow adiabatic turbine (expander) accepts gas at conditions $T_1 = 500 \text{ K}$, $P_1 = 6 \text{ bar}$, and discharges at conditions $T_2 = 371 \text{ K}$, $P_2 = 1.2 \text{ bar}$. Assuming ideal gases, determine (per mole of gas) W_{actual} , W_{ideal} , W_{lost} , and entropy generation rate. $T_{\text{surr}} = 300 \text{ K}$, $C_p/R = 7/2$.

$$\Delta H = nC_p(T_2 - T_1); W_s = \Delta H \Rightarrow W_s = -3753.85 \text{ J}$$

$$\Delta S = n \left[C_p \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1} \right] = 4.698 \text{ J / K}$$

$$W_{\text{ideal}} = \Delta H - T_{\text{surr}} \Delta S = -5163 \text{ J}$$

$$W_{\text{lost}} = |W_{\text{ideal}} - W_{s,\text{actual}}| = 1409.3 \text{ J}$$

$$S_G = W_{\text{lost}} / T_{\text{surr}} = 4.698 \text{ J / K}$$

Example 4.6

A steam turbine operates adiabatically at a power level of 3500 kW. Steam enters the turbine at 2400 kPa and 500°C and exhausts from the turbine at 20 kPa. What is the steam rate through the turbine, and what is the turbine efficiency?

$$\dot{W}_s = -3500 \text{ kW}, H_2 = 2609.9 \text{ kJ/kg}, S_1 = 7.3439 \text{ kJ/kg}^0\text{K}, H_1 = 3462.9 \text{ kJ/kg}$$

$$\dot{m} = \dot{W}_s / \Delta H = 4.1 \text{ kg/s};$$

Since the process is adiabatic for a reversible process: $S_1 = S_2$

$$\text{Thus } S_2 = 7.3439 \text{ kJ/kg}^0\text{K}$$

At 20kPa checking the steam table we find that at the exit the steam is 'wet', since the following condition holds at 20kPa:

$$S_{\text{liq}} (= 0.8321 \text{ kJ / kg}^0\text{K}) < S_2 < S_{\text{vap}} (= 7.9094 \text{ kJ / kg}^0\text{K})$$

$$\text{Thus: } S_2 = S_{\text{liq}} + x(S_{\text{vap}} - S_{\text{liq}})$$

On substituting the values of all the parameters we get:

$$x = 0.92.$$

Thus for reversible and adiabatic process:

$$H_2^{\text{id}} = H_{\text{liq}} + x(H_{\text{vap}} - H_{\text{liq}}) \approx 2.421 \times 10^3 \frac{\text{kJ}}{\text{kg}}$$

$$\eta = (H_2 - H_1) / (H_2^{\text{id}} - H_1) \approx 0.82$$

