Thermodynamics - I

Lecture 23

Entropy Change of Real gases for Adiabatic Process (Ch-7)

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Example Problem: Entropy change during constant volume process for steam/real gases

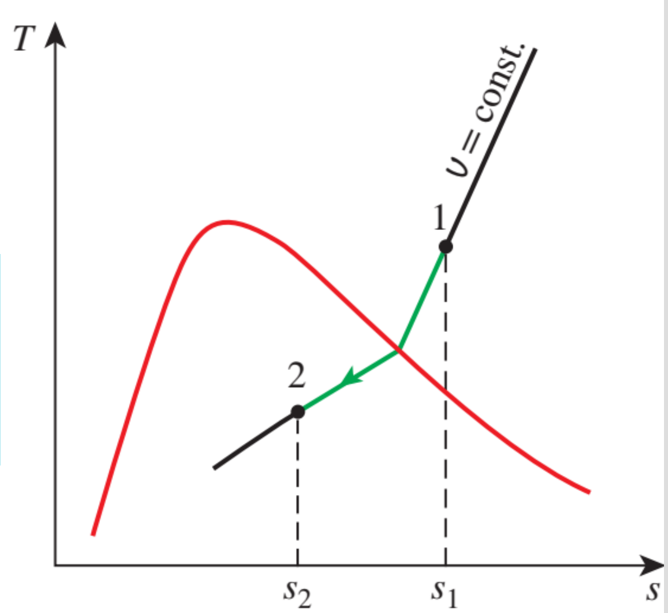
A rigid tank contains 5 kg of refrigerant-134a initially at 20°C and 140 kPa. The refrigerant is now cooled while being stirred until its pressure drops to 100 kPa. Determine the entropy change of the refrigerant during this process.

State 1:

$$\left.\begin{aligned} P_1 &= 140 \text{ kPa} \\ T_1 &= 20°\text{C} \end{aligned}\right\} \begin{aligned} s_1 &= 1.0625 \text{ kJ/kg·K} \\ \upsilon_1 &= 0.16544 \text{ m}^3\text{/kg} \end{aligned}$$

State 2:

$$\left.\begin{aligned} P_2 &= 100 \text{ kPa} \\ \upsilon_2 &= \upsilon_1 \end{aligned}\right\} \begin{aligned} \upsilon_f &= 0.0007258 \text{ m}^3\text{/kg} \\ \upsilon_g &= 0.19255 \text{ m}^3\text{/kg} \end{aligned}$$



$$x_2 = \frac{\upsilon_2 - \upsilon_f}{\upsilon_{fg}} = \frac{0.16544 - 0.0007258}{0.19255 - 0.0007258} = 0.859$$

$$s_2 = s_f + x_2 s_{fg} = 0.07182 + (0.859)(0.88008) = 0.8278 \text{ kJ/kg·K}$$

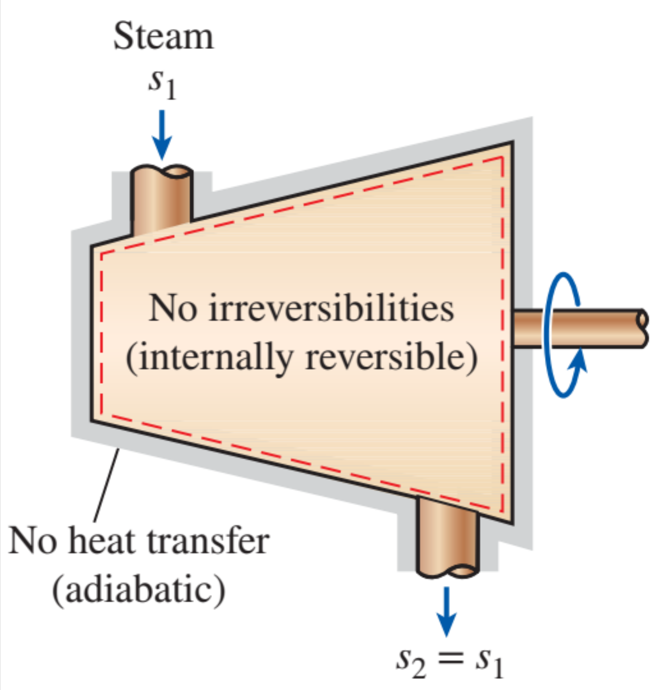
$$\Delta S = m(s_2 - s_1) = (5 \text{ kg})(0.8278 - 1.0625) \text{ kJ/kg·K}$$

$$= \mathbf{-1.173 \text{ kJ/K}}$$

Entropy Change of an Adiabatic Process (Real Gases)

The entropy of a fixed mass can be changed by **(1)** heat transfer and **(2)** irreversibilities.

The entropy of a fixed mass does not change during a process that is *internally reversible* and *adiabatic*



Isentropic process:

$$\Delta s = 0 \quad \text{or} \quad s_2 = s_1 \qquad (\text{kJ/kg·K})$$

Many Engineering devices are adiabatic in operation:

Pumps, Turbines, Nozzles, and Diffusers

Heat Transfer and Work

$$\underbrace{S_2 - S_1}_{\text{entropy change}} = \underbrace{\int_1^2 \left(\frac{\delta Q}{T}\right)_b}_{\text{entropy transfer}} + \underbrace{\sigma}_{\text{entropy production}}$$

$$\left(\frac{\dot{Q}_{cv}}{\dot{m}}\right)_{\substack{\text{int}\\\text{rev}}} = \int_1^2 T\,ds$$

$$\frac{\dot{W}_{cv}}{\dot{m}} = \frac{\dot{Q}_{cv}}{\dot{m}} + (h_1 - h_2) + \left(\frac{V_1^2 - V_2^2}{2}\right) + g(z_1 - z_2)$$

$$\left(\frac{\dot{W}_{cv}}{\dot{m}}\right)_{\substack{\text{int}\\\text{rev}}} = \int_1^2 T\,ds + (h_1 - h_2) + \left(\frac{V_1^2 - V_2^2}{2}\right) + g(z_1 - z_2)$$

$$T\,ds = dh - v\,dp \Longrightarrow \int_1^2 T\,ds = (h_2 - h_1) - \int_1^2 v\,dp$$

$$\left(\frac{\dot{W}_{cv}}{\dot{m}}\right)_{\substack{\text{int}\\\text{rev}}} = -\int_1^2 v\,dp + \left(\frac{V_1^2 - V_2^2}{2}\right) + g(z_1 - z_2)$$

Pump *(vs)* Compressor

Heat Transfer and Work – Polytropic Process – $PV^n = constant$

$$\left(\frac{\dot{W}_{cv}}{\dot{m}}\right)_{\substack{\text{int}\\\text{rev}}} = -\int_1^2 v\,dp = -(constant)^{1/n}\int_1^2 \frac{dp}{p^{1/n}}$$

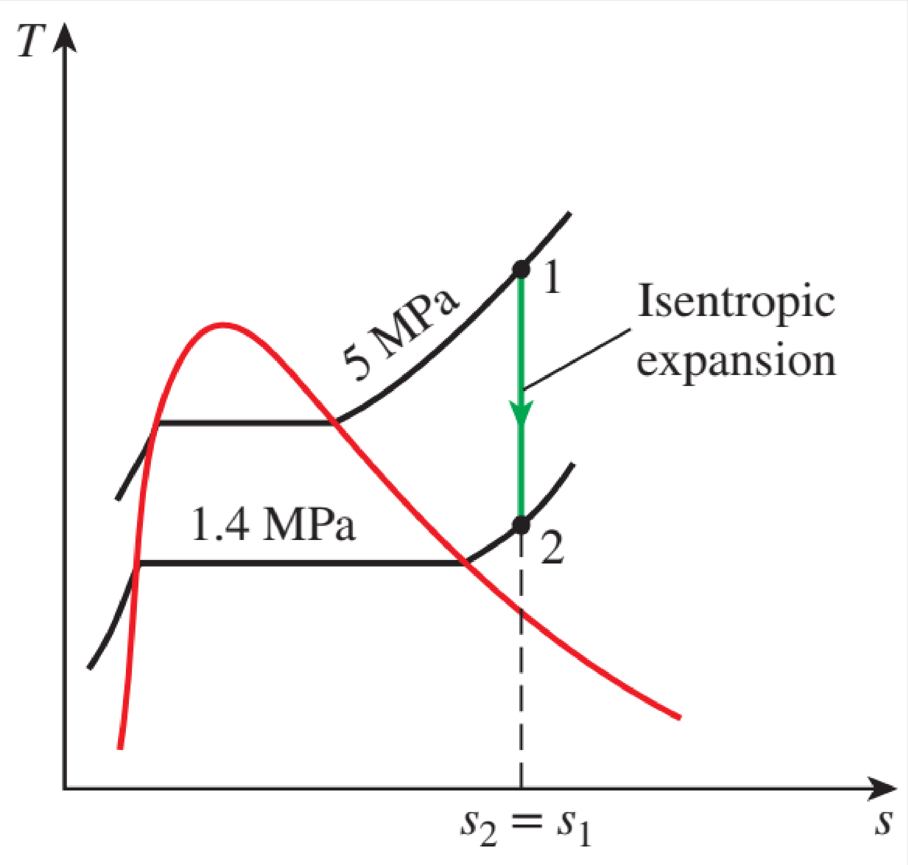
$$= -\frac{n}{n-1}(p_2 v_2 - p_1 v_1) \qquad (\text{polytropic}, n \neq 1)$$

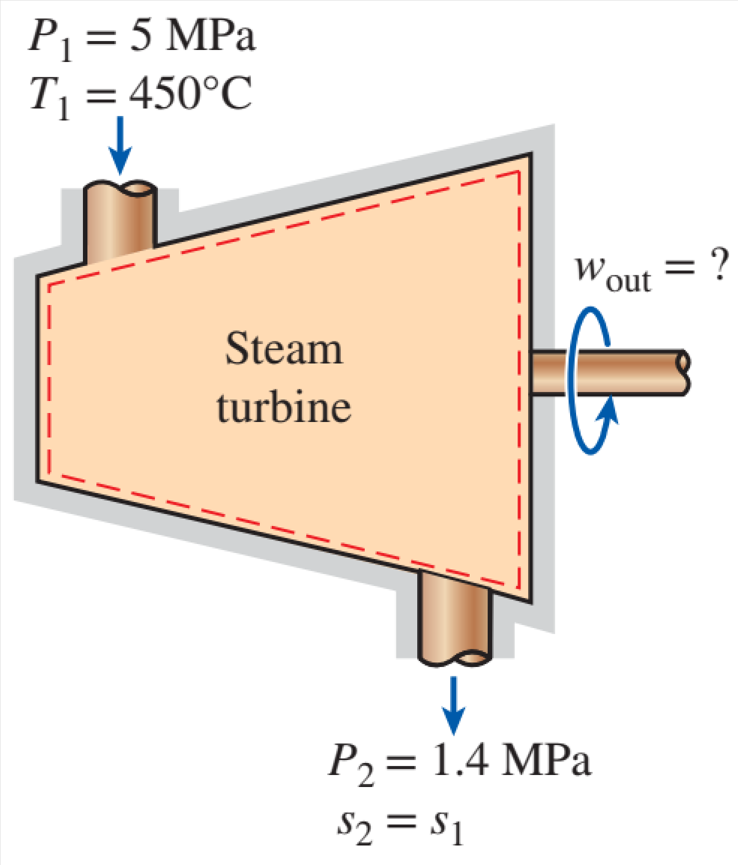
$$\left(\frac{\dot{W}_{cv}}{\dot{m}}\right)_{\substack{\text{int}\\\text{rev}}} = -\int_1^2 v\,dp = -constant\int_1^2 \frac{dp}{p}$$

$$= -(p_1 v_1)\ln(p_2/p_1) \qquad (\text{polytropic}, n = 1)$$

Isentropic Expansion of Steam in a Turbine

Steam enters an adiabatic turbine at 5 MPa and 450°C and leaves at a pressure of 1.4 MPa. Determine the work output of the turbine per unit mass of steam if the process is reversible.





$$\dot{E}_{in} = \dot{E}_{out}$$

$$\dot{m}h_1 = \dot{W}_{out} + \dot{m}h_2 \quad (\text{since } \dot{Q} = 0, \text{ke} \cong \text{pe} \cong 0)$$

$$\dot{W}_{out} = \dot{m}(h_1 - h_2)$$

State 1: $\left.\begin{array}{l} P_1 = 5 \text{ MPa} \\ T_1 = 450°\text{C} \end{array}\right\}$ $\begin{array}{l} h_1 = 3317.2 \text{ kJ/kg} \\ s_1 = 6.8210 \text{ kJ/kg·K} \end{array}$

State 2: $\left.\begin{array}{l} P_2 = 1.4 \text{ MPa} \\ s_2 = s_1 \end{array}\right\}$ $h_2 = 2967.4 \text{ kJ/kg}$

$$w_{out} = h_1 - h_2 = 3317.2 - 2967.4 = \mathbf{349.8 \text{ kJ/kg}}$$