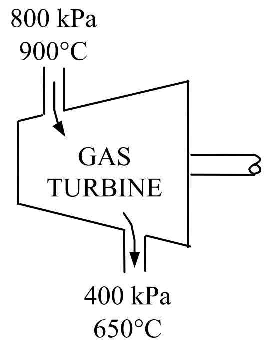
8-64 Combustion gases expand in a turbine from a specified state to another specified state. The exergy of the gases at the inlet and the reversible work output of the turbine are to be determined.

Assumptions **1** This is a steady-flow process since there is no change with time. **2** Potential energy changes are negligible. **3** The temperature of the surroundings is given to be 25°C. **4** The combustion gases are ideal gases with constant specific heats.

Properties The constant pressure specific heat and the specific heat ratio are given to be c_p = 1.15 kJ/kg.K and k = 1.3. The gas constant R is determined from

$$R = c_p - c_v = c_p - c_p / k = c_p(1 - 1/k) = (1.15\,\text{kJ/kg}\cdot\text{K})(1 - 1/1.3) = 0.265\,\text{kJ/kg}\cdot\text{K}$$

Analysis (a) The exergy of the gases at the turbine inlet is simply the flow exergy,



$$\psi_1 = h_1 - h_0 - T_0(s_1 - s_0) + \frac{V_1^2}{2} + gz_1^{\nearrow 0}$$

where

$$\begin{aligned} s_1 - s_0 &= c_p \ln\frac{T_1}{T_0} - R\ln\frac{P_1}{P_0} \\ &= (1.15\,\text{kJ/kg}\cdot\text{K})\ln\frac{1173\,\text{K}}{298\,\text{K}} - (0.265\,\text{kJ/kg}\cdot\text{K})\ln\frac{800\,\text{kPa}}{100\,\text{kPa}} \\ &= 1.025\,\text{kJ/kg}\cdot\text{K} \end{aligned}$$

Thus,

$$\psi_1 = (1.15\,\text{kJ/kg.K})(900-25)°\text{C} - (298\,\text{K})(1.025\,\text{kJ/kg}\cdot\text{K}) + \frac{(100\,\text{m/s})^2}{2}\left(\frac{1\,\text{kJ/kg}}{1000\,\text{m}^2/\text{s}^2}\right) = \mathbf{705.8\,kJ/kg}$$

(b) The reversible (or maximum) work output is determined from an exergy balance applied on the turbine and setting the exergy destruction term equal to zero,

$$\underbrace{\dot{X}_{\text{in}} - \dot{X}_{\text{out}}}_{\substack{\text{Rate of net exergy transfer}\\ \text{by heat, work, and mass}}} - \underbrace{\dot{X}_{\text{destroyed}}^{\nearrow 0\ \text{(reversible)}}}_{\substack{\text{Rate of exergy}\\ \text{destruction}}} = \underbrace{\Delta\dot{X}_{\text{system}}^{\nearrow 0\ \text{(steady)}}}_{\substack{\text{Rate of change}\\ \text{of exergy}}} = 0$$

$$\dot{X}_{\text{in}} = \dot{X}_{\text{out}}$$

$$\dot{m}\psi_1 = \dot{W}_{\text{rev,out}} + \dot{m}\psi_2$$

$$\dot{W}_{\text{rev,out}} = \dot{m}(\psi_1 - \psi_2) = \dot{m}[(h_1 - h_2) - T_0(s_1 - s_2) - \Delta\text{ke} - \Delta\text{pe}^{\nearrow 0}]$$

where

$$\Delta\text{ke} = \frac{V_2^2 - V_1^2}{2} = \frac{(220\,\text{m/s})^2 - (100\,\text{m/s})^2}{2}\left(\frac{1\,\text{kJ/kg}}{1000\,\text{m}^2/\text{s}^2}\right) = 19.2\,\text{kJ/kg}$$

and

$$\begin{aligned} s_2 - s_1 &= c_p \ln\frac{T_2}{T_1} - R\ln\frac{P_2}{P_1} \\ &= (1.15\,\text{kJ/kg}\cdot\text{K})\ln\frac{923\,\text{K}}{1173\,\text{K}} - (0.265\,\text{kJ/kg}\cdot\text{K})\ln\frac{400\,\text{kPa}}{800\,\text{kPa}} \\ &= -0.09196\,\text{kJ/kg}\cdot\text{K} \end{aligned}$$

Then the reversible work output on a unit mass basis becomes

$$\begin{aligned} w_{\text{rev,out}} &= h_1 - h_2 + T_0(s_2 - s_1) - \Delta\text{ke} = c_p(T_1 - T_2) + T_0(s_2 - s_1) - \Delta\text{ke} \\ &= (1.15\,\text{kJ/kg}\cdot\text{K})(900-650)°\text{C} + (298\,\text{K})(-0.09196\,\text{kJ/kg}\cdot\text{K}) - 19.2\,\text{kJ/kg} \\ &= \mathbf{240.9\,kJ/kg} \end{aligned}$$