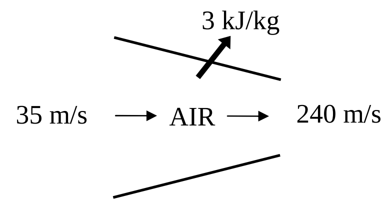
8-57 Air is accelerated in a nozzle while losing some heat to the surroundings. The exit temperature of air and the exergy destroyed during the process are to be determined.

Assumptions **1** Air is an ideal gas with variable specific heats. **2** The nozzle operates steadily.

Properties The gas constant of air is R = 0.287 kJ/kg.K (Table A-1). The properties of air at the nozzle inlet are (Table A-17)

$$T_1 = 338\text{ K} \longrightarrow h_1 = 338.40\text{ kJ/kg}$$
$$s_1^o = 1.8219\text{ kJ/kg}\cdot\text{K}$$

Analysis (a) We take the nozzle as the system, which is a control volume. The energy balance for this steady-flow system can be expressed in the rate form as



$$\underbrace{\dot{E}_{\text{in}} - \dot{E}_{\text{out}}}_{\substack{\text{Rate of net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{\Delta \dot{E}_{\text{system}}^{\nearrow 0\ \text{(steady)}}}_{\substack{\text{Rate of change in internal, kinetic,}\\ \text{potential, etc. energies}}} = 0$$

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

$$\dot{m}(h_1 + V_1^2/2) = \dot{m}(h_2 + V_2^2/2) + \dot{Q}_{\text{out}}$$

or

$$0 = q_{\text{out}} + h_2 - h_1 + \frac{V_2^2 - V_1^2}{2}$$

Therefore,

$$h_2 = h_1 - q_{\text{out}} - \frac{V_2^2 - V_1^2}{2} = 338.40 - 3 - \frac{(240\text{ m/s})^2 - (35\text{ m/s})^2}{2}\left(\frac{1\text{ kJ/kg}}{1000\ \text{m}^2/\text{s}^2}\right) = 307.21\text{ kJ/kg}$$

At this h_2 value we read, from Table A-17, $T_2 = 307.0$ K **= 34.0°C** and $s_2^o = 1.7251\text{ kJ/kg}\cdot\text{K}$

(b) The exergy destroyed during a process can be determined from an exergy balance or directly from its definition $X_{\text{destroyed}} = T_0 S_{gen}$ where the entropy generation S_{gen} is determined from an entropy balance on an *extended system* that includes the device and its immediate surroundings so that the boundary temperature of the extended system is T_{surr} at all times. It gives

$$\underbrace{\dot{S}_{\text{in}} - \dot{S}_{\text{out}}}_{\substack{\text{Rate of net entropy transfer}\\ \text{by heat and mass}}} + \underbrace{\dot{S}_{\text{gen}}}_{\substack{\text{Rate of entropy}\\ \text{generation}}} = \underbrace{\Delta \dot{S}_{\text{system}}^{\ 0}}_{\substack{\text{Rate of change}\\ \text{of entropy}}} = 0$$

$$\dot{m}s_1 - \dot{m}s_2 - \frac{\dot{Q}_{\text{out}}}{T_{\text{b,surr}}} + \dot{S}_{\text{gen}} = 0$$

$$\dot{S}_{\text{gen}} = \dot{m}(s_2 - s_1) + \frac{\dot{Q}_{\text{out}}}{T_{\text{surr}}}$$

where

$$\Delta s_{\text{air}} = s_2^o - s_1^o - R\ln\frac{P_2}{P_1} = (1.7251 - 1.8219)\text{kJ/kg}\cdot\text{K} - (0.287\text{ kJ/kg}\cdot\text{K})\ln\frac{95\text{ kPa}}{200\text{ kPa}} = 0.1169\text{ kJ/kg}\cdot\text{K}$$

Substituting, the entropy generation and exergy destruction per unit mass of air are determined to be

$$x_{\text{destroyed}} = T_0 s_{gen} = T_{surr} s_{gen}$$
$$= T_0\left(s_2 - s_1 + \frac{q_{surr}}{T_{surr}}\right) = (290\text{ K})\left(0.1169\text{ kJ/kg}\cdot\text{K} + \frac{3\text{ kJ/kg}}{290\text{ K}}\right) = \mathbf{36.9\ kJ/kg}$$

Alternative solution The exergy destroyed during a process can be determined from an exergy balance applied on the *extended system* that includes the device and its immediate surroundings so that the boundary temperature of the extended system is environment temperature T_0 (or T_{surr}) at all times. Noting that exergy transfer with heat is zero when the temperature at the point of transfer is the environment temperature, the exergy balance for this steady-flow system can be expressed as

$$\underbrace{\dot{X}_{in} - \dot{X}_{out}}_{\substack{\text{Rate of net exergy transfer}\\ \text{by heat, work, and mass}}} - \underbrace{\dot{X}_{destroyed}}_{\substack{\text{Rate of exergy}\\ \text{destruction}}} = \underbrace{\Delta \dot{X}_{system}^{\nearrow 0\ \text{(steady)}}}_{\substack{\text{Rate of change}\\ \text{of exergy}}} = 0 \rightarrow \dot{X}_{destroyed} = \dot{X}_{in} - \dot{X}_{out} = \dot{m}\psi_1 - \dot{m}\psi_2 = \dot{m}(\psi_1 - \psi_2)$$

$$= \dot{m}[(h_1 - h_2) - T_0(s_1 - s_2) - \Delta ke - \Delta pe^{\nearrow 0}] = \dot{m}[T_0(s_2 - s_1) - (h_2 - h_1 + \Delta ke)]$$

$$= \dot{m}[T_0(s_2 - s_1) + q_{out}] \quad \text{since, from energy balance,} \ -q_{out} = h_2 - h_1 + \Delta ke$$

$$= T_0\left(\dot{m}(s_2 - s_1) + \frac{\dot{Q}_{out}}{T_0}\right) = T_0 \dot{S}_{gen}$$

Therefore, the two approaches for the determination of exergy destruction are identical.