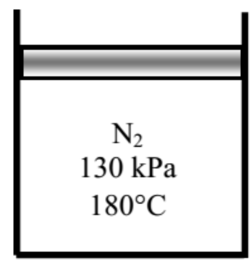
Homework-5 Solutions

Q 4-23

A piston-cylinder device contains nitrogen gas at a specified state. The boundary work is to be determined for the isothermal expansion of nitrogen.

Properties The properties of nitrogen are R = 0.2968 kJ/kg.K, k = 1.4 (Table A-2a).

Analysis We first determine initial and final volumes from ideal gas relation, and find the boundary work using the relation for isothermal expansion of an ideal gas



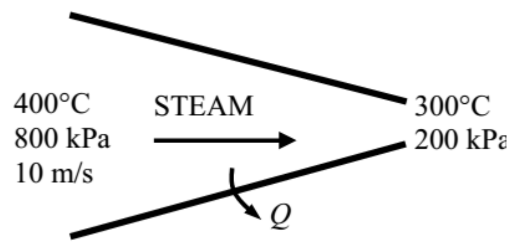
$$\boldsymbol{V}_1 = \frac{mRT}{P_1} = \frac{(0.25\,\text{kg})(0.2968\,\text{kJ/kg.K})(180 + 273\,\text{K})}{(130\,\text{kPa})} = 0.2586\,\text{m}^3$$

$$\boldsymbol{V}_2 = \frac{mRT}{P_2} = \frac{(0.25\,\text{kg})(0.2968\,\text{kJ/kg.K})(180 + 273\,\text{K})}{80\,\text{kPa}} = 0.4202\,\text{m}^3$$

$$W_b = P_1\boldsymbol{V}_1 \ln\left(\frac{\boldsymbol{V}_2}{\boldsymbol{V}_1}\right) = (130\,\text{kPa})(0.2586\,\text{m}^3)\ln\left(\frac{0.4202\,\text{m}^3}{0.2586\,\text{m}^3}\right) = \mathbf{16.3\,kJ}$$

Q 5-34

Heat is lost from the steam flowing in a nozzle. The velocity and the volume flow rate at the nozzle exit are to be determined.



Assumptions **1** This is a steady-flow process since there is no change with time. **2** Potential energy change is negligible. **3** There are no work interactions.

Analysis We take the steam as the system, which is a control volume since mass crosses the boundary. The energy balance for this steady-flow system can be expressed in the rate form as

Energy balance:

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

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

$$\dot{m}\left(h_1 + \frac{V_1^2}{2}\right) = \dot{m}\left(h_2 + \frac{V_2^2}{2}\right) + \dot{Q}_{out} \quad \text{since } \dot{W} \cong \Delta\text{pe} \cong 0)$$

or

$$h_1 + \frac{V_1^2}{2} = h_2 + \frac{V_2^2}{2} + \frac{\dot{Q}_{out}}{\dot{m}}$$

The properties of steam at the inlet and exit are (Table A-6)

$$\left.\begin{array}{l} P_1 = 800 \text{ kPa} \\ T_1 = 400°\text{C} \end{array}\right\} \begin{array}{l} \boldsymbol{v}_1 = 0.38429 \text{ m}^3/\text{kg} \\ h_1 = 3267.7 \text{ kJ/kg} \end{array}$$

$$\left.\begin{array}{l} P_2 = 200 \text{ kPa} \\ T_1 = 300°\text{C} \end{array}\right\} \begin{array}{l} \boldsymbol{v}_2 = 1.31623 \text{ m}^3/\text{kg} \\ h_2 = 3072.1 \text{ kJ/kg} \end{array}$$

The mass flow rate of the steam is

$$\dot{m} = \frac{1}{\boldsymbol{v}_1} A_1 V_1 = \frac{1}{0.38429 \text{ m}^3/\text{s}} (0.08 \text{ m}^2)(10 \text{ m/s}) = 2.082 \text{ kg/s}$$

Substituting,

$$3267.7 \text{ kJ/kg} + \frac{(10 \text{ m/s})^2}{2}\left(\frac{1 \text{ kJ/kg}}{1000 \text{ m}^2/\text{s}^2}\right) = 3072.1 \text{ kJ/kg} + \frac{V_2^2}{2}\left(\frac{1 \text{ kJ/kg}}{1000 \text{ m}^2/\text{s}^2}\right) + \frac{25 \text{ kJ/s}}{2.082 \text{ kg/s}}$$

$$\longrightarrow V_2 = \mathbf{606 \text{ m/s}}$$

The volume flow rate at the exit of the nozzle is

$$\dot{\boldsymbol{V}}_2 = \dot{m}\boldsymbol{v}_2 = (2.082 \text{ kg/s})(1.31623 \text{ m}^3/\text{kg}) = \mathbf{2.74 \text{ m}^3/\text{s}}$$

Q 5-54

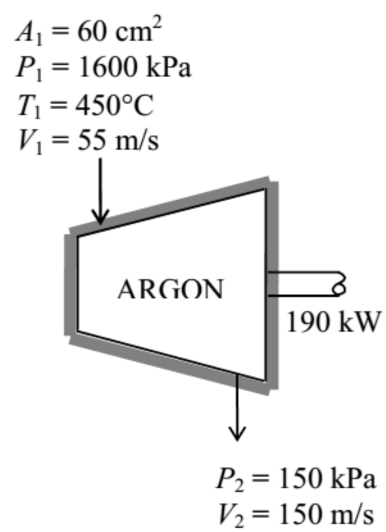
Argon gas expands in a turbine. The exit temperature of the argon for a power output of 190 kW is to be determined.

Assumptions **1** This is a steady-flow process since there is no change with time. **2** Potential energy changes are negligible. **3** The device is adiabatic and thus heat transfer is negligible. **4** Argon is an ideal gas with constant specific heats.

Properties The gas constant of Ar is R = 0.2081 kPa.m3/kg.K. The constant pressure specific heat of Ar is cp = 0.5203 kJ/kg·°C (Table A-2a)

Analysis There is only one inlet and one exit, and thus m &1 2 = m & = m & . The inlet specific volume of argon and its mass flow rate are

$$\boldsymbol{v}_1 = \frac{RT_1}{P_1} = \frac{(0.2081\text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(723\text{ K})}{1600\text{ kPa}} = 0.09404\text{ m}^3/\text{kg}$$



Thus,

$$\dot{m} = \frac{1}{\boldsymbol{v}_1} A_1 V_1 = \frac{1}{0.09404\text{ m}^3/\text{kg}}(0.006\text{ m}^2)(55\text{ m/s}) = 3.509\text{ kg/s}$$

We take the turbine as the system, which is a control volume since mass crosses the boundary. The energy balance for this steady-flow system can be expressed in the rate form as

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

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

$$\dot{m}(h_1 + V_1^2/2) = \dot{W}_{\text{out}} + \dot{m}(h_2 + V_2^2/2) \quad (\text{since } \dot{Q} \cong \Delta\text{pe} \cong 0)$$

$$\dot{W}_{\text{out}} = -\dot{m}\left(h_2 - h_1 + \frac{V_2^2 - V_1^2}{2}\right)$$

Substituting,

$$190\text{ kJ/s} = -(3.509\text{ kg/s})\left[(0.5203\text{ kJ/kg}\cdot{}^\circ\text{C})(T_2 - 450^\circ\text{C}) + \frac{(150\text{ m/s})^2 - (55\text{ m/s})^2}{2}\left(\frac{1\text{ kJ/kg}}{1000\text{ m}^2/\text{s}^2}\right)\right]$$

It yields

T_2 = **327°C**

Q 5-57

Air is expanded in an adiabatic turbine. The mass flow rate of the air and the power produced are to be determined.

Assumptions **1** This is a steady-flow process since there is no change with time. **2** The turbine is well-insulated, and thus there is no heat transfer. **3** Air is an ideal gas with constant specific heats.

Properties The constant pressure specific heat of air at the average temperature of (500+127)/2=314°C=587 K is cp = 1.048 kJ/kg·K (Table A-2b). The gas constant of air is R = 0.287 kPa·m3/kg·K (Table A-1).

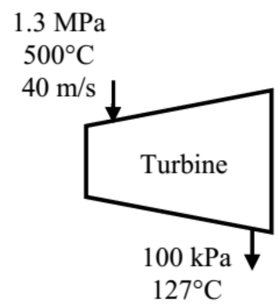
Analysis (a) There is only one inlet and one exit, and thus $\dot{m}_1 = \dot{m}_2 = \dot{m}$. We take the turbine as the system, which is a control volume since mass crosses the boundary. The energy balance for this steady-flow system can be expressed in the rate form as

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

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

$$\dot{m}\left(h_1 + \frac{V_1^2}{2}\right) = \dot{m}\left(h_2 + \frac{V_2^2}{2}\right) + \dot{W}_{out}$$

$$\dot{W}_{out} = \dot{m}\left(h_1 - h_2 + \frac{V_1^2 - V_2^2}{2}\right) = \dot{m}\left(c_p(T_1 - T_2) + \frac{V_1^2 - V_2^2}{2}\right)$$



The specific volume of air at the inlet and the mass flow rate are

$$\boldsymbol{v}_1 = \frac{RT_1}{P_1} = \frac{(0.287\ \text{kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(500+273\ \text{K})}{1300\ \text{kPa}} = 0.1707\ \text{m}^3/\text{kg}$$

$$\dot{m} = \frac{A_1 V_1}{\boldsymbol{v}_1} = \frac{(0.2\ \text{m}^2)(40\ \text{m/s})}{0.1707\ \text{m}^3/\text{kg}} = \mathbf{46.88\ kg/s}$$

Similarly at the outlet,

$$\boldsymbol{v}_2 = \frac{RT_2}{P_2} = \frac{(0.287\ \text{kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(127+273\ \text{K})}{100\ \text{kPa}} = 1.148\ \text{m}^3/\text{kg}$$

$$V_2 = \frac{\dot{m}\boldsymbol{v}_2}{A_2} = \frac{(46.88\ \text{kg/s})(1.148\ \text{m}^3/\text{kg})}{1\ \text{m}^2} = 53.82\ \text{m/s}$$

(*b*) Substituting into the energy balance equation gives

$$\begin{aligned}\dot{W}_{out} &= \dot{m}\left(c_p(T_1 - T_2) + \frac{V_1^2 - V_2^2}{2}\right) \\ &= (46.88\ \text{kg/s})\left[(1.048\ \text{kJ/kg}\cdot\text{K})(500-127)\text{K} + \frac{(40\ \text{m/s})^2 - (53.82\ \text{m/s})^2}{2}\left(\frac{1\ \text{kJ/kg}}{1000\ \text{m}^2/\text{s}^2}\right)\right] \\ &= \mathbf{18{,}300\ kW}\end{aligned}$$

Q 5-67

Steam is throttled from a specified pressure to a specified state. The quality at the inlet is to be determined.

Assumptions **1** This is a steady-flow process since there is no change with time. **2** Kinetic and potential energy changes are negligible. **3** Heat transfer to or from the fluid is negligible. **4** There are no work interactions involved.

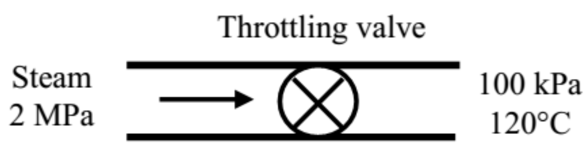
Analysis There is only one inlet and one exit, and thus $\dot{m}_1 = \dot{m}_2 = \dot{m}$ .e take the throttling valve as the system, which is a control volume since mass crosses the boundary. The energy balance for this steady-flow system can be expressed in the rate form as

$$\dot{E}_{in} - \dot{E}_{out} = \Delta\dot{E}_{system}^{\nearrow 0 \text{ (steady)}} = 0$$

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

$$\dot{m}h_1 = \dot{m}h_2$$

$$h_1 = h_2$$



Since $\dot{Q} \cong \dot{W} = \Delta\text{ke} \cong \Delta\text{pe} \cong 0$.

The enthalpy of steam at the exit is (Table A-6),

$$\left.\begin{array}{l} P_2 = 100\ \text{kPa} \\ T_2 = 120°\text{C} \end{array}\right\} h_2 = 2716.1\ \text{kJ/kg}$$

The quality of the steam at the inlet is (Table A-5)

$$\left.\begin{array}{l} P_1 = 2000\ \text{kPa} \\ h_1 = h_2 = 2716.1\ \text{kJ/kg} \end{array}\right\} x_1 = \frac{h_2 - h_f}{h_{fg}} = \frac{2716.1 - 908.47}{1889.8} = \mathbf{0.957}$$