TERMODİNAMİK ÇALIŞMA SORULARI

SÜREKLİ AKIŞLI AÇIK SİSTEMLER LÜLELER VE YAYICILAR

5-28 Sürekli akışlı adyabatik bir lülede, hava lüleye 300 kPa basınç, 200º C sıcaklık ve 45 m/s hızla girmekte, 100 kPa basınç ve 110 m/s hızla çıkmaktadır.Lülenin giriş kesit alanı 80 cm²'dir. (a) Lüleden akan havanın kütlesel debisini, (b) Havanın lüleden çıkış sıcaklığını, (c) Lülenin çıkış kesit alanını hesaplayınız. *çözüm: (a) 1.09 kg/s (b) 185º* C (c) 79.9 cm²

5-31 800 kPa basınç ve 400º C sıcaklıktaki su buharı, sürekli akışlı, adyabatik bir lüleye 10 m/s hızla girmekte, 200 kPa basınç 300º C sıcaklıkta çıkmakadır, bu sıra 25 kW ısı kaybı meydana gelmektedir.Çıkış hızını ve buharın lüleye çıkışındaki hacimsel debisini hesaplayınız. *çözüm: 606 m/s 2.74 m³/s*

5-33 Hava sürekli akışlı adyabatik bir lüleye 90 kPa basınç, -10º C sıcaklık ve 180 m/s hızla girmekte, 100 kPa basınçta giriş hızından düşük çıkmaktadır. (a) Havanın çıkış sıcaklığını, (b) Havanın çıkış hızını hesaplayınız.

TÜRBİNLER VE KOMPRESÖRLER

5-46 Su buharı sürekli akışlı adyabatik türbine 6 MPa basınç, 400º C sıcaklık ve 80 m/s hızla girmekte, 40 kPa basınç ve yüzde 92 kuruluk derecesinde, 50 m/s hızla çıkmaktadır.Buharın kütle debisi 20 kg/s olduğuna göre, (a) Akışın kinetik enerjisindeki değişimi, (b) Türbinde üretilen gücü, (c) Türbin giriş kesit alanını hesaplayınız. *çözüm: (a) -1.95 kj/kg, (b) 14.6 MW (c) 0.0119 m²*

5-48 Su buharı sürekli akışlı bir adyabatik türbine 10 MPa basınç ve 500º C sıcaklıkta girmekte, 10 kPa basınç ve yüzde 90 kuruluk derecesiyle çıkmaktadır. Kinetik ve potansiyel enerji değişimlerini ihmal ederek, 5 MW güç üretilebilmesi için gerekli kütle debisini hesaplayınız. *çözüm: 4.852 kg/s*

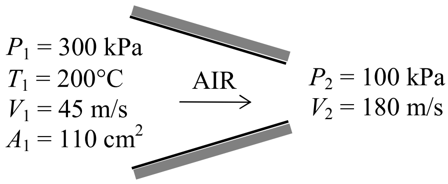
5-50 Adyabatik bir hava kompresörü 10 L/s debi ile hava 120 kPa basınç ve 20º C sıcaklıktan 1000 kPa basınç ve 300º C sıcaklığa sıkıştırmaktadır. (a) Kompresör için gerekli işi (b) Kompresörü çalıştırmak için gerekli gücü hesaplayınız.

5-53 Karbon dioksit sürekli akışlı adyabatik bir kompresöre 100 kPa basınç ve 300 K sıcaklıkta, 0.5 kg/s debiyle girmekte, 600 kPa basınç ve 450 K sıcaklıkta çıkmaktadır.Kinetik enerji değişimlerini ihmal ederek, (a) Kompresör girişinde karbon dioksitin hacimsel debisini, (b) Kompresörü çalıştırmak için gerekli gücü hesaplayınız. *çözüm: (a) 0.28 m³/s (b) 68.8 kW*

5-30 Air is accelerated in a nozzle from 45 m/s to 180 m/s. The mass flow rate, the exit temperature, and the exit area of the nozzle are to be determined.

Assumptions **1** This is a steady-flow process since there is no change with time. **2** Air is an ideal gas with constant specific heats. **3** Potential energy changes are negligible. **4** The device is adiabatic and thus heat transfer is negligible. **5** There are no work interactions.

Properties The gas constant of air is 0.287 kPa.m^3/kg.K (Table A-1). The specific heat of air at the anticipated average temperature of 450 K is c_p = 1.02 kJ/kg.°C (Table A-2).



Analysis (*a*) There is only one inlet and one exit, and thus $\dot{m}_1 = \dot{m}_2 = \dot{m}$. Using the ideal gas relation, the specific volume and the mass flow rate of air are determined to be

$$\boldsymbol{v}_1 = \frac{RT_1}{P_1} = \frac{(0.287\ \text{kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(473\ \text{K})}{300\ \text{kPa}} = 0.4525\ \text{m}^3/\text{kg}$$

$$\dot{m} = \frac{1}{\boldsymbol{v}_1}A_1V_1 = \frac{1}{0.4525\ \text{m}^3/\text{kg}}(0.0110\ \text{m}^2)(45\ \text{m/s}) = \mathbf{1.094\ kg/s}$$

(*b*) We take nozzle 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

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

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

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

$$0 = h_2 - h_1 + \frac{V_2^2 - V_1^2}{2} \longrightarrow 0 = c_{p,ave}(T_2 - T_1) + \frac{V_2^2 - V_1^2}{2}$$

Substituting,

$$0 = (1.02\ \text{kJ/kg}\cdot\text{K})(T_2 - 200^\circ\text{C}) + \frac{(180\ \text{m/s})^2 - (45\ \text{m/s})^2}{2}\left(\frac{1\ \text{kJ/kg}}{1000\ \text{m}^2/\text{s}^2}\right)$$

It yields

T_2 = **185.2°C**

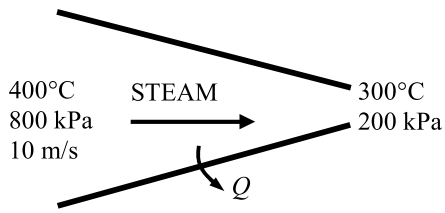
(*c*) The specific volume of air at the nozzle exit is

$$\boldsymbol{v}_2 = \frac{RT_2}{P_2} = \frac{(0.287\ \text{kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(185.2 + 273\ \text{K})}{100\ \text{kPa}} = 1.315\ \text{m}^3/\text{kg}$$

$$\dot{m} = \frac{1}{\boldsymbol{v}_2}A_2V_2 \longrightarrow 1.094\ \text{kg/s} = \frac{1}{1.315\ \text{m}^3/\text{kg}}A_2(180\ \text{m/s}) \rightarrow A_2 = 0.00799\ \text{m}^2 = \mathbf{79.9\ cm^2}$$

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:

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

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

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

or

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

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

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

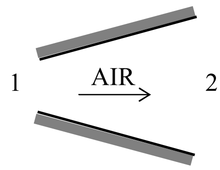
5-36E Air is decelerated in a diffuser from 600 ft/s to a low velocity. The exit temperature and the exit velocity of air are to be determined.

Assumptions **1** This is a steady-flow process since there is no change with time. **2** Air is an ideal gas with variable specific heats. **3** Potential energy changes are negligible. **4** The device is adiabatic and thus heat transfer is negligible. **5** There are no work interactions.

Properties The enthalpy of air at the inlet temperature of 50°F is h_1 = 121.88 Btu/lbm (Table A-17E).

Analysis (*a*) There is only one inlet and one exit, and thus $\dot{m}_1 = \dot{m}_2 = \dot{m}$. We take diffuser 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

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



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

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

$$0 = h_2 - h_1 + \frac{V_2^2 - V_1^2}{2},$$

or,

$$h_2 = h_1 - \frac{V_2^2 - V_1^2}{2} = 121.88 \text{ Btu/lbm} - \frac{0 - (600 \text{ ft/s})^2}{2}\left(\frac{1 \text{ Btu/lbm}}{25{,}037 \text{ ft}^2/\text{s}^2}\right) = 129.07 \text{ Btu/lbm}$$

From Table A-17E,

T_2 = **540 R**

(*b*) The exit velocity of air is determined from the conservation of mass relation,

$$\frac{1}{v_2} A_2 V_2 = \frac{1}{v_1} A_1 V_1 \longrightarrow \frac{1}{RT_2/P_2} A_2 V_2 = \frac{1}{RT_1/P_1} A_1 V_1$$

Thus,

$$V_2 = \frac{A_1 T_2 P_1}{A_2 T_1 P_2} V_1 = \frac{1}{4} \frac{(540 \text{ R})(13 \text{ psia})}{(510 \text{ R})(14.5 \text{ psia})}(600 \text{ ft/s}) = \mathbf{142 \text{ ft/s}}$$

5-49 Steam expands in a turbine. The change in kinetic energy, the power output, and the turbine inlet area are to be determined.

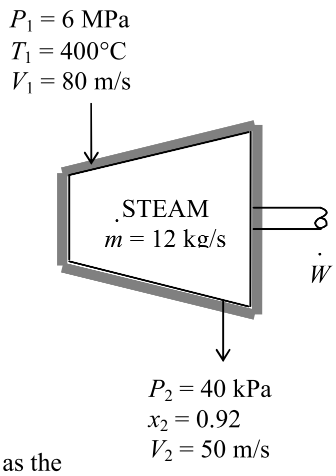
Assumptions **1** This is a steady-flow process since there is no change with time. **2** Potential energy changes are negligible. **3** The device is adiabatic and thus heat transfer is negligible.

Properties From the steam tables (Tables A-4 through 6)

$$\left.\begin{array}{l} P_1 = 6\text{ MPa} \\ T_1 = 400°\text{C} \end{array}\right\} \begin{array}{l} \boldsymbol{v}_1 = 0.047420\text{ m}^3/\text{kg} \\ h_1 = 3178.3\text{ kJ/kg} \end{array}$$

and

$$\left.\begin{array}{l} P_2 = 40\text{ kPa} \\ x_2 = 0.92 \end{array}\right\} h_2 = h_f + x_2 h_{fg} = 317.62 + 0.92 \times 2392.1 = 2318.5\text{ kJ/kg}$$



Analysis (a) The change in kinetic energy is determined from

$$\Delta ke = \frac{V_2^2 - V_1^2}{2} = \frac{(50\text{ m/s})^2 - (80\text{ m/s})^2}{2}\left(\frac{1\text{ kJ/kg}}{1000\text{ m}^2/\text{s}^2}\right) = \mathbf{-1.95\text{ kJ/kg}}$$

(*b*) 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

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

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

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

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

Then the power output of the turbine is determined by substitution to be

$$\dot{W}_{\text{out}} = -(20\text{ kg/s})(2318.5 - 3178.3 - 1.95)\text{kJ/kg} = 14{,}590\text{ kW} = \mathbf{14.6\text{ MW}}$$

(*c*) The inlet area of the turbine is determined from the mass flow rate relation,

$$\dot{m} = \frac{1}{\boldsymbol{v}_1}A_1V_1 \longrightarrow A_1 = \frac{\dot{m}\boldsymbol{v}_1}{V_1} = \frac{(20\text{ kg/s})(0.047420\text{ m}^3/\text{kg})}{80\text{ m/s}} = \mathbf{0.0119\text{ m}^2}$$

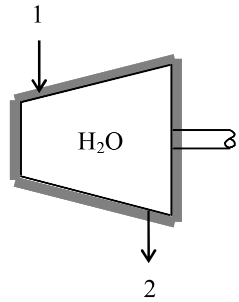
5-51 Steam expands in a turbine. The mass flow rate of steam for a power output of 5 MW is to be determined.

Assumptions **1** This is a steady-flow process since there is no change with time. **2** Kinetic and potential energy changes are negligible. **3** The device is adiabatic and thus heat transfer is negligible.

Properties From the steam tables (Tables A-4 through 6)

$$\left.\begin{array}{l} P_1 = 10\text{ MPa} \\ T_1 = 500°\text{C} \end{array}\right\} h_1 = 3375.1\text{ kJ/kg}$$

$$\left.\begin{array}{l} P_2 = 10\text{ kPa} \\ x_2 = 0.90 \end{array}\right\} h_2 = h_f + x_2 h_{fg} = 191.81 + 0.90 \times 2392.1 = 2344.7\text{ kJ/kg}$$



Analysis 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

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

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

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

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

Substituting, the required mass flow rate of the steam is determined to be

$$5000\text{ kJ/s} = -\dot{m}(2344.7 - 3375.1)\text{ kJ/kg} \longrightarrow \dot{m} = \mathbf{4.852\ kg/s}$$

5-53 Air is compressed at a rate of 10 L/s by a compressor. The work required per unit mass and the power required are 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** Air is an ideal gas with constant specific heats.

Properties The constant pressure specific heat of air at the average temperature of (20+300)/2=160°C=433 K is c_p = 1.018 kJ/kg·K (Table A-2b). The gas constant of air is R = 0.287 kPa·m^3/kg·K (Table A-1).

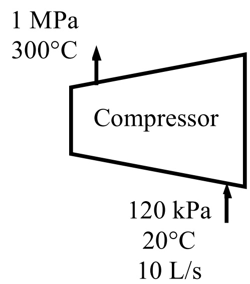
Analysis (*a*) There is only one inlet and one exit, and thus $\dot{m}_1 = \dot{m}_2 = \dot{m}$. We take the compressor as the system, which is a control volume since mass crosses the boundary. The energy balance for this steady-flow system can be expressed in the rate form as

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

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

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

$$\dot{W}_{in} = \dot{m}(h_2 - h_1) = \dot{m}c_p(T_2 - T_1)$$



Thus,

$$w_{in} = c_p(T_2 - T_1) = (1.018\text{ kJ/kg}\cdot\text{K})(300 - 20)\text{K} = \mathbf{285.0\text{ kJ/kg}}$$

(*b*) The specific volume of air at the inlet and the mass flow rate are

$$v_1 = \frac{RT_1}{P_1} = \frac{(0.287\text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(20 + 273\text{ K})}{120\text{ kPa}} = 0.7008\text{ m}^3/\text{kg}$$

$$\dot{m} = \frac{\dot{V}_1}{v_1} = \frac{0.010\text{ m}^3/\text{s}}{0.7008\text{ m}^3/\text{kg}} = 0.01427\text{ kg/s}$$

Then the power input is determined from the energy balance equation to be

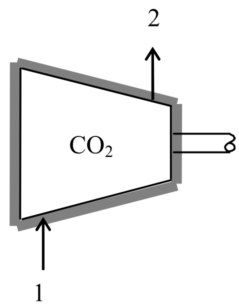
$$\dot{W}_{in} = \dot{m}c_p(T_2 - T_1) = (0.01427\text{ kg/s})(1.018\text{ kJ/kg}\cdot\text{K})(300 - 20)\text{K} = \mathbf{4.068\text{ kW}}$$

5-56 CO_2 is compressed by a compressor. The volume flow rate of CO_2 at the compressor inlet and the power input to the compressor are 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** Helium is an ideal gas with variable specific heats. **4** The device is adiabatic and thus heat transfer is negligible.

Properties The gas constant of CO_2 is R = 0.1889 kPa.m^3/kg.K, and its molar mass is M = 44 kg/kmol (Table A-1). The inlet and exit enthalpies of CO_2 are (Table A-20)

$$T_1 = 300\text{ K} \rightarrow \bar{h}_1 = 9{,}431\text{ kJ/kmol}$$
$$T_2 = 450\text{ K} \rightarrow \bar{h}_2 = 15{,}483\text{ kJ/kmol}$$



Analysis (*a*) There is only one inlet and one exit, and thus $\dot{m}_1 = \dot{m}_2 = \dot{m}$. The inlet specific volume of air and its volume flow rate are

$$v_1 = \frac{RT_1}{P_1} = \frac{(0.1889\text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(300\text{ K})}{100\text{ kPa}} = 0.5667\text{ m}^3/\text{kg}$$

$$\dot{V} = \dot{m}v_1 = (0.5\text{ kg/s})(0.5667\text{ m}^3/\text{kg}) = \mathbf{0.283\ m^3/s}$$

(*b*) We take the compressor 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

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

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

$$\dot{W}_{in} + \dot{m}h_1 = \dot{m}h_2 \quad (\text{since } \dot{Q} \cong \Delta\text{ke} \cong \Delta\text{pe} \cong 0)$$
$$\dot{W}_{in} = \dot{m}(h_2 - h_1) = \dot{m}(\bar{h}_2 - \bar{h}_1)/M$$

Substituting

$$\dot{W}_{in} = \frac{(0.5\text{ kg/s})(15{,}483 - 9{,}431\text{ kJ/kmol})}{44\text{ kg/kmol}} = \mathbf{68.8\ kW}$$