Εντροπία και η αρχή αύξησης της εντροπίας

7-27 Ψυκτικό R-134a εισέρχεται στις σπείρες ενός εξατμιστήρα συστήματος ψύξης ως κορεσμένο μίγμα υγρού – ατμών σε πίεση 160 kPa. Το ψυκτικό απορροφά 180 kJ θερμότητας από τον υπό ψύξη χώρο, ο οποίος διατηρείται στους -5°C και εξέρχεται από αυτόν ως κορεσμένος ατμός στην ίδια πίεση. Να προσδιορίσετε (α) τη μεταβολή της εντροπίας του ψυκτικού, (β) τη μεταβολή της εντροπίας του υπό ψύξη χώρου και (γ) τη συνολική μεταβολή της εντροπίας για αυτή τη διεργασία.

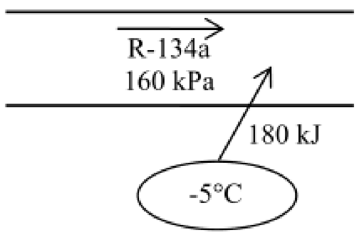
Assumptions **1** Both the refrigerant and the cooled space involve no internal irreversibilities such as friction. **2** Any temperature change occurs within the wall of the tube, and thus both the refrigerant and the cooled space remain isothermal during this process. Thus it is an isothermal, internally reversible process.

Analysis Noting that both the refrigerant and the cooled space undergo reversible isothermal processes, the entropy change for them can be determined from

$$\Delta S = \frac{Q}{T}$$

(*a*) The pressure of the refrigerant is maintained constant. Therefore, the temperature of the refrigerant also remains constant at the saturation value,

$$T = T_{\text{sat@160 kPa}} = -15.6°\text{C} = 257.4 \text{ K} \qquad \text{(Table A-12)}$$



Then, $\Delta S_{\text{refrigerant}} = \dfrac{Q_{\text{refrigerant,in}}}{T_{\text{refrigerant}}} = \dfrac{180 \text{ kJ}}{257.4 \text{ K}} = \mathbf{0.699\ kJ/K}$

(*b*) Similarly,

$$\Delta S_{\text{space}} = -\frac{Q_{\text{space,out}}}{T_{\text{space}}} = -\frac{180 \text{ kJ}}{268 \text{ K}} = \mathbf{-0.672\ kJ/K}$$

(*c*) The total entropy change of the process is

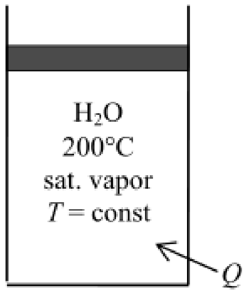
$$S_{\text{gen}} = \Delta S_{\text{total}} = \Delta S_{\text{refrigerant}} + \Delta S_{\text{space}} = 0.699 - 0.672 = \mathbf{0.027\ kJ/K}$$

Μεταβολή εντροπίας καθαρών ουσιών

7-41 Μια διάταξη εμβόλου – κυλίνδρου περιέχει 1,2 kg κορεσμένου νερού σε κατάσταση ατμού στους 200°C. Τώρα μεταφέρεται θερμότητα στον ατμό, και αυτός εκτονώνεται αντιστρεπτά και ισόθερμα σε τελική πίεση 800 kPa. Να προσδιορίσετε τη θερμότητα που μεταφέρεται, καθώς και το έργο που παράγεται κατά τη διάρκεια αυτής της διεργασίας.

Assumptions **1** The kinetic and potential energy changes are negligible. **2** The cylinder is well-insulated and thus heat transfer is negligible. **3** The thermal energy stored in the cylinder itself is negligible. **4** The process is stated to be reversible and isothermal.

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



$$\left.\begin{array}{l} T_1 = 200°\text{C} \\ sat.vapor \end{array}\right\} \begin{array}{l} u_1 = u_{g@200°\text{C}} = 2594.2 \text{ kJ/kg} \\ s_1 = s_{g@200°\text{C}} = 6.4302 \text{ kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} P_2 = 800 \text{ kPa} \\ T_2 = T_1 \end{array}\right\} \begin{array}{l} u_2 = 2631.1 \text{ kJ/kg} \\ s_2 = 6.8177 \text{ kJ/kg}\cdot\text{K} \end{array}$$

The heat transfer for this reversible isothermal process can be determined from

$$Q = T\Delta S = Tm(s_2 - s_1) = (473 \text{ K})(1.2 \text{ kg})(6.8177 - 6.4302)\text{kJ/kg}\cdot\text{K} = \mathbf{219.9 \ \ kJ}$$

We take the contents of the cylinder as the system. This is a closed system since no mass enters or leaves. The energy balance for this closed system can be expressed as

$$\underbrace{E_{in} - E_{out}}_{\substack{\text{Net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{system}}_{\substack{\text{Change in internal, kinetic,} \\ \text{potential, etc. energies}}}$$

$$Q_{in} - W_{b,out} = \Delta U = m(u_2 - u_1)$$

$$W_{b,out} = Q_{in} - m(u_2 - u_1)$$

Substituting, the work done during this process is determined to be

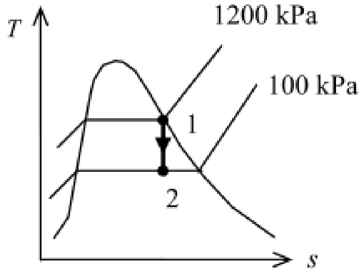
$$W_{b,out} = 219.9 \text{ kJ} - (1.2 \text{ kg})(2631.1 - 2594.2) \text{ kJ/kg} = \mathbf{175.6 \ \ kJ}$$

7-51 Ψυκτικό R-134a εισέρχεται σε αδιαβατικό στρόβιλο σταθεροποιημένης ροής ως κορεσμένος ατμός υπό πίεση 1200 kPa και εκτονώνεται στα 100 kPa. Η ισχύς που παράγεται από το στρόβιλο, βρίσκεται ίση με 100 kW όταν η διεργασία είναι επίσης αντιστρεπτή.

(α) Να σχεδιάσετε το διάγραμμα *T-s* ως προς τις γραμμές κορεσμού για αυτήν τη διεργασία

(β) Να προσδιορίσετε την παροχή όγκου του ψυκτικού R-134a στην έξοδο του στροβίλου, σε m^3/s.

Assumptions The process is steady.



Analysis (b) Noting that the process is isentropic (constant entropy) the inlet and exit states are obtained from R-134a tables (Table A-12) as follows:

$$\left.\begin{array}{l} P_1 = 1200\text{ kPa} \\ x_1 = 1 \end{array}\right\} \begin{array}{l} h_1 = 273.87\text{ kJ/kg} \\ s_1 = 0.9130\text{ kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} P_2 = 100\text{ kPa} \\ s_2 = s_1 = 0.9130\text{ kJ/kg}\cdot\text{K} \end{array}\right\} \begin{array}{l} x_2 = \dfrac{s_2 - s_f}{s_{fg}} = \dfrac{0.9130 - 0.07188}{0.87995} = 0.9559 \\ h_2 = h_f + xh_{fg} = 17.28 + 0.9559 \times 217.16 = 224.87\text{ kJ/kg} \\ \boldsymbol{v}_2 = \boldsymbol{v}_f + x\boldsymbol{v}_{fg} = 0.0007259 + 0.9559 \times (0.19254 - 0.0007259) = 0.1841\text{ m}^3/\text{kg} \end{array}$$

We take the turbine as the system, which is a control volume since mass crosses the boundary. Noting that one fluid stream enters and leaves the turbine, the energy balance for this steady-flow system can be expressed in the rate form as

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

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

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

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

Solving for the mass flow rate and substituting,

$$\dot{m} = \frac{\dot{W}_{out}}{h_1 - h_2} = \frac{100\text{ kW}}{(273.87 - 224.87)\text{kJ/kg}} = 2.041\text{ kg/s}$$

The volume flow rate at the exit is then,

$$\dot{\boldsymbol{V}}_2 = \dot{m}\boldsymbol{v}_2 = (2.041\text{ kg/s})(0.1841\text{ m}^3/\text{kg}) = \mathbf{0.376\ m^3/s}$$

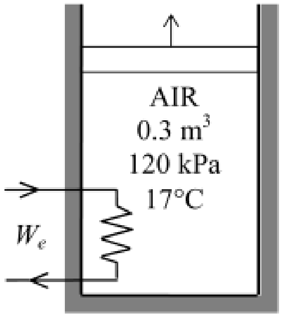
Μεταβολή εντροπίας ιδανικών αερίων

7-77 Μία μονωμένη διάταξη εμβόλου – κυλίνδρου αρχικά περιέχει 300 λίτρα αέρα σε 120 kPa και 17^{o}C. Ο αέρας τώρα θερμαίνεται για 15 λεπτά από ένα θερμαντήρα ηλεκτρικής αντίστασης ισχύος 200W τοποθετημένο στο εσωτερικό του κυλίνδρου. Κατά τη διάρκεια αυτής της διεργασίας η πίεση του αέρα διατηρείται σταθερή. Να προσδιορίσετε τη μεταβολή της εντροπίας του αέρα, υποθέτοντας (α) σταθερές ειδικές θερμότητες και (β) μεταβλητές ειδικές θερμότητες.

Assumptions At specified conditions, air can be treated as an ideal gas.

Properties The gas constant of air is $R = 0.287$ kJ/kg.K (Table A-1).

Analysis The mass of the air and the electrical work done during this process are



$$m = \frac{P_1 V_1}{RT_1} = \frac{(120 \text{ kPa})(0.3 \text{ m}^3)}{(0.287 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(290 \text{ K})} = 0.4325 \text{ kg}$$

$$W_{e,\text{in}} = \dot{W}_{e,\text{in}} \Delta t = (0.2 \text{ kJ/s})(15 \times 60 \text{ s}) = 180 \text{ kJ}$$

The energy balance for this stationary closed system can be expressed as

$$\underbrace{E_{\text{in}} - E_{\text{out}}}_{\substack{\text{Net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{\text{system}}}_{\substack{\text{Change in internal, kinetic,}\\ \text{potential, etc. energies}}}$$

$$W_{e,\text{in}} - W_{b,\text{out}} = \Delta U \longrightarrow W_{e,\text{in}} = m(h_2 - h_1) \cong c_p(T_2 - T_1)$$

since $\Delta U + W_b = \Delta H$ during a constant pressure quasi-equilibrium process.

(*a*) Using a constant c_p value at the anticipated average temperature of 450 K, the final temperature becomes

Thus, $$T_2 = T_1 + \frac{W_{e,\text{in}}}{mc_p} = 290 \text{ K} + \frac{180 \text{ kJ}}{(0.4325 \text{ kg})(1.02 \text{ kJ/kg}\cdot\text{K})} = 698 \text{ K}$$

Then the entropy change becomes

$$\Delta S_{\text{sys}} = m(s_2 - s_1) = m\left(c_{p,\text{avg}} \ln\frac{T_2}{T_1} - R\ln\frac{P_2}{P_1}^{\nearrow 0}\right) = mc_{p,\text{avg}} \ln\frac{T_2}{T_1}$$

$$= (0.4325 \text{ kg})(1.020 \text{ kJ/kg}\cdot\text{K})\ln\left(\frac{698 \text{ K}}{290 \text{ K}}\right) = \mathbf{0.387 \text{ kJ/K}}$$

(*b*) Assuming variable specific heats,

$$W_{e,\text{in}} = m(h_2 - h_1) \longrightarrow h_2 = h_1 + \frac{W_{e,\text{in}}}{m} = 290.16 \text{ kJ/kg} + \frac{180 \text{ kJ}}{0.4325 \text{ kg}} = 706.34 \text{ kJ/kg}$$

From the air table (Table A-17, we read $s_2^\circ = 2.5628$ kJ/kg·K corresponding to this h_2 value. Then,

$$\Delta S_{\text{sys}} = m\left(s_2^\circ - s_1^\circ + R\ln\frac{P_2}{P_1}^{\nearrow 0}\right) = m(s_2^\circ - s_1^\circ) = (0.4325 \text{ kg})(2.5628 - 1.66802)\text{kJ/kg}\cdot\text{K} = \mathbf{0.387 \text{ kJ/K}}$$

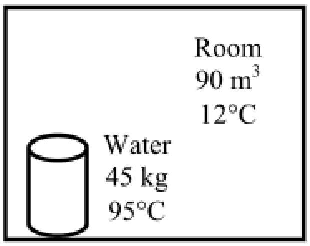
7-95 Ένα δοχείο που είναι γεμάτο με 45 kg υγρό νερό σε 95°C, τοποθετείται μέσα σε ένα δωμάτιο 90 m^3 που αρχικά βρίσκεται στους 12°C. Μετά από λίγο αποκαθίσταται θερμική ισορροπία ως αποτέλεσμα της μεταφοράς θερμότητας ανάμεσα στο υγρό και στον αέρα του δωματίου. Χρησιμοποιώντας σταθερές ειδικές θερμότητες, να προσδιορίσετε (α) την τελική θερμοκρασία ισορροπίας, (β) την ποσότητα της θερμότητας που μεταφέρεται ανάμεσα στο νερό και στον αέρα του δωματίου και (γ) την παραγωγή εντροπίας. Θεωρείστε ότι το δωμάτιο είναι επαρκώς σφραγισμένο και ισχυρά μονωμένο.

Assumptions **1** Kinetic and potential energy changes are negligible. **2** Air is an ideal gas with constant specific heats. **3** The room is well-sealed and there is no heat transfer from the room to the surroundings. **4** Sea level atmospheric pressure is assumed. P = 101.3 kPa.

Properties The properties of air at room temperature are R = 0.287 kPa.m³/kg.K, c_p = 1.005 kJ/kg.K, c_v = 0.718 kJ/kg.K. The specific heat of water at room temperature is c_w = 4.18 kJ/kg.K (Tables A-2, A-3).

Analysis (*a*) The mass of the air in the room is

$$m_a = \frac{PV}{RT_{a1}} = \frac{(101.3\text{ kPa})(90\text{ m}^3)}{(0.287\text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(12+273\text{ K})} = 111.5\text{ kg}$$



An energy balance on the system that consists of the water in the container and the air in the room gives the final equilibrium temperature

$$0 = m_w c_w (T_2 - T_{w1}) + m_a c_v (T_2 - T_{a1})$$

$$0 = (45\text{ kg})(4.18\text{ kJ/kg.K})(T_2 - 95) + (111.5\text{ kg})(0.718\text{ kJ/kg.K})(T_2 - 12) \longrightarrow T_2 = \mathbf{70.2°C}$$

(*b*) The heat transfer to the air is

$$Q = m_a c_v (T_2 - T_{a1}) = (111.5\text{ kg})(0.718\text{ kJ/kg.K})(70.2 - 12) = \mathbf{4660\text{ kJ}}$$

(*c*) The entropy generation associated with this heat transfer process may be obtained by calculating total entropy change, which is the sum of the entropy changes of water and the air.

$$\Delta S_w = m_w c_w \ln\frac{T_2}{T_{w1}} = (45\text{ kg})(4.18\text{ kJ/kg.K})\ln\frac{(70.2+273)\text{ K}}{(95+273)\text{ K}} = -13.11\text{ kJ/K}$$

$$P_2 = \frac{m_a R T_2}{V} = \frac{(111.5\text{ kg})(0.287\text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(70.2+273\text{ K})}{(90\text{ m}^3)} = 122\text{ kPa}$$

$$\Delta S_a = m_a\left(c_p \ln\frac{T_2}{T_{a1}} - R\ln\frac{P_2}{P_1}\right)$$

$$= (111.5\text{ kg})\left[(1.005\text{ kJ/kg.K})\ln\frac{(70.2+273)\text{ K}}{(12+273)\text{ K}} - (0.287\text{ kJ/kg.K})\ln\frac{122\text{ kPa}}{101.3\text{ kPa}}\right] = 14.88\text{ kJ/K}$$

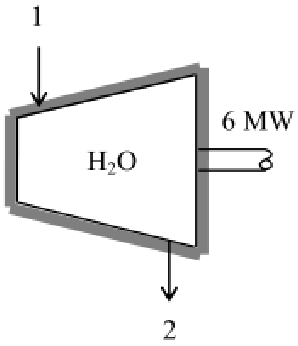
$$S_{\text{gen}} = \Delta S_{\text{total}} = \Delta S_w + \Delta S_a = -13.11 + 14.88 = \mathbf{1.77\text{ kJ/K}}$$

Ισεντροπικές αποδόσεις διατάξεων σταθεροποιημένης ροής

7-117 Υδρατμός εισέρχεται σε αδιαβατικό στρόβιλο με 7 MPa, 600°C και 80 m/s και εξέρχεται σε 50 kPa, 150°C με 140 m/s. Εάν η ισχύς εξόδου του στροβίλου είναι 6 MW, να προσδιορίσετε (α) την παροχή μάζας του υδρατμού που ρέει μέσα από το στρόβιλο και (β) την ισεντροπική απόδοση του στροβίλου.

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.

Analysis (*a*) From the steam tables (Tables A-4 and A-6),



$$\left.\begin{array}{l} P_1 = 7 \text{ MPa} \\ T_1 = 600°\text{C} \end{array}\right\} \begin{array}{l} h_1 = 3650.6 \text{ kJ/kg} \\ s_1 = 7.0910 \text{ kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} P_2 = 50 \text{ kPa} \\ T_2 = 150°\text{C} \end{array}\right\} h_{2a} = 2780.2 \text{ kJ/kg}$$

There is only one inlet and one exit, and thus $\dot{m}_1 = \dot{m}_2 = \dot{m}$. We take the actual 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

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

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

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

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

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

$$6000 \text{ kJ/s} = -\dot{m}\left(2780.2 - 3650.6 + \frac{(140 \text{ m/s})^2 - (80 \text{ m/s})^2}{2}\left(\frac{1 \text{ kJ/kg}}{1000 \text{ m}^2/\text{s}^2}\right)\right)$$

$$\dot{m} = \mathbf{6.95 \text{ kg/s}}$$

(*b*) The isentropic exit enthalpy of the steam and the power output of the isentropic turbine are

$$\left.\begin{array}{l} P_{2s} = 50 \text{ kPa} \\ s_{2s} = s_1 \end{array}\right\} \begin{array}{l} x_{2s} = \dfrac{s_{2s} - s_f}{s_{fg}} = \dfrac{7.0910 - 1.0912}{6.5019} = 0.9228 \\ h_{2s} = h_f + x_{2s} h_{fg} = 340.54 + (0.9228)(2304.7) = 2467.3 \text{ kJ/kg} \end{array}$$

and

$$\dot{W}_{\text{s,out}} = -\dot{m}\left(h_{2s} - h_1 + \left\{\left(V_2^2 - V_1^2\right)/2\right\}\right)$$

$$\dot{W}_{\text{s,out}} = -(6.95 \text{ kg/s})\left(2467.3 - 3650.6 + \frac{(140 \text{ m/s})^2 - (80 \text{ m/s})^2}{2}\left(\frac{1 \text{ kJ/kg}}{1000 \text{ m}^2/\text{s}^2}\right)\right)$$

$$= 8174 \text{ kW}$$

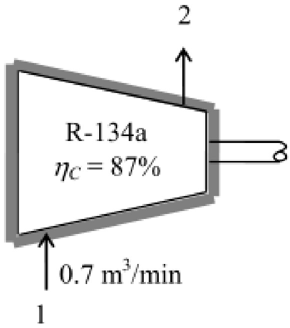
Then the isentropic efficiency of the turbine becomes

$$\eta_T = \frac{\dot{W}_a}{\dot{W}_s} = \frac{6000 \text{ kW}}{8174 \text{ kW}} = 0.734 = \mathbf{73.4\%}$$

7-123 Ψυκτικό R-134α εισέρχεται σε αδιαβατικό συμπιεστή ως κορεσμένος ατμός με 100 kPa και 0,7 m^3/min και εξέρχεται με 1 MPa. Εάν η ισεντροπική απόδοση του συμπιεστή είναι 87%, να προσδιορίσετε (α) τη θερμοκρασία του ψυκτικού στην έξοδο του συμπιεστή και (β) την ισχύ εισόδου σε kW. Να αναπαραστήσετε επίσης τη διεργασία σε διάγραμμα *T*–*s* ως προς τις γραμμές κορεσμού.

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.

Analysis (a) From the refrigerant tables (Tables A-11E through A-13E),



$$\left.\begin{array}{l} P_1 = 100 \text{ kPa} \\ \text{sat. vapor} \end{array}\right\} \begin{array}{l} h_1 = h_{g@100 \text{ kPa}} = 234.44 \text{ kJ/kg} \\ s_1 = s_{g@100 \text{ kPa}} = 0.95183 \text{ kJ/kg}\cdot\text{K} \\ \boldsymbol{v}_1 = \boldsymbol{v}_{g@100 \text{ kPa}} = 0.19254 \text{ m}^3\text{/kg} \end{array}$$

$$\left.\begin{array}{l} P_2 = 1 \text{ MPa} \\ s_{2s} = s_1 \end{array}\right\} h_{2s} = 282.51 \text{ kJ/kg}$$

From the isentropic efficiency relation,

$$\eta_C = \frac{h_{2s} - h_1}{h_{2a} - h_1} \longrightarrow h_{2a} = h_1 + (h_{2s} - h_1)/\eta_C = 234.44 + (282.51 - 234.44)/0.87 = 289.69 \text{ kJ/kg}$$

Thus,

$$\left.\begin{array}{l} P_{2a} = 1 \text{ MPa} \\ h_{2a} = 289.69 \text{ kJ/kg} \end{array}\right\} T_{2a} = \mathbf{56.5°C}$$

(b) The mass flow rate of the refrigerant is determined from

$$\dot{m} = \frac{\dot{\boldsymbol{V}}_1}{\boldsymbol{v}_1} = \frac{0.7/60 \text{ m}^3\text{/s}}{0.19254 \text{ m}^3\text{/kg}} = 0.06059 \text{ kg/s}$$

There is only one inlet and one exit, and thus $\dot{m}_1 = \dot{m}_2 = \dot{m}$. We take the actual 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 as

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

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

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

$$\dot{W}_{a,in} = \dot{m}(h_2 - h_1)$$

Substituting, the power input to the compressor becomes,

$$\dot{W}_{a,in} = (0.06059 \text{ kg/s})(289.69 - 234.44)\text{kJ/kg} = \mathbf{3.35 \text{ kW}}$$

7-128 Αέρας εισέρχεται σε αδιαβατικό ακροφύσιο σε 400 kPa και 547°C με μικρή ταχύτητα και εξέρχεται με 240 m/s. Εάν η ισεντροπική απόδοση του ακροφυσίου είναι 90%, να προσδιορίσετε τη θερμοκρασία εξόδου και την πίεση του αέρα.

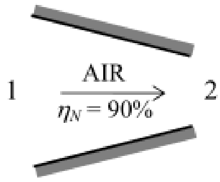
Assumptions **1** This is a steady-flow process since there is no change with time. **2** Potential energy changes are negligible. **3** The device is adiabatic and thus heat transfer is negligible. **4** Air is an ideal gas with variable specific heats.

Analysis From the air table (Table A-17),

$$T_1 = 820 \text{ K} \longrightarrow h_1 = 843.98 \text{ kJ/kg},\ P_{r_1} = 52.59$$

There is only one inlet and one exit, and thus $\dot{m}_1 = \dot{m}_2 = \dot{m}$. We take the 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 as

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



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

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

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

Substituting, the exit temperature of air is determined to be

$$h_2 = 843.98 \text{ kJ/kg} - \frac{(240 \text{ m/s})^2 - 0}{2}\left(\frac{1 \text{ kJ/kg}}{1000 \text{ m}^2/\text{s}^2}\right) = 815.18 \text{ kJ/kg}$$

From the air table we read

$$T_{2a} = \mathbf{793.8\ K}$$

From the isentropic efficiency relation $\eta_N = \dfrac{h_{2a} - h_1}{h_{2s} - h_1}$,

$$h_{2s} = h_1 + (h_{2a} - h_1)/\eta_N = 843.98 + (815.18 - 843.98)/(0.90) = 811.98 \text{ kJ/kg} \longrightarrow P_{r_2} = 45.75$$

Then the exit pressure is determined from the isentropic relation to be

$$\frac{P_2}{P_1} = \frac{P_{r_2}}{P_{r_1}} \longrightarrow P_2 = \left(\frac{P_{r_2}}{P_{r_1}}\right) P_1 = \left(\frac{45.75}{52.59}\right)(400 \text{ kPa}) = \mathbf{348\ kPa}$$

Ισοζύγιο εντροπίας

7-132 Οξυγόνο εισέρχεται σε μονωμένο σωλήνα διαμέτρου 12 cm με ταχύτητα 70 m/s. Στην είσοδο του σωλήνα, το οξυγόνο έχει πίεση 240 kPa και θερμοκρασία 20^{o}C, ενώ οι αντίστοιχες τιμές στην έξοδο του σωλήνα είναι 200 kPa και 18^{o}C. Να υπολογίσετε το ρυθμό με τον οποίο παράγεται η εντροπία στο σωλήνα.

Assumptions **1** Steady operating conditions exist. **2** The pipe is well-insulated so that heat loss to the surroundings is negligible. **3** Changes in the kinetic and potential energies are negligible. **4** Oxygen is an ideal gas with constant specific heats.

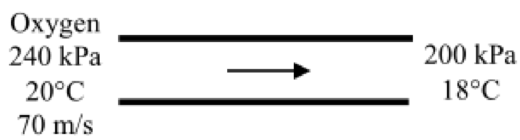
Properties The properties of oxygen at room temperature are R = 0.2598 kJ/kg·K, c_p = 0.918 kJ/kg·K (Table A-2a).

Analysis The rate of entropy generation in the pipe is determined by applying the rate form of the entropy balance on the pipe:

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

$$\dot{m}_1 s_1 - \dot{m}_2 s_2 + \dot{S}_{\text{gen}} = 0 \quad (\text{since } Q = 0)$$

$$\dot{S}_{\text{gen}} = \dot{m}(s_2 - s_1)$$



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

$$\boldsymbol{v}_1 = \frac{RT_1}{P_1} = \frac{(0.2598\,\text{kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(293\,\text{K})}{240\,\text{kPa}} = 0.3172\,\text{m}^3/\text{kg}$$

$$\dot{m} = \frac{A_1 V_1}{\boldsymbol{v}_1} = \frac{\pi D^2 V_1}{4\boldsymbol{v}_1} = \frac{\pi (0.12\,\text{m})^2 (70\,\text{m/s})}{4(0.3172\,\text{m}^3/\text{kg})} = 2.496\,\text{kg/s}$$

Substituting into the entropy balance relation,

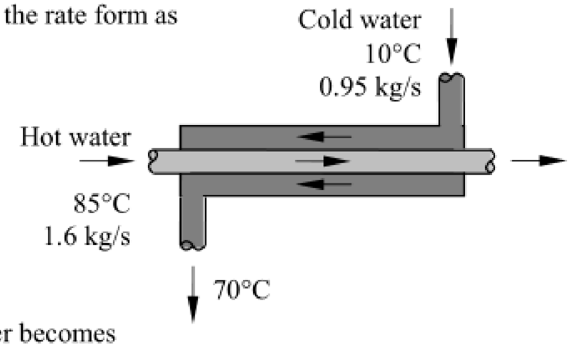
$$\begin{aligned}
\dot{S}_{\text{gen}} &= \dot{m}(s_2 - s_1) \\
&= \dot{m}\left(c_p \ln\frac{T_2}{T_1} - R\ln\frac{P_2}{P_1}\right) \\
&= (2.496\,\text{kg/s})\left[(0.918\,\text{kJ/kg}\cdot\text{K})\ln\frac{291\,\text{K}}{293\,\text{K}} - (0.2598\,\text{kJ/kg}\cdot\text{K})\ln\frac{200\,\text{kPa}}{240\,\text{kPa}}\right] \\
&= \mathbf{0.1025\ kW/K}
\end{aligned}$$

7-135 Κρύο νερό (c_p=4,18 kJ/kg·°C) που καταλήγει σε μια ντουζιέρα, εισέρχεται σε ένα καλά μονωμένο εναλλάκτη θερμότητας, αντιρροής, διπλού σωλήνα, με λεπτό τοίχωμα σε θερμοκρασία 10°C με ρυθμό 0,95 kg/s και θερμαίνεται με τη βοήθεια ζεστού νερού (c_p=4,18 kJ/kg·°C) στους 70°C που εισέρχεται στους 85°C και με ρυθμό 1,6 kg/s. Να προσδιορίσετε (α) το ρυθμό μεταφοράς θερμότητας και (β) το ρυθμό δημιουργίας εντροπίας στον εναλλάκτη θερμότητας.

Assumptions **1** Steady operating conditions exist. **2** The heat exchanger is well-insulated so that heat loss to the surroundings is negligible and thus heat transfer from the hot fluid is equal to the heat transfer to the cold fluid. **3** Changes in the kinetic and potential energies of fluid streams are negligible. **4** Fluid properties are constant.

Properties The specific heats of cold and hot water are given to be 4.18 and 4.19 kJ/kg.°C, respectively.

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



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

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

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

$$\dot{Q}_{\text{in}} = \dot{m}c_p(T_2 - T_1)$$

Then the rate of heat transfer to the cold water in this heat exchanger becomes

$$\dot{Q}_{\text{in}} = [\dot{m}c_p(T_{\text{out}} - T_{\text{in}})]_{\text{cold water}} = (0.95 \text{ kg/s})(4.18 \text{ kJ/kg.°C})(70°\text{C} - 10°\text{C}) = \mathbf{238.3 \text{ kW}}$$

Noting that heat gain by the cold water is equal to the heat loss by the hot water, the outlet temperature of the hot water is determined to be

$$\dot{Q} = [\dot{m}c_p(T_{\text{in}} - T_{\text{out}})]_{\text{hot water}} \longrightarrow T_{\text{out}} = T_{\text{in}} - \frac{\dot{Q}}{\dot{m}c_p} = 85°\text{C} - \frac{238.3 \text{ kW}}{(1.6 \text{ kg/s})(4.19 \text{ kJ/kg.°C})} = 49.5°\text{C}$$

(*b*) The rate of entropy generation within the heat exchanger is determined by applying the rate form of the entropy balance on the entire heat exchanger:

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

$$\dot{m}_1 s_1 + \dot{m}_3 s_3 - \dot{m}_2 s_2 - \dot{m}_3 s_4 + \dot{S}_{\text{gen}} = 0 \quad (\text{since } Q = 0)$$

$$\dot{m}_{\text{cold}} s_1 + \dot{m}_{\text{hot}} s_3 - \dot{m}_{\text{cold}} s_2 - \dot{m}_{\text{hot}} s_4 + \dot{S}_{\text{gen}} = 0$$

$$\dot{S}_{\text{gen}} = \dot{m}_{\text{cold}}(s_2 - s_1) + \dot{m}_{\text{hot}}(s_4 - s_3)$$

Noting that both fluid streams are liquids (incompressible substances), the rate of entropy generation is determined to be

$$\dot{S}_{\text{gen}} = \dot{m}_{\text{cold}} c_p \ln\frac{T_2}{T_1} + \dot{m}_{\text{hot}} c_p \ln\frac{T_4}{T_3}$$

$$= (0.95 \text{ kg/s})(4.18 \text{ kJ/kg.K})\ln\frac{70+273}{10+273} + (1.6 \text{ kg/s})(4.19 \text{ kJ/kg.K})\ln\frac{49.5+273}{85+273}$$

$$= \mathbf{0.06263 \text{ kW/K}}$$

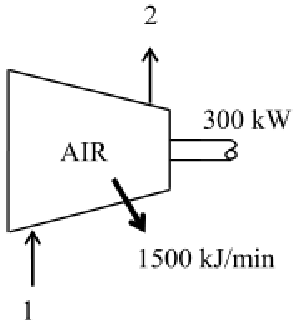
7-151 Αέρας εισέρχεται σε συμπιεστή σε συνθήκες περιβάλλοντος 100 kPa και 17^{o}C με μικρή ταχύτητα και εξέρχεται με 1 MPa, 327^{o}C και 105 m/s. Ο συμπιεστής ψύχεται από τον αέρα του περιβάλλοντος στους 15^{o}C με ρυθμό 15 kJ/min. Η ισχύς εισόδου στο συμπιεστή είναι 300 kW. Να προσδιορίσετε (α) την παροχή μάζας του αέρα και (β) το ρυθμό δημιουργίας εντροπίας.

Assumptions **1** This is a steady-flow process since there is no change with time. **2** Potential energy changes are negligible. **3** Air is an ideal gas with variable specific heats.

Properties The gas constant of air is 0.287 kJ/kg.K. The inlet and exit enthalpies of air are (Table A-17)

$$\left.\begin{aligned} T_1 &= 290\text{ K} \\ P_1 &= 100\text{ kPa} \end{aligned}\right\} \begin{aligned} h_1 &= 290.16\text{ kJ/kg} \\ s_1^\circ &= 1.66802\text{ kJ/kg}\cdot\text{K} \end{aligned}$$

$$\left.\begin{aligned} T_2 &= 600\text{ K} \\ P_2 &= 1\text{ MPa} \end{aligned}\right\} \begin{aligned} h_2 &= 607.02\text{ kJ/kg} \\ s_2^\circ &= 2.40902\text{ kJ/kg}\cdot\text{K} \end{aligned}$$



Analysis (*a*) 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

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

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

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

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

Substituting, the mass flow rate is determined to be

Thus,

$$(300\text{ kW}) - \frac{1500\text{ kJ}}{60\text{ s}} = \dot{m}\left(607.02 - 290.16 + \frac{(105\text{ m/s})^2}{2}\left(\frac{1\text{ kJ/kg}}{1000\text{ m}^2/\text{s}^2}\right)\right)$$

It yields

$$\dot{m} = \mathbf{0.853\text{ kg/s}}$$

(*b*) Again we take the compressor to be the system. Noting that no heat or mass crosses the boundaries of this combined system, the entropy balance for it can be expressed as

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

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

where

$$\Delta\dot{S}_{\text{air}} = \dot{m}(s_2 - s_1) = \dot{m}\left(s_2^\circ - s_1^\circ - R\ln\frac{P_2}{P_1}\right)$$

$$= (0.853\text{ kg/s})\left(2.40902 - 1.66802 - (0.287\text{ kJ/kg}\cdot\text{K})\ln\frac{1000\text{ kPa}}{100\text{ kPa}}\right) = 0.0684\text{ kW/K}$$

Substituting, the rate of entropy generation during this process is determined to be

$$\dot{S}_{\text{gen}} = \dot{m}(s_2 - s_1) + \frac{\dot{Q}_{\text{out}}}{T_{\text{b,surr}}} = 0.0684\text{ kW/K} + \frac{1500/60\text{ kJ/s}}{290\text{ K}} = \mathbf{0.155\ \ kW/K}$$