İdeal ve Gerçek Gaz Türbini (Brayton) Çevrimleri

9-92 İş akışkanı hava olan rejeneratörlü bir Brayton çevriminin basınç oranı 7 ‘ dir. Çevrimin en düşük ve en yüksek sıcaklıkları 310 K ve 1150 K ‘ dir. Kompresörün izantropik verimi yüzde 75, türbinin izantropik verimi yüzde 82 ve rejeneratörün etkinliği yüzde 65 olduğuna göre, (a) türbin çıkışında havanın sıcaklığını, (b) çevrimin net işini ve (c) çevrimin ısıl verimini hesaplayınız. Çözüm: (a) 783 K, (b) 108.1 kJ/kg, %22.5

9-94 Hava, rejeneratörlü bir gaz türbininin kompresörüne 300 K sıcaklıkta ve 100 kPa basınçta girmekte ve burada 800 kPa basınca ve 580 K sıcaklığa sıkıştırılmaktadır. Rejeneratör etkinliği yüzde 72 olup, hava türbine 1200 K sıcaklıkta girmektedir. Türbin verimi yüzde 86 olduğuna göre, havanın özgül ısılarının sıcaklıkla değişimini dikkate alarak, (a) rejeneratörde geçen ısı miktarını ve (b) ısıl verimi hesaplayınız. Çözüm: (a) 152.5 kJ/kg, (b) %36

Ara Soğutmalı, Ara Isıtmalı, Rejenaratörlü Brayton Çevrimi

9-104 İkişer kademeli sıkıştırma ve genişlemenin olduğu ideal bir gaz türbini çevriminde kompresör ve türbinin her iki kademesinde basınç oranı 3’ tür. Hava kompresörün her iki kademesine 300 K, türbinin her iki kademesine ise 1200 K sıcaklıkta girmektedir. (a) Rejeneratör kullanılmaması ve (b) yüzde 75 etkinliğe sahip bir rejeneratör kullanılması durumunda, çevrimin geri iş oranını ve ısıl verimini hesaplayınız. Oda sıcaklığındaki özgül ısıların sabit olduğunu varsayınız.

9-106 İki kademeli sıkıştırma ve iki kademeli genişlemenin olduğu rejeneratörlü bir gaz türbini santralinde toplam basınç oranı 9 ‘ dur. Hava kompresörün her kademesine 300 K, türbinin her kademesine ise 1200 K sıcaklıkta girmektedir. Özgül ısıların sıcaklıkla değişimini dikkate alarak, 110 MW net güç üretilmesi için havanın sahip olması gereken en az kütlesel debi ne kadar olmalıdır? Çözüm: 250 kg/s

Basit Rankine Çevrimi

10-15 210 MW gücünde bir buharlı güç santrali, basit ideal Rankine çevrimine göre çalışmaktadır. Buhar türbine 10 MPa basınç ve 500 ˚C sıcaklıkta girmekte ve yoğuşturucuda10 kPa basınçta soğutulmaktadır. Çevrimi doymuş sıvı ve doymuş buhar eğrilerinin de yer aldığı bir T-s diyagramında göstererek, (a) türbin çıkışında buharın kuruluk derecesini (b) çevrimin ısıl verimini ve (c) buharın kütlesel debisini hesaplayınız. Çözüm (a) 0.793, (b) yüzde 40.2, (c) 165 kg/s

10-16 Türbin ve pompanın izantropik verimini yüzde 85 alarak Problem 10-15’ i tekrar çözünüz. Çözüm: (a) 0.874, (b) %34.1, (c) 194 kg/s

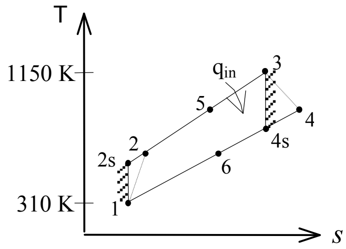
10-19 Kömür yakarak 300 MW güç üreten bir buharlı güç santrali basit ideal Rankine çevrimine göre çalışmaktadır. Türbin girişinde buharın basıncı 5 MPa, sıcaklığı 450 ˚C ve yoğuşturucu basıncı 25 kPa ’ dır. Kömürün ısıl değeri (yakıldığında açığa çıkan ısı miktarı) 29300 kJ/kg ‘dır. Kazanda bu enerjinin yüzde 75 ‘i buhara aktarılmakta olup, elektrik jeneratörünün verimi yüzde 96 ‘dır. (a) Santralin toplam verimini (net elektriksel güç çıkışının yakıt olarak girilen enerjiye oranı) (b) birim zamanda gereken kömür miktarını hesaplayınız. Çözüm: (a) %24.5, (b) 150 t/h

10-21 Basit ideal Rankine çevrimine göre çalışan bir buharlı güç santralinin net gücü 45 MW 'tır. Su buharı türbine 7 MPa basınç ve 500 ˚C sıcaklıkta girmekte, yoğuşturucuda 10 kPa basınçta soğutulmaktadır. Yoğuşturucunun soğutulmasında kullanılan göl suyunun yoğuşturucu borularındaki kütlesel debisi 2000 kg/s dir. Çevrimi doymuş sıvı ve doymuş buhar eğrilerinin de yer aldığı bir T-s diyagramında göstererek, (a) çevrimin ısıl verimini, (b) buharın debisini ve (c) soğutma suyunun sıcaklığındaki yükselme miktarını hesaplayınız. Çözüm: (a) %38.9 (b) 36 kg/s, (c) 8.4 ˚C

10-22 Türbin ve pompanın izantropik verimini yüzde 87 alarak Problem 10-21 'i tekrar çözünüz. Çözüm: (a) % 33.8, (b) 41.4 kg/s, (c) 10.5 ˚C

9-96 A Brayton cycle with regeneration using air as the working fluid is considered. The air temperature at the turbine exit, the net work output, and the thermal efficiency are to be determined.

Assumptions **1** The air standard assumptions are applicable. **2** Air is an ideal gas with variable specific heats. **3** Kinetic and potential energy changes are negligible.



Properties The properties of air are given in Table A-17.

Analysis (a) The properties of air at various states are

$$T_1 = 310 \text{ K} \longrightarrow \begin{array}{l} h_1 = 310.24 \text{ kJ/kg} \\ P_{r_1} = 1.5546 \end{array}$$

$$P_{r_2} = \frac{P_2}{P_1} P_{r_1} = (7)(1.5546) = 10.88 \longrightarrow h_{2s} = 541.26 \text{ kJ/kg}$$

$$\eta_C = \frac{h_{2s} - h_1}{h_2 - h_1} \longrightarrow h_2 = h_1 + (h_{2s} - h_1)/\eta_C = 310.24 + (541.26 - 310.24)/(0.75) = 618.26 \text{ kJ/kg}$$

$$T_3 = 1150 \text{ K} \longrightarrow \begin{array}{l} h_3 = 1219.25 \text{ kJ/kg} \\ P_{r_3} = 200.15 \end{array}$$

$$P_{r_4} = \frac{P_4}{P_3} P_{r_3} = \left(\frac{1}{7}\right)(200.15) = 28.59 \longrightarrow h_{4s} = 711.80 \text{ kJ/kg}$$

$$\eta_T = \frac{h_3 - h_4}{h_3 - h_{4s}} \longrightarrow h_4 = h_3 - \eta_T (h_3 - h_{4s}) = 1219.25 - (0.82)(1219.25 - 711.80) = 803.14 \text{ kJ/kg}$$

Thus, $T_4 = \mathbf{782.8\ K}$

(*b*) $$w_{\text{net}} = w_{\text{T,out}} - w_{\text{C,in}} = (h_3 - h_4) - (h_2 - h_1)$$
$$= (1219.25 - 803.14) - (618.26 - 310.24)$$
$$= \mathbf{108.09\ kJ/kg}$$

(*c*) $$\varepsilon = \frac{h_5 - h_2}{h_4 - h_2} \longrightarrow h_5 = h_2 + \varepsilon(h_4 - h_2)$$
$$= 618.26 + (0.65)(803.14 - 618.26)$$
$$= 738.43 \text{ kJ/kg}$$

Then,

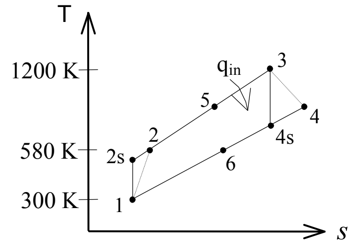
$$q_{\text{in}} = h_3 - h_5 = 1219.25 - 738.43 = 480.82 \text{ kJ/kg}$$

$$\eta_{\text{th}} = \frac{w_{\text{net}}}{q_{\text{in}}} = \frac{108.09 \text{ kJ/kg}}{480.82 \text{ kJ/kg}} = \mathbf{22.5\%}$$

9-98 A regenerative gas-turbine engine using air as the working fluid is considered. The amount of heat transfer in the regenerator and the thermal efficiency are to be determined.

Assumptions **1** The air standard assumptions are applicable. **2** Air is an ideal gas with variable specific heats. **3** Kinetic and potential energy changes are negligible.

Properties The properties of air are given in Table A-17.



Analysis (*a*) The properties at various states are

$$r_p = P_2 / P_1 = 800/100 = 8$$

$$T_1 = 300 \text{ K} \longrightarrow h_1 = 300.19 \text{ kJ/kg}$$
$$T_2 = 580 \text{ K} \longrightarrow h_2 = 586.04 \text{ kJ/kg}$$
$$T_3 = 1200 \text{ K} \longrightarrow h_3 = 1277.79 \text{ kJ/kg}$$
$$P_{r_3} = 238.0$$

$$P_{r_4} = \frac{P_4}{P_3} P_{r_3} = \left(\frac{1}{8}\right)(238.0) = 29.75 \longrightarrow h_{4s} = 719.75 \text{ kJ/kg}$$

$$\eta_T = \frac{h_3 - h_4}{h_3 - h_{4s}} \longrightarrow h_4 = h_3 - \eta_T (h_3 - h_{4s})$$
$$= 1277.79 - (0.86)(1277.79 - 719.75)$$
$$= 797.88 \text{ kJ/kg}$$

$$q_{\text{regen}} = \varepsilon(h_4 - h_2) = (0.72)(797.88 - 586.04) = \mathbf{152.5\ kJ/kg}$$

(*b*)
$$w_{\text{net}} = w_{\text{T,out}} - w_{\text{C,in}} = (h_3 - h_4) - (h_2 - h_1)$$
$$= (1277.79 - 797.88) - (586.04 - 300.19) = 194.06 \text{ kJ/kg}$$

$$q_{\text{in}} = (h_3 - h_2) - q_{\text{regen}} = (1277.79 - 586.04) - 152.52 = 539.23 \text{ kJ/kg}$$

$$\eta_{\text{th}} = \frac{w_{\text{net}}}{q_{\text{in}}} = \frac{194.06 \text{ kJ/kg}}{539.23 \text{ kJ/kg}} = \mathbf{36.0\%}$$

9-110 A regenerative gas-turbine cycle with two stages of compression and two stages of expansion is considered. The minimum mass flow rate of air needed to develop a specified net power output is to be determined.

Assumptions **1** The air standard assumptions are applicable. **2** Air is an ideal gas with variable specific heats. **3** Kinetic and potential energy changes are negligible.

Properties The properties of air are given in Table A-17.

Analysis The mass flow rate will be a minimum when the cycle is ideal. That is, the turbine and the compressors are isentropic, the regenerator has an effectiveness of 100%, and the compression ratios across each compression or expansion stage are identical. In our case it is $r_p = \sqrt{9} = 3$. Then the work inputs to each stage of compressor are identical, so are the work outputs of each stage of the turbine.

$$T_1 = 300 \text{ K} \longrightarrow h_1 = 300.19 \text{ kJ/kg}, \quad P_{r_1} = 1.386$$

$$P_{r_2} = \frac{P_2}{P_1} P_{r_1} = (3)(1.386) = 4.158 \longrightarrow h_2 = h_4 = 411.26 \text{ kJ/kg}$$

$$T_5 = 1200 \text{ K} \longrightarrow h_5 = h_7 = 1277.79 \text{ kJ/kg}, \quad P_{r_5} = 238$$

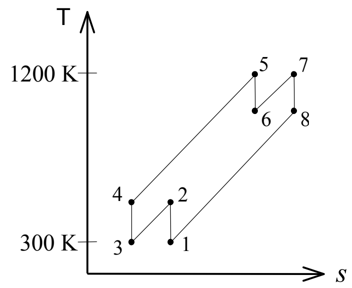
$$P_{r_6} = \frac{P_6}{P_5} P_{r_5} = \left(\frac{1}{3}\right)(238) = 79.33 \longrightarrow h_6 = h_8 = 946.36 \text{ kJ/kg}$$

$$w_{\text{C,in}} = 2(h_2 - h_1) = 2(411.26 - 300.19) = 222.14 \text{ kJ/kg}$$

$$w_{\text{T,out}} = 2(h_5 - h_6) = 2(1277.79 - 946.36) = 662.86 \text{ kJ/kg}$$

$$w_{\text{net}} = w_{\text{T,out}} - w_{\text{C,in}} = 662.86 - 222.14 = 440.72 \text{ kJ/kg}$$

$$\dot{m} = \frac{\dot{W}_{\text{net}}}{w_{\text{net}}} = \frac{110{,}000 \text{ kJ/s}}{440.72 \text{ kJ/kg}} = \mathbf{249.6 \text{ kg/s}}$$



9-111 A regenerative gas-turbine cycle with two stages of compression and two stages of expansion is considered. The minimum mass flow rate of air needed to develop a specified net power output is to be determined.

Assumptions **1** Argon is an ideal gas with constant specific heats. **2** Kinetic and potential energy changes are negligible.

Properties The properties of argon at room temperature are c_p = 0.5203 kJ/kg.K and k = 1.667 (Table A-2a).

Analysis The mass flow rate will be a minimum when the cycle is ideal. That is, the turbine and the compressors are isentropic, the regenerator has an effectiveness of 100%, and the compression ratios across each compression or expansion stage are identical. In our case it is $r_p = \sqrt{9} = 3$. Then the work inputs to each stage of compressor are identical, so are the work outputs of each stage of the turbine.

$$T_2 = T_1 \left(\frac{P_2}{P_1}\right)^{(k-1)/k} = (300 \text{ K})(3)^{0.667/1.667} = 465.6 \text{ K}$$

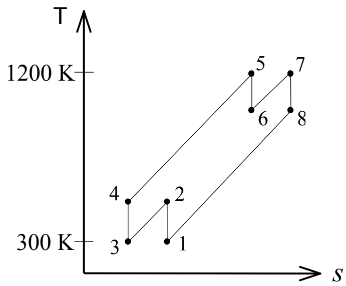
$$T_6 = T_5 \left(\frac{P_6}{P_5}\right)^{(k-1)/k} = (1200 \text{ K})\left(\frac{1}{3}\right)^{0.667/1.667} = 773.2 \text{ K}$$

$$w_{\text{C,in}} = 2(h_2 - h_1) = 2c_p(T_2 - T_1) = 2(0.5203 \text{ kJ/kg} \cdot \text{K})(465.6 - 300)\text{K} = 172.3 \text{ kJ/kg}$$

$$w_{\text{T,out}} = 2(h_5 - h_6) = 2c_p(T_5 - T_6) = 2(0.5203 \text{ kJ/kg} \cdot \text{K})(1200 - 773.2)\text{K} = 444.1 \text{ kJ/kg}$$

$$w_{\text{net}} = w_{\text{T,out}} - w_{\text{C,in}} = 444.1 - 172.3 = 271.8 \text{ kJ/kg}$$

$$\dot{m} = \frac{\dot{W}_{\text{net}}}{w_{\text{net}}} = \frac{110{,}000 \text{ kJ/s}}{271.8 \text{ kJ/kg}} = \mathbf{404.7 \text{ kg/s}}$$



10-16 A steam power plant that operates on a simple ideal Rankine cycle is considered. The quality of the steam at the turbine exit, the thermal efficiency of the cycle, and the mass flow rate of the steam are to be determined.

Assumptions **1** Steady operating conditions exist. **2** Kinetic and potential energy changes are negligible.

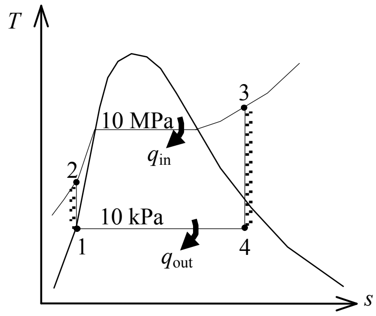
Analysis (*a*) From the steam tables (Tables A-4, A-5, and A-6),

$$h_1 = h_{f@\,10\text{ kPa}} = 191.81 \text{ kJ/kg}$$

$$v_1 = v_{f@\,10\text{ kPa}} = 0.00101 \text{ m}^3/\text{kg}$$

$$\begin{aligned} w_{p,\text{in}} &= v_1(P_2 - P_1) \\ &= (0.00101 \text{ m}^3/\text{kg})(10{,}000 - 10 \text{ kPa})\left(\frac{1 \text{ kJ}}{1 \text{ kPa}\cdot\text{m}^3}\right) \\ &= 10.09 \text{ kJ/kg} \end{aligned}$$

$$h_2 = h_1 + w_{p,\text{in}} = 191.81 + 10.09 = 201.90 \text{ kJ/kg}$$



$$\left.\begin{array}{l} P_3 = 10 \text{ MPa} \\ T_3 = 500\,^\circ\text{C} \end{array}\right\} \begin{array}{l} h_3 = 3375.1 \text{ kJ/kg} \\ s_3 = 6.5995 \text{ kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} P_4 = 10 \text{ kPa} \\ s_4 = s_3 \end{array}\right\} x_4 = \frac{s_4 - s_f}{s_{fg}} = \frac{6.5995 - 0.6492}{7.4996} = \mathbf{0.7934}$$

$$h_4 = h_f + x_4 h_{fg} = 191.81 + (0.7934)(2392.1) = 2089.7 \text{ kJ/kg}$$

(*b*)

$$q_{\text{in}} = h_3 - h_2 = 3375.1 - 201.90 = 3173.2 \text{ kJ/kg}$$

$$q_{\text{out}} = h_4 - h_1 = 2089.7 - 191.81 = 1897.9 \text{ kJ/kg}$$

$$w_{\text{net}} = q_{\text{in}} - q_{\text{out}} = 3173.2 - 1897.9 = 1275.4 \text{ kJ/kg}$$

and

$$\eta_{\text{th}} = \frac{w_{\text{net}}}{q_{\text{in}}} = \frac{1275.4 \text{ kJ/kg}}{3173.2 \text{ kJ/kg}} = \mathbf{40.2\%}$$

(*c*)

$$\dot{m} = \frac{\dot{W}_{\text{net}}}{w_{\text{net}}} = \frac{210{,}000 \text{ kJ/s}}{1275.4 \text{ kJ/kg}} = \mathbf{164.7 \text{ kg/s}}$$

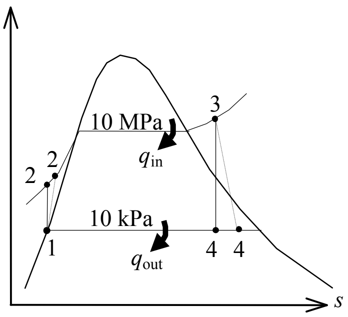
10-17 A steam power plant that operates on a simple nonideal Rankine cycle is considered. The quality of the steam at the turbine exit, the thermal efficiency of the cycle, and the mass flow rate of the steam are to be determined.

Assumptions **1** Steady operating conditions exist. **2** Kinetic and potential energy changes are negligible.

Analysis (*a*) From the steam tables (Tables A-4, A-5, and A-6),

$$h_1 = h_{f@\,10\text{ kPa}} = 191.81 \text{ kJ/kg}$$
$$v_1 = v_{f@\,10\text{ kPa}} = 0.00101 \text{ m}^3/\text{kg}$$

$$\begin{aligned} w_{p,\text{in}} &= v_1 (P_2 - P_1)/\eta_p \\ &= (0.00101 \text{ m}^3/\text{kg})(10{,}000 - 10 \text{ kPa})\left(\frac{1 \text{ kJ}}{1 \text{ kPa}\cdot\text{m}^3}\right)/(0.85) \\ &= 11.87 \text{ kJ/kg} \end{aligned}$$
$$h_2 = h_1 + w_{p,\text{in}} = 191.81 + 11.87 = 203.68 \text{ kJ/kg}$$



$$\left.\begin{aligned} P_3 &= 10 \text{ MPa} \\ T_3 &= 500\,°\text{C} \end{aligned}\right\} \begin{aligned} h_3 &= 3375.1 \text{ kJ/kg} \\ s_3 &= 6.5995 \text{ kJ/kg}\cdot\text{K} \end{aligned}$$

$$\left.\begin{aligned} P_{4s} &= 10 \text{ kPa} \\ s_{4s} &= s_3 \end{aligned}\right\} x_{4s} = \frac{s_{4s} - s_f}{s_{fg}} = \frac{6.5995 - 0.6492}{7.4996} = \mathbf{0.7934}$$
$$h_{4s} = h_f + x_4 h_{fg} = 191.81 + (0.7934)(2392.1) = 2089.7 \text{ kJ/kg}$$

$$\eta_T = \frac{h_3 - h_4}{h_3 - h_{4s}} \longrightarrow h_4 = h_3 - \eta_T(h_3 - h_{4s}) = 3375.1 - (0.85)(3375.1 - 2089.7) = 2282.5 \text{ kJ/kg}$$

$$\left.\begin{aligned} P_4 &= 10 \text{ kPa} \\ h_4 &= 2282.5 \text{ kJ/kg} \end{aligned}\right\} x_4 = \frac{h_4 - h_f}{h_{fg}} = \frac{2282.5 - 191.81}{2392.1} = \mathbf{0.874}$$

(*b*)
$$\begin{aligned} q_{\text{in}} &= h_3 - h_2 = 3375.1 - 203.68 = 3171.4 \text{ kJ/kg} \\ q_{\text{out}} &= h_4 - h_1 = 2282.5 - 191.81 = 2090.7 \text{ kJ/kg} \\ w_{\text{net}} &= q_{\text{in}} - q_{\text{out}} = 3171.4 - 2090.7 = 1080.7 \text{ kJ/kg} \end{aligned}$$

and

$$\eta_{\text{th}} = \frac{w_{\text{net}}}{q_{\text{in}}} = \frac{1080.7 \text{ kJ/kg}}{3171.5 \text{ kJ/kg}} = \mathbf{34.1\%}$$

(*c*)
$$\dot{m} = \frac{\dot{W}_{\text{net}}}{w_{\text{net}}} = \frac{210{,}000 \text{ kJ/s}}{1080.7 \text{ kJ/kg}} = \mathbf{194.3 \text{ kg/s}}$$

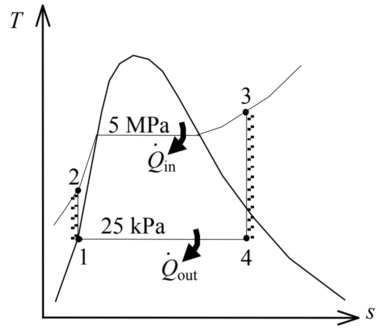
10-20 A 300-MW coal-fired steam power plant operates on a simple ideal Rankine cycle between the specified pressure limits. The overall plant efficiency and the required rate of the coal supply are to be determined.

Assumptions **1** Steady operating conditions exist. **2** Kinetic and potential energy changes are negligible.

Analysis (*a*) From the steam tables (Tables A-4, A-5, and A-6),

$$h_1 = h_{f@\ 25\ \text{kPa}} = 271.96\ \text{kJ/kg}$$
$$v_1 = v_{f@\ 25\ \text{kPa}} = 0.001020\ \text{m}^3/\text{kg}$$

$$\begin{aligned} w_{p,\text{in}} &= v_1(P_2 - P_1) \\ &= (0.00102\ \text{m}^3/\text{kg})(5000 - 25\ \text{kPa})\left(\frac{1\ \text{kJ}}{1\ \text{kPa}\cdot\text{m}^3}\right) \\ &= 5.07\ \text{kJ/kg} \end{aligned}$$
$$h_2 = h_1 + w_{p,\text{in}} = 271.96 + 5.07 = 277.03\ \text{kJ/kg}$$



$$\left.\begin{aligned} P_3 &= 5\ \text{MPa} \\ T_3 &= 450°\text{C} \end{aligned}\right\} \begin{aligned} h_3 &= 3317.2\ \text{kJ/kg} \\ s_3 &= 6.8210\ \text{kJ/kg}\cdot\text{K} \end{aligned}$$

$$\left.\begin{aligned} P_4 &= 25\ \text{kPa} \\ s_4 &= s_3 \end{aligned}\right\} x_4 = \frac{s_4 - s_f}{s_{fg}} = \frac{6.8210 - 0.8932}{6.9370} = 0.8545$$
$$h_4 = h_f + x_4 h_{fg} = 271.96 + (0.8545)(2345.5) = 2276.2\ \text{kJ/kg}$$

The thermal efficiency is determined from

$$q_{\text{in}} = h_3 - h_2 = 3317.2 - 277.03 = 3040.2\ \text{kJ/kg}$$
$$q_{\text{out}} = h_4 - h_1 = 2276.2 - 271.96 = 2004.2\ \text{kJ/kg}$$

and

$$\eta_{\text{th}} = 1 - \frac{q_{\text{out}}}{q_{\text{in}}} = 1 - \frac{2004.2}{3040.2} = 0.3407$$

Thus,

$$\eta_{\text{overall}} = \eta_{\text{th}} \times \eta_{\text{comb}} \times \eta_{\text{gen}} = (0.3407)(0.75)(0.96) = \mathbf{24.5\%}$$

(*b*) Then the required rate of coal supply becomes

$$\dot{Q}_{\text{in}} = \frac{\dot{W}_{\text{net}}}{\eta_{\text{overall}}} = \frac{300{,}000\ \text{kJ/s}}{0.2453} = 1{,}222{,}992\ \text{kJ/s}$$

and

$$\dot{m}_{\text{coal}} = \frac{\dot{Q}_{\text{in}}}{C_{\text{coal}}} = \frac{1{,}222{,}992\ \text{kJ/s}}{29{,}300\ \text{kJ/kg}}\left(\frac{1\ \text{ton}}{1000\ \text{kg}}\right) = 0.04174\ \text{tons/s} = \mathbf{150.3\ tons/h}$$

10-22 A steam power plant operates on a simple ideal Rankine cycle between the specified pressure limits. The thermal efficiency of the cycle, the mass flow rate of the steam, and the temperature rise of the cooling water are to be determined.

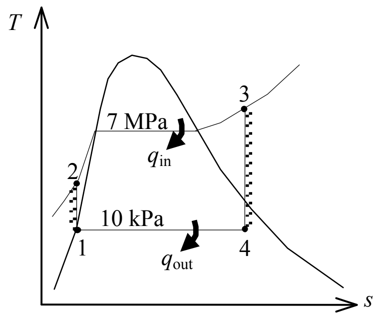
Assumptions **1** Steady operating conditions exist. **2** Kinetic and potential energy changes are negligible.

Analysis (*a*) From the steam tables (Tables A-4, A-5, and A-6),

$$h_1 = h_{f@\,10\text{ kPa}} = 191.81\text{ kJ/kg}$$

$$v_1 = v_{f@\,10\text{ kPa}} = 0.00101\ \text{m}^3/\text{kg}$$

$$w_{p,\text{in}} = v_1(P_2 - P_1) = (0.00101\ \text{m}^3/\text{kg})(7{,}000 - 10\text{ kPa})\left(\frac{1\text{ kJ}}{1\text{ kPa}\cdot\text{m}^3}\right) = 7.06\text{ kJ/kg}$$



$$h_2 = h_1 + w_{p,\text{in}} = 191.81 + 7.06 = 198.87\ \text{kJ/kg}$$

$$\left.\begin{array}{l} P_3 = 7\text{ MPa} \\ T_3 = 500°\text{C} \end{array}\right\} \begin{array}{l} h_3 = 3411.4\text{ kJ/kg} \\ s_3 = 6.8000\text{ kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} P_4 = 10\text{ kPa} \\ s_4 = s_3 \end{array}\right\} x_4 = \frac{s_4 - s_f}{s_{fg}} = \frac{6.8000 - 0.6492}{7.4996} = 0.8201$$

$$h_4 = h_f + x_4 h_{fg} = 191.81 + (0.8201)(2392.1) = 2153.6\text{ kJ/kg}$$

Thus,

$$q_\text{in} = h_3 - h_2 = 3411.4 - 198.87 = 3212.5\text{ kJ/kg}$$

$$q_\text{out} = h_4 - h_1 = 2153.6 - 191.81 = 1961.8\text{ kJ/kg}$$

$$w_\text{net} = q_\text{in} - q_\text{out} = 3212.5 - 1961.8 = 1250.7\text{ kJ/kg}$$

and

$$\eta_\text{th} = \frac{w_\text{net}}{q_\text{in}} = \frac{1250.7\text{ kJ/kg}}{3212.5\text{ kJ/kg}} = \mathbf{38.9\%}$$

(*b*)

$$\dot m = \frac{\dot W_\text{net}}{w_\text{net}} = \frac{45{,}000\text{ kJ/s}}{1250.7\text{ kJ/kg}} = \mathbf{36.0\ kg/s}$$

(*c*) The rate of heat rejection to the cooling water and its temperature rise are

$$\dot Q_\text{out} = \dot m q_\text{out} = (35.98\text{ kg/s})(1961.8\text{ kJ/kg}) = 70{,}586\ \text{kJ/s}$$

$$\Delta T_\text{coolingwater} = \frac{\dot Q_\text{out}}{(\dot m c)_\text{coolingwater}} = \frac{70{,}586\text{ kJ/s}}{(2000\text{ kg/s})(4.18\text{ kJ/kg}\cdot°\text{C})} = \mathbf{8.4°C}$$

10-23 A steam power plant operates on a simple nonideal Rankine cycle between the specified pressure limits. The thermal efficiency of the cycle, the mass flow rate of the steam, and the temperature rise of the cooling water are to be determined.

Assumptions **1** Steady operating conditions exist. **2** Kinetic and potential energy changes are negligible.

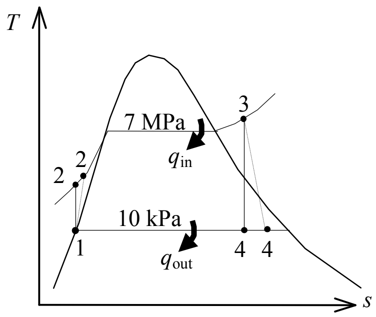
Analysis (*a*) From the steam tables (Tables A-4, A-5, and A-6),

$$h_1 = h_{f @ 10\text{ kPa}} = 191.81 \text{ kJ/kg}$$

$$v_1 = v_{f @ 10\text{ kPa}} = 0.00101 \text{ m}^3\text{/kg}$$

$$\begin{aligned} w_{p,\text{in}} &= v_1 (P_2 - P_1)/\eta_p \\ &= \left(0.00101 \text{ m}^3\text{/kg}\right)\left(7{,}000 - 10 \text{ kPa}\right)\left(\frac{1 \text{ kJ}}{1 \text{ kPa}\cdot\text{m}^3}\right)/(0.87) \\ &= 8.11 \text{ kJ/kg} \end{aligned}$$

$$h_2 = h_1 + w_{p,\text{in}} = 191.81 + 8.11 = 199.92 \text{ kJ/kg}$$



$$\left.\begin{array}{l} P_3 = 7 \text{ MPa} \\ T_3 = 500°\text{C} \end{array}\right\} \begin{array}{l} h_3 = 3411.4 \text{ kJ/kg} \\ s_3 = 6.8000 \text{ kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} P_4 = 10 \text{ kPa} \\ s_4 = s_3 \end{array}\right\} x_4 = \frac{s_4 - s_f}{s_{fg}} = \frac{6.8000 - 0.6492}{7.4996} = 0.8201$$

$$h_{4s} = h_f + x_4 h_{fg} = 191.81 + (0.820)(2392.1) = 2153.6 \text{ kJ/kg}$$

$$\eta_T = \frac{h_3 - h_4}{h_3 - h_{4s}} \longrightarrow h_4 = h_3 - \eta_T (h_3 - h_{4s}) = 3411.4 - (0.87)(3411.4 - 2153.6) = 2317.1 \text{ kJ/kg}$$

Thus,

$$q_{\text{in}} = h_3 - h_2 = 3411.4 - 199.92 = 3211.5 \text{ kJ/kg}$$

$$q_{\text{out}} = h_4 - h_1 = 2317.1 - 191.81 = 2125.3 \text{ kJ/kg}$$

$$w_{\text{net}} = q_{\text{in}} - q_{\text{out}} = 3211.5 - 2125.3 = 1086.2 \text{ kJ/kg}$$

and

$$\eta_{\text{th}} = \frac{w_{\text{net}}}{q_{\text{in}}} = \frac{1086.2 \text{ kJ/kg}}{3211.5 \text{ kJ/kg}} = \mathbf{33.8\%}$$

(*b*)

$$\dot{m} = \frac{\dot{W}_{\text{net}}}{w_{\text{net}}} = \frac{45{,}000 \text{ kJ/s}}{1086.2 \text{ kJ/kg}} = \mathbf{41.43 \text{ kg/s}}$$

(*c*) The rate of heat rejection to the cooling water and its temperature rise are

$$\dot{Q}_{\text{out}} = \dot{m} q_{\text{out}} = (41.43 \text{ kg/s})(2125.3 \text{ kJ/kg}) = 88{,}051 \text{ kJ/s}$$

$$\Delta T_{\text{cooling water}} = \frac{\dot{Q}_{\text{out}}}{(\dot{m}c)_{\text{cooling water}}} = \frac{88{,}051 \text{ kJ/s}}{(2000 \text{ kg/s})(4.18 \text{ kJ/kg}\cdot°\text{C})} = \mathbf{10.5°C}$$