HW9.2

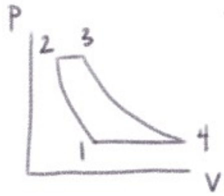
Tuesday, October 24, 2023 1:34 PM

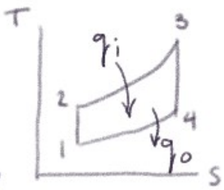
Chapter 9:

Problems: 32, 45, 55, 57 and 66.

9.32 WP Air enters the compressor of an ideal cold air-standard Brayton cycle at 100 kPa, 300 K, with a mass flow rate of 6 kg/s. The compressor pressure ratio is 10, and the turbine inlet temperature is 1400 K. For k = 1.4, calculate

a. the thermal efficiency of the cycle.
b. the back work ratio.
c. the net power developed, in kW.





① $P_1 = 100$ KPa $P_2/P_1 = 10$
$T_1 = 300$ K
$\dot{m} = 6$ Kg/s $K = 1.4 = C_p/C_v$

③ $T_3 = 1400$K

TA22 @ 300K $\longrightarrow$ $h_1 = 300.19$ KJ/Kg

$$T_2 = T_1\left(\frac{P_2}{P_1}\right)^{K-1/K} = (300)(10)^{(1.4)-1/(1.4)} = 579.21\,K$$

TA22 @ 579.21K $\longrightarrow$ $h_2 = 586.04$ KJ/Kg

TA22 @ 1400K $\longrightarrow$ $h_3 = 1515.42$ KJ/Kg

$$T_4 = T_3\left(\frac{P_4}{P_3}\right)^{K-1/K} = (1400)(1/10)^{(1.4)-1/(1.4)} = 725.13\,K$$

TA22 @ 725.13 $\longrightarrow$ $h_4 \approx 740$ KJ/Kg

$$\eta_{TH} = \frac{\dot{W}_{net}}{q_{in}} = \frac{(h_3-h_4)-(h_2-h_1)}{h_3-h_2}$$

$$\eta_{TH} = \frac{(1515.42-740)-(586.04-300.19)}{(1515.42-586.04)} = 52.7\% = \eta_{TH}$$

$$BWR = \frac{W_i}{W_0} = \frac{h_2-h_1}{h_3-h_4}$$

$$BWR = \frac{(586.04)-(300.19)}{(1515.42)-(740)} = 0.369 = BWR$$

$$W_{cyl} = \dot{m}(W_0 - W_i) = \dot{m}[(h_3-h_4)-(h_2-h_1)]$$

$$W_{cyl} = (6)[(1515.42-740)-(586.04-300.19)] = 2937.42\text{ KW} = W_{cyl}$$

9.45 WP Air enters the compressor of a regenerative air-standard Brayton cycle with a volumetric flow rate of 60 m³/s at 0.8 bar, 280 K. The compressor pressure ratio is 20, and the maximum cycle temperature is 2100 K. For the compressor, the isentropic efficiency is 92% and for the turbine the isentropic efficiency is 95%. For a regenerator effectiveness of 85%, determine

a. the net power developed, in MW.
b. the rate of heat addition in the combustor, in MW.
c. the thermal efficiency of the cycle.
~~d. C Plot the quantities calculated in parts (a) through (c) for regenerator effectiveness values ranging from 0 to 100%. Discuss.~~

$$\eta_c = 0.92 = \frac{W_c}{W_{cs}} = \frac{h_1-h_2}{h_1-h_{2s}}$$

$$\eta_T = 0.95 = \frac{W_T}{W_{Ts}} = \frac{h_4-h_3}{h_4-h_{3s}}$$

$$\eta_{Reg} = 0.85 = \frac{h_x-h_2}{h_4-h_2}$$

TA22 @ 280K $\longrightarrow$ $h_1 = 280.13$ KJ/Kg
$pr_1 = 1.0889$

$$Pr_2 = Pr_1\left(\frac{P_2}{P_1}\right) = (1.0889)(20) = 21.778$$

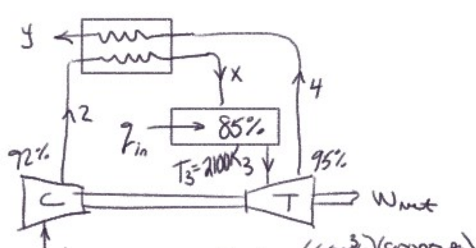
$\hookrightarrow$ TA22 $\longrightarrow$ $T_2 \approx 650$K
$h_{2s} \approx 659.84$ KJ/Kg
$h_2 = 0.92(657.84) = 603.05$

TA22 @ T=1300K $\longrightarrow$ $h_3 = 1395.97$ KJ/Kg
$Pr_3 = 330.9$

$$Pr_4 = Pr_3\left(\frac{P_4}{P_3}\right) = 330.9(1/20) = 16.545$$

$\hookrightarrow$ TA22 $\longrightarrow$ $T_4 \approx 600$K
$h_{4s} \approx 607.02$ KJ/Kg
$h_4 = 0.95(607.02) = 579.67$ KJ/Kg

$h_x = (h_4 - h_2)0.85 + h_2 = 583.18$ KJ/Kg



$P_1 = 0.8$ bar $\dot{V} = 60$ m³/s
$T_1 = 280$K $\frac{P_4}{P_1} = 20$

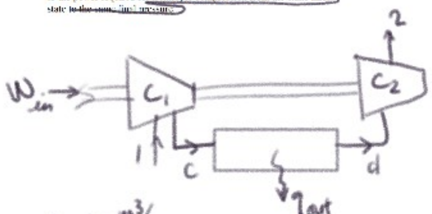
$$\dot{m} = \frac{(60\,m^3/s)(80000\,Pa)}{\left(\frac{8314\,N\cdot m}{28.97\,Kg\cdot K}\right)(280K)} = 59.73\,Kg/s$$

$$W_{net} = \dot{W}_T - \dot{W}_c = \dot{m}[(h_3-h_4)-(h_2-h_1)] = 29470.78\,KW$$

$$q_{in} = \dot{m}(h_3 - h_x) = 48548.13\,KW$$

$$\eta_{TH} = \frac{W_{net}}{q_{in}} = 60.7\%$$

9.55 A two-stage air compressor operates at steady state, compressing 10 m³/min of air from 100 kPa, 300 K, to 1200 kPa. An intercooler between the two stages cools the air to 300 K at a constant pressure of 350 kPa. The compression processes are isentropic. Calculate the power required to run the compressor, in kW, and compare the result to the power required for isentropic compression from the same inlet state to the same final pressure.



$\dot{V}_1 = 600 \, m^3/s$

$P_1 = 100$ KPa $\quad P_c = P_d = 350$ KPa $\quad P_2 = 1200$ KPa

$T_1 = 300$K $\quad T_d = 300$K

$$\dot{m} = \frac{(600 \, m^3/s)(100000 \, Pa)}{\left(\frac{8314 \, N \cdot m}{28.97 \, Kg \cdot K}\right)(300 \, K)} = 686.89 \, Kg/s$$

TA22 @ $T_1 = 300K \rightarrow h_1 = 300.19$

$Pr_1 = 1.3860$

$$Pr_c = Pr_1\left(\frac{P_c}{P_1}\right) = (1.3860)\left(\frac{350}{100}\right) = 4.851$$

$\hookrightarrow$ TA22 @ $Pr_1 = 4.851 \longrightarrow T_c \approx 428$ K

$h_c = 429$ KJ/Kg

TA22 @ $T_d = 300K \longrightarrow h_d = 300.19$ KJ/Kg

$Pr_d = 1.3860$

$$Pr_4 = Pr_d\left(\frac{P_4}{P_d}\right) = (1.3860)\left(\frac{1200}{350}\right) = 4.752$$

$\hookrightarrow$ TA22 @ $Pr_4 = 4.752 \longrightarrow T_4 = 425.85$ K

$h_2 = 427.5$ KJ/Kg

$$\dot{W}_{in} = \dot{m}\left[(h_c - h_1) + (h_2 - h_d)\right] = 178489.2 \text{ KW}$$

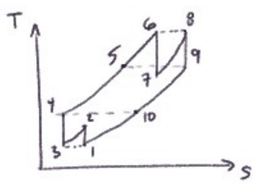
9.57 WP An air-standard regenerative Brayton cycle operating at steady state with intercooling and reheat produces 10 MW of power. Operating data at principal states in the cycle are given in the table below. The states are numbered as in Fig. 9.19. Sketch the T–s diagram for the cycle and determine

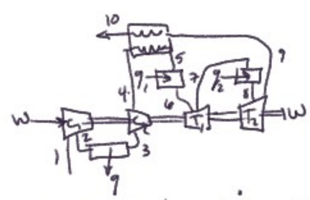
a. the mass flow rate of air, in kg/s.

b. the rate of heat transfer, in kW, to the working fluid passing through each combustor.

c. the thermal efficiency.

State	p (kPa)	T (K)	h (kJ/kg)
1	100	300	300.19
2	300	410.1	411.22
3	300	300	300.19
4	1200	444.8	446.50
5	1200	1111.0	1173.84
6	1200	1450	1575.57
7	300	1034.3	1085.31
8	300	1450	1575.57
9	100	1111.0	1173.84
10	100	444.8	446.50





$Q_{cv} + \dot{m}h_i = \dot{m}h_o + W_{cv}$

$$\begin{cases} \dot{W}_{T_1} = h_6 - h_7 \\ \dot{W}_{T_2} = h_8 - h_9 \end{cases} \quad \begin{cases} \dot{W}_{C_1} = h_2 - h_1 \\ \dot{W}_{C_2} = h_4 - h_3 \end{cases} \quad \begin{cases} \dot{q}_{in_1} = h_6 - h_5 \\ \dot{q}_{in_2} = h_8 - h_7 \end{cases}$$

$$W_{net} = 10 \text{ MW} = \dot{m}\frac{W_T - W_c}{q_{in}}$$

$$\hookrightarrow \dot{m} = (10 \times 10^6)\frac{(1575.57 - 1173.84) + (1575.57 - 1085.31)}{\left[(1575.57 - 1085.31) + (1575.57 - 1173.84)\right] - \left[(411.22 - 300.19) + (446.5 - 300.19)\right]}$$

```
jakob@JW-MACHINE ~/software/TU/23FL/Adv_Thermo (main)
λ python HW9.57.py
[ 300.19  411.22  300.19  446.5   1173.84 1575.57 1085.31 1575.57 1173.84
  446.5 ]
m_dot =  14054833.372725125
jakob@JW-MACHINE ~/software/TU/23FL/Adv_Thermo (main)
λ
```

HW9.57.py

```python
import math
import numpy as np

W_net = 10e6
hh = np.array([300.19, 411.22, 300.19, 446.50, 1173.84, 1575.57, 1085.31,

W_T = (hh[5] - hh[6]) + (hh[7] - hh[8])
W_C = (hh[1] - hh[0]) + (hh[3] - hh[2])
q_in = (hh[5] - hh[4]) + (hh[7] - hh[6])

m_dot = W_net * q_in / (W_T - W_C)

print(hh)
print('m_dot = ', m_dot)
```

9.66 WP A combined gas turbine–vapor power plant operates as shown in Fig. P9.66. Pressure and temperature data are given at principal states, and the net power developed by the gas turbine is 147 MW. Using air-standard analysis for the gas turbine, determine

a. the net power, in MW, developed by the power plant.

b. the overall thermal efficiency of the plant.

Stray heat transfer and kinetic and potential energy effects can be ignored.

HW9.66.py

```python
import math
import numpy as np
```

shown in Fig. P9.66. Pressure and temperature data are given at principal states, and the net power developed by the gas turbine is 147 MW. Using air-standard analysis for the gas turbine, determine

a. the net power, in MW, developed by the power plant.

b. the overall thermal efficiency of the plant.

Stray heat transfer and kinetic and potential energy effects can be ignored.

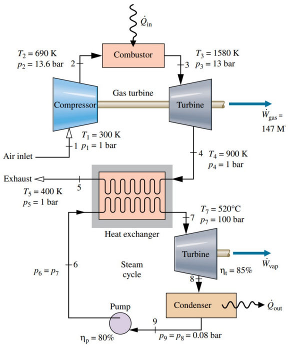


FIGURE P9.66

HW9.66.py

```python
import math
import numpy as np

W_net = 10e6
hh = np.array([300.19, 411.22, 300.19, 446.50, 1173.84, 1575.57, 1085.31, 

W_T = (hh[2] - hh[3]) + 0.85*(hh[6] - hh[7])
W_C = (hh[1] - hh[0])
W_P = 0.8*(hh[5]-hh[8])
q_in = (hh[5] - hh[4]) + (hh[7] - hh[6])

m_dot = W_net * q_in / (W_T - W_C)

print(hh)
print('m_dot = ', m_dot)
```