Fundamentals of Engineering Thermodynamics, 8th ed.
Problem set 12 corresponding to HW12

9.42 An ideal air-standard Brayton cycle operating at steady state 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. 9.9. 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 the heat exchanger.
(c) the thermal efficiency.

<table>
<thead>
<tr>
<th>State</th>
<th>$p$ (kPa)</th>
<th>$T$ (K)</th>
<th>$h$ (kJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100</td>
<td>300</td>
<td>300.19</td>
</tr>
<tr>
<td>2</td>
<td>1200</td>
<td>603.5</td>
<td>610.65</td>
</tr>
<tr>
<td>3</td>
<td>1200</td>
<td>1450</td>
<td>1575.57</td>
</tr>
<tr>
<td>4</td>
<td>100</td>
<td>780.7</td>
<td>800.78</td>
</tr>
</tbody>
</table>

9.46 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.

9.47 For the Brayton cycle of Problem 9.46, investigate the effects of varying compressor pressure ratio and turbine inlet temperature. Plot the same quantities calculated in Problem 9.46 for

(a) a compressor pressure ratio of 10 and turbine inlet temperatures ranging from 1000 to 1600 K.
(b) a turbine inlet temperature of 1400 K and compressor pressure ratios ranging from 2 to 20. Discuss.
9.55 Air enters the compressor of a simple gas turbine at $p_1 = 14$ lbf/in.$^2$, $T_1 = 520^\circ$R, and a volumetric flow rate of 10,000 ft$^3$/min. The isentropic efficiencies of the compressor and turbine are 83 and 87\%, respectively. The compressor pressure ratio is 14 and the temperature at the turbine inlet is 2500$^\circ$R. On the basis of an air-standard analysis, calculate

(a) the thermal efficiency of the cycle.
(b) the net power developed, in hp.
(c) the rates at which entropy is produced within the compressor and turbine, each in hp/$^\circ$R.

9.56 Solve Problem 9.55 on a cold air-standard basis with specific heats evaluated at 520$^\circ$R.

9.58 Air enters the compressor of a simple gas turbine at 14.5 lbf/in.$^2$, 80$^\circ$F, and exits at 87 lbf/in.$^2$, 514$^\circ$F. The air enters the turbine at 1540$^\circ$F, 87 lbf/in.$^2$ and expands to 917$^\circ$F, 14.5 lbf/in.$^2$. The compressor and turbine operate adiabatically, and kinetic and potential energy effects are negligible. On the basis of an air-standard analysis,

(a) develop a full accounting of the net exergy increase of the air passing through the gas turbine combustor, in Btu/lb.
(b) devise and evaluate an exergetic efficiency for the gas turbine cycle.

Let $T_0 = 80^\circ$F, $p_0 = 14.5$ lbf/in.$^2$. 
9.67 An air-standard Brayton cycle has a compressor pressure ratio of 10. Air enters the compressor at \( p_1 = 14.7 \text{ lbf/in}^2 \), \( T_1 = 70^\circ\text{F} \) with a mass flow rate of 90,000 lb/h. The turbine inlet temperature is 2200\(^\circ\text{R} \). Calculate the thermal efficiency and the net power developed, in horsepower, if

(a) the turbine and compressor isentropic efficiencies are each 100%.

(b) the turbine and compressor isentropic efficiencies are 88 and 84%, respectively.

(c) the turbine and compressor isentropic efficiencies are 88 and 84%, respectively, and a regenerator with an effectiveness of 80% is incorporated.

9.76 Air enters a two-stage compressor operating at steady state at 1 bar, 290 K. The overall pressure ratio across the stages is 16 and each stage operates isentropically. Intercooling occurs at the pressure that minimizes total compressor work, as determined in Example 9.10. Air exits the intercooler at 290 K. Assuming ideal gas behavior with \( k = 1.4 \), determine

(a) the intercooler pressure, in bar, and the heat transfer, in kJ per kg of air flowing.

(b) the work required for each compressor stage, in kJ per kg of air flowing.
9.85 Air at 26 kPa, 230 K, and 220 m/s enters a turbojet engine in flight. The air mass flow rate is 25 kg/s. The compressor pressure ratio is 11, the turbine inlet temperature is 1400 K, and air exits the nozzle at 26 kPa. The diffuser and nozzle processes are isentropic, the compressor and turbine have isentropic efficiencies of 85% and 90%, respectively, and there is no pressure drop for flow through the combustor. Kinetic energy is negligible everywhere except at the diffuser inlet and the nozzle exit. On the basis of air-standard analysis, determine

(a) the pressures, in kPa, and temperatures, in K, at each principal state.
(b) the rate of heat addition to the air passing through the combustor, in kJ/s.
(c) the velocity at the nozzle exit, in m/s.

9.88 Consider the addition of an afterburner to the turbojet in Problem 9.85 that raises the temperature at the inlet of the nozzle to 1300 K. Determine the velocity at the nozzle exit, in m/s.