Simple Brayton, Gas Turbine, Cycle

![Diagram of Brayton cycle]

Compressor, Combustion, and Turbine are Open Thermodynamic Systems

Steady Flow Energy Equation Form of First Law

\[ Q = \Delta(h + KE) + W_{\text{net}} \]
Propulsion Gas Turbine
Furnas Hall  J79-GE-8A Turbojet Engine  
Compressor (right end), Combustor (red) Turbine (left end)
Furnas Hall  J79-GE-8A Turbojet Engine
Combustor (red) and Turbine Stages
Aero-derivative Gas Turbine

\[ Q_{\text{in}} \]

\[ W = W \]

compressor
turbine

Gas Generator

Power Turbine

net output
Brayton Cycle with Real Compression and Expansion

Turbine Efficiency
\[ \eta_t = \frac{\text{actual work}}{\text{isentropic work}} \]
\[ \eta_t = \frac{h_3 - h_4}{h_3 - h_{4s}} \]

Compressor Efficiency
\[ \eta_c = \frac{\text{isentropic work}}{\text{actual work}} \]
\[ \eta_c = \frac{h_{2s} - h_1}{h_2 - h_1} \]
**Brayton Air Standard Cycle**

Steady Flow, Open System - region in space

**Steady Flow Energy Equation**

\[ Q = m \times \Delta(u + pv + \frac{V^2}{2} + \rho gh) + W_{\text{shaft}} \]

Compression Process, \( Q = 0, \ W = m(h_2 - h_1) \)

Combustion Process, \( W = 0, \ Q = m(h_3 - h_2) \)

Expansion Process, \( Q = 0, \ W = m(h_3 - h_4) \)

Exhaust Process, \( W = 0, \ Q = m(h_4 - h_1) \)
In an air COLD standard gas turbine, 60°F and 14.7 psia air is compressed through a pressure ratio of 10. Air enters at 1540°F and expands to 14.7 psia. If the isentropic efficiency of the compressor and turbine are 83% and 93% respectively. What is the thermal efficiency of the cycle?

\[
T_{2i} = T_i \left( \frac{p_2}{p_1} \right)^{\frac{k-1}{k}} = (460 + 60) \times 10^{2857} = 1003.9°F
\]

\[
\eta_{compressor} = \frac{W_{ideal}}{W_{actual}} = \frac{h_{2is} - h_1}{h_2 - h_1} = \frac{c_p(T_{2is} - T_1)}{c_p(T_2 - T_1)} = .83
\]

\[
T_2 = T_1 + \frac{T_{2is} - T_1}{.83} = 520 + \frac{1003.9 - 520}{.83} = 1103.0°F
\]

\[
q_{2-3} = h_3 - h_2 = c_p(T_3 - T_2)
\]

\[
q_{2-3} = .24l(2000 - 1103.01) = 215.26 BTU/lb
\]

\[
w_{1-2} = h_2 - h_1
\]

\[
w_{1-2} = c_p(T_2 - T_1) = .24l(1103.01 - 520) = 139.92 BTU/lb
\]

\[
T_{4i} = T_3 \left( \frac{p_4}{p_3} \right)^{\frac{k-1}{k}} = 2000 \times \left( \frac{1}{10} \right)^{2857} = 1035.9°F
\]

\[
\eta_{turbine} = \frac{w_{actual}}{w_{ideal}} = \frac{h_3 - h_4}{h_3 - h_{4is}} = \frac{c_p(T_3 - T_4)}{c_p(T_3 - T_{4is})} = 1959.7 - 1029.5 = .93
\]

\[
T_4 = T_3 - .92 \times (T_3 - T_{4is}) = 2000 - .93 \times (2000 - 1035.9) = 1113.03°F
\]

\[
w_{3-4} = h_3 - h_4 = .24l(2000 - 1110.03) = 213.59 BTU/lb
\]

\[
q_{4-1} = h_4 - h_1 = .24l(T_4 - T_1) = .24l(1113.03 - 520) = 142.33 BTU/lb
\]

\[
\eta_{cycle} = 1 - \frac{h_4 - h_1}{h_3 - h_2} = 1 - \frac{1113.03 - 520}{2000 - 1103.01} = 33.9%
\]

\[
\eta_{cycle} = \frac{w_{net}}{q_{in}} = \frac{215.26 - 139.92}{215.26} = 33.9%
\]
In an air standard gas turbine, 60°F and 14.7 psia air is compressed through a pressure ratio of 10. Air enters at 1540°F and expands to 14.7 psia. If the isentropic efficiency of the compressor and turbine are 83% and 93% respectively. What is the thermal efficiency of the cycle?

At 520°F, \( p_{r1} = 1.2147, \ h_1 = 124.27 \) BTU/lb

\[
p_{r2is} = p_{r1} \left( \frac{p_{2is}}{p_1} \right) = 1.2147 \times 10 = 12.147
\]

\( h_{2is} = 240.48 \) BTU/lb

\[
\eta_{compressor} = \frac{W_{ideal}}{W_{actual}} = \frac{h_{2is} - h_1}{h_2 - h_1} = .83
\]

\( h_2 = h_1 + \frac{h_{2is} - h_1}{.83} = 124.27 + \frac{240.48 - 124.27}{.83} \)

\( h_2 = 264.28 \) BTU/lb

At 2000°F, \( p_{r3} = 174, \ h_3 = 504.71 \)

\[
p_{r4is} = p_{r3} \left( \frac{p_{4is}}{p_1} \right) = 174 \times 1/10 = 17.4
\]

by interpolation at \( p_{r4is} = 1.74, \ h_{4is} = 265.99 \) BTU/lb

\[
\eta_{turbine} = \frac{W_{actual}}{W_{ideal}} = \frac{h_3 - h_4}{h_3 - h_{4i}} = .93
\]

\( h_4 = h_3 - .92 \times (h_3 - h_{4is}) = 282.7 \) BTU/lb

\[
q_{in} = h_3 - h_2 = 504.7 - 264.28 = 240.42 \) BTU/lb

\[
q_{out} = h_4 - h_1 = 282.7 - 124.27 = 155.43 \) BTU/lb

\[
\eta = 1 - \frac{Q_{in}}{Q_{out}} = 1 - \frac{155.43}{240.42} = 35.3\%
\]