Engineering Software

P.O. Box 2134
Kensington, MD 20891
Phone: (301) 919-9670
E-Mail: info@engineering-4e.com
http://www.engineering-4e.com

Power Cycles Analysis with Plots

In this power cycles analysis, the engineering students and professionals get familiar with the ideal simple and basic power cycles and their T - s, p - V and h - T diagrams, operation and major performance trends when air is considered as the working fluid.

Performance Objectives:

Introduce basic energy conversion engineering assumptions and equations

Know basic elements of Carnot Cycle, Brayton Cycle, Otto Cycle and Diesel Cycle and their T - s, p - V and h - T diagrams

Be familiar with Carnot Cycle, Brayton Cycle, Otto Cycle and Diesel Cycle operation

Understand general Carnot Cycle, Brayton Cycle, Otto Cycle and Diesel Cycle performance trends

Engineering Assumptions

The power cycles analysis presented in this material considers ideal (isentropic) operation and the working fluid is air. Furthermore, the following assumptions are valid:

Power Cycles

Single species consideration -- fuel mass flow rate is ignored and its impact on the properties of the working fluid

Basic equations hold (continuity, momentum and energy equations)

Specific heat is constant

Power Cycle Components/Processes

Single species consideration

Basic equations hold (continuity, momentum and energy equations)

Specific heat is constant

Basic Conservation Equations

Continuity Equation

$m = \rho v A$ [kg/s]

Momentum Equation

$F = (vm + pA)_{out - in}$ [N]

Energy Equation

$Q - W = ((h + v^2/2 + gh)m)_{out - in}$ [kW]

Basic Engineering Equations

Ideal Gas State Equation

$pv = RT$ [kJ/kg]

Perfect Gas

c_p = constant [kJ/kg*K]

Kappa

$\chi = c_p/c_v$ [/]

For air: χ = 1.4 [/], R = 0.2867 [kJ/kg*K] and

c_p = 1.004 [kJ/kg*K]

Power Cycles Engineering Equations

Cycle Efficiency

$$\eta = W_{net}/Q \text{ [/]}$$

Heat Rate

$$HR = (1/\eta)3{,}412 \text{ [Btu/kWh]}$$

Carnot Cycle Efficiency

$$\eta = 1 - T_R/T_A$$

Brayton Cycle Efficiency

$$\eta = 1 - 1/r_p^{(\chi-1)/\chi}$$

Otto Cycle Efficiency

$$\eta = 1 - 1/\varepsilon^{(\chi-1)}$$

Diesel Cycle Efficiency

$$\eta = 1 - (\phi^{\chi}-1)/\left(\chi\varepsilon^{(\chi-1)}(\phi-1)\right)$$

$$r_p = p_2/p_1 \text{ [/]};\ \varepsilon = V_1/V_2 \text{ [/]};\ \phi = V_3/V_2 \text{ [/]}$$

Power Cycles Engineering Equations

Brayton Cycle

$$w_{net} = q_h - q_l = c_p(T_3 - T_2) - c_p(T_4 - T_1) \text{ [kJ/kg]}$$

$$W_{net} = w_{net}m \text{ [kW]}$$

Otto Cycle

$$w_{net} = q_h - q_l = c_v(T_3 - T_2) - c_v(T_4 - T_1) \text{ [kJ/kg]}$$

$$W_{net} = w_{net}m \text{ [kW]}$$

Diesel Cycle

$$w_{net} = q_h - q_l = c_p(T_3 - T_2) - c_v(T_4 - T_1) \text{ [kJ/kg]}$$

$$W_{net} = w_{net}m \text{ [kW]}$$

Power Cycle Components/Processes Engineering Equations

Isentropic Compression

$$T_2/T_1 = (p_2/p_1)^{(X-1)/X} \ [/]$$

$$T_2/T_1 = (V_1/V_2)^{(X-1)} \ [/]$$

$$p_2/p_1 = (V_1/V_2)^{X} \ [/]$$

$$w_c = c_p(T_2 - T_1) \ [kJ/kg]$$

$$W_c = c_p(T_2 - T_1)m \ [kW]$$

Power Cycle Components/Processes Engineering Equations

Isentropic Expansion

$$T_1/T_2 = (p_1/p_2)^{(X-1)/X} \ [/]$$

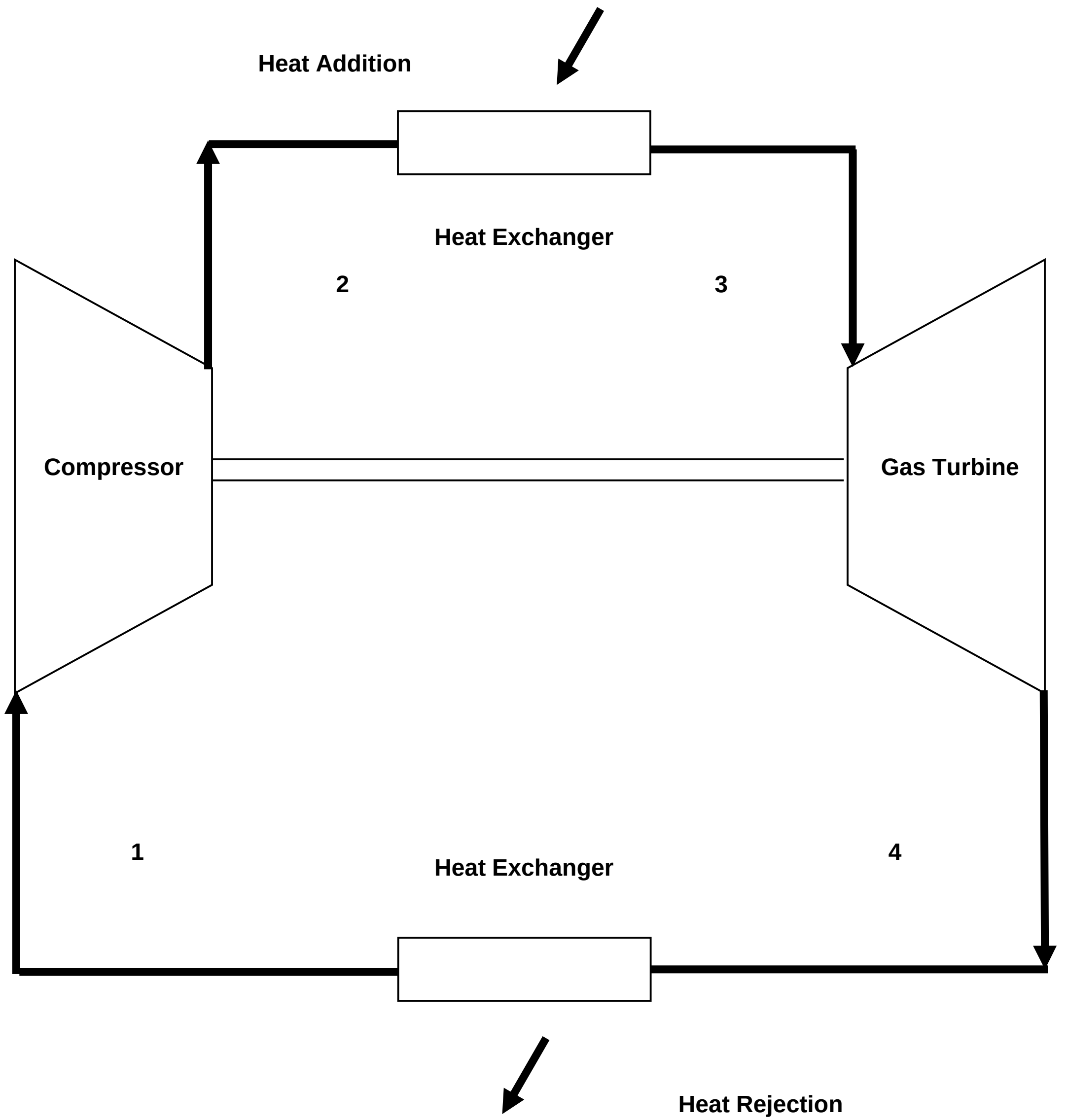
$$T_1/T_2 = (V_2/V_1)^{(X-1)} \ [/]$$

$$p_1/p_2 = (V_2/V_1)^{X} \ [/]$$

$$w_e = c_p(T_1 - T_2) \ [kJ/kg]$$

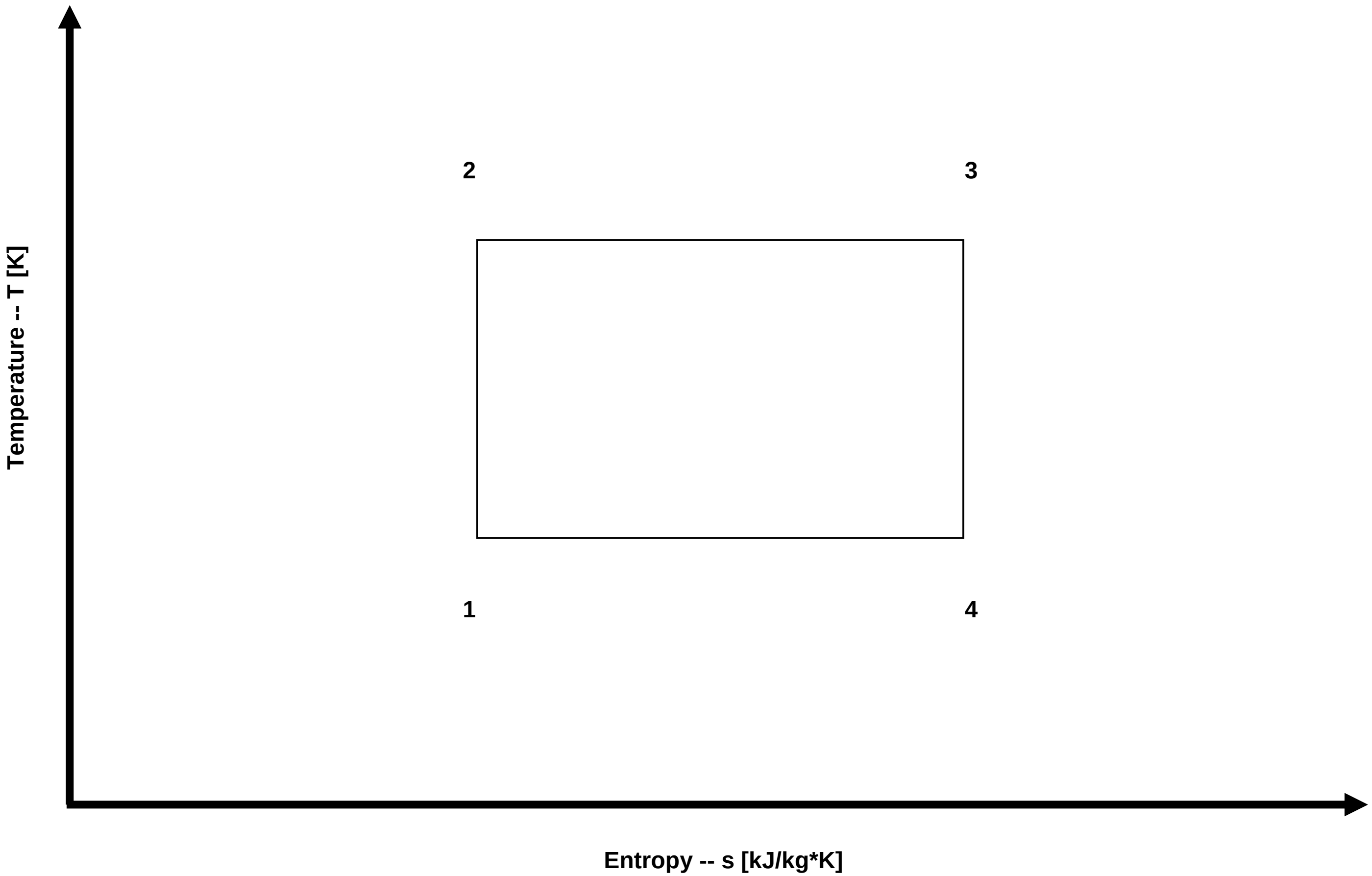
$$W_e = c_p(T_1 - T_2)m \ [kW]$$

Carnot Cycle



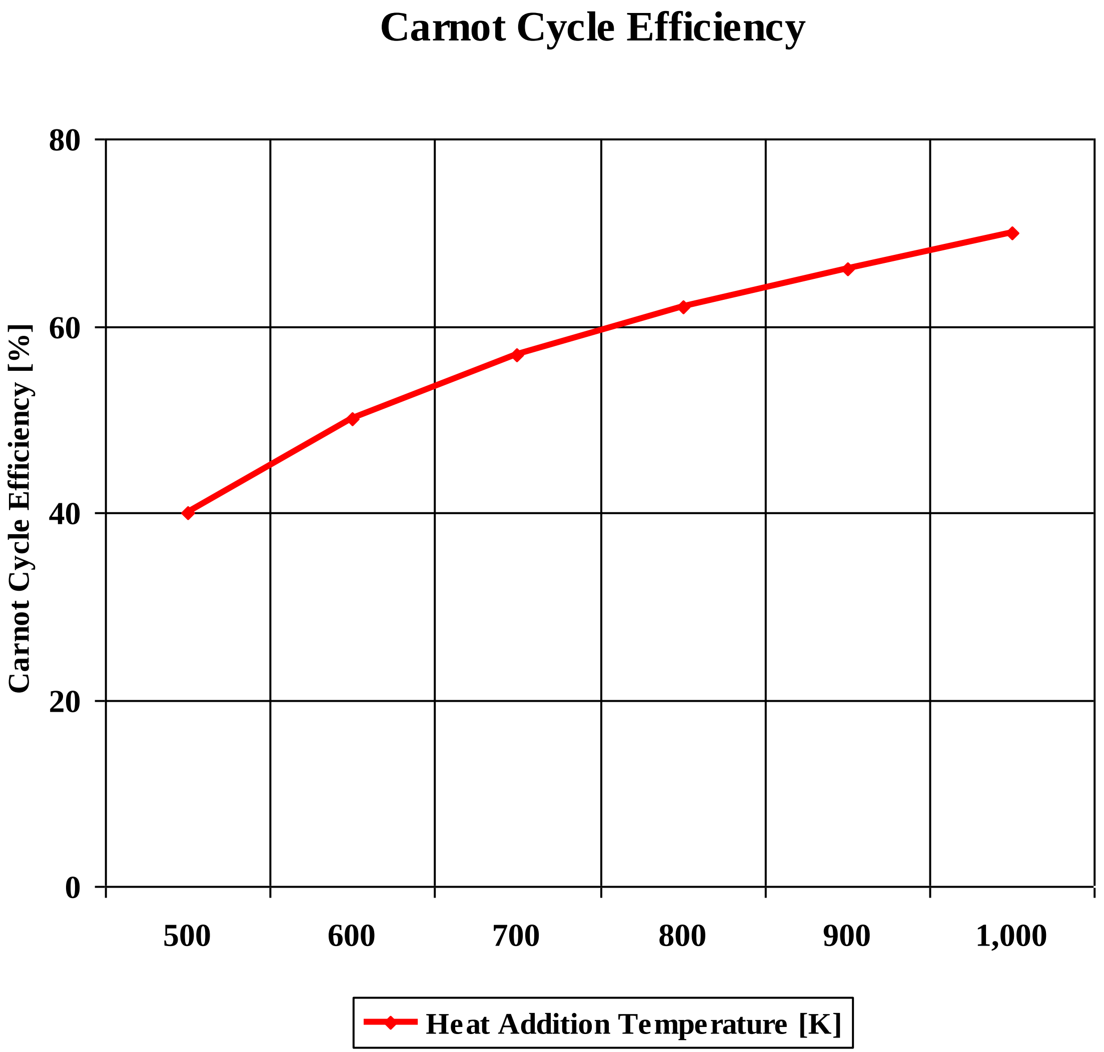
Carnot Cycle Schematic Layout

Carnot Cycle



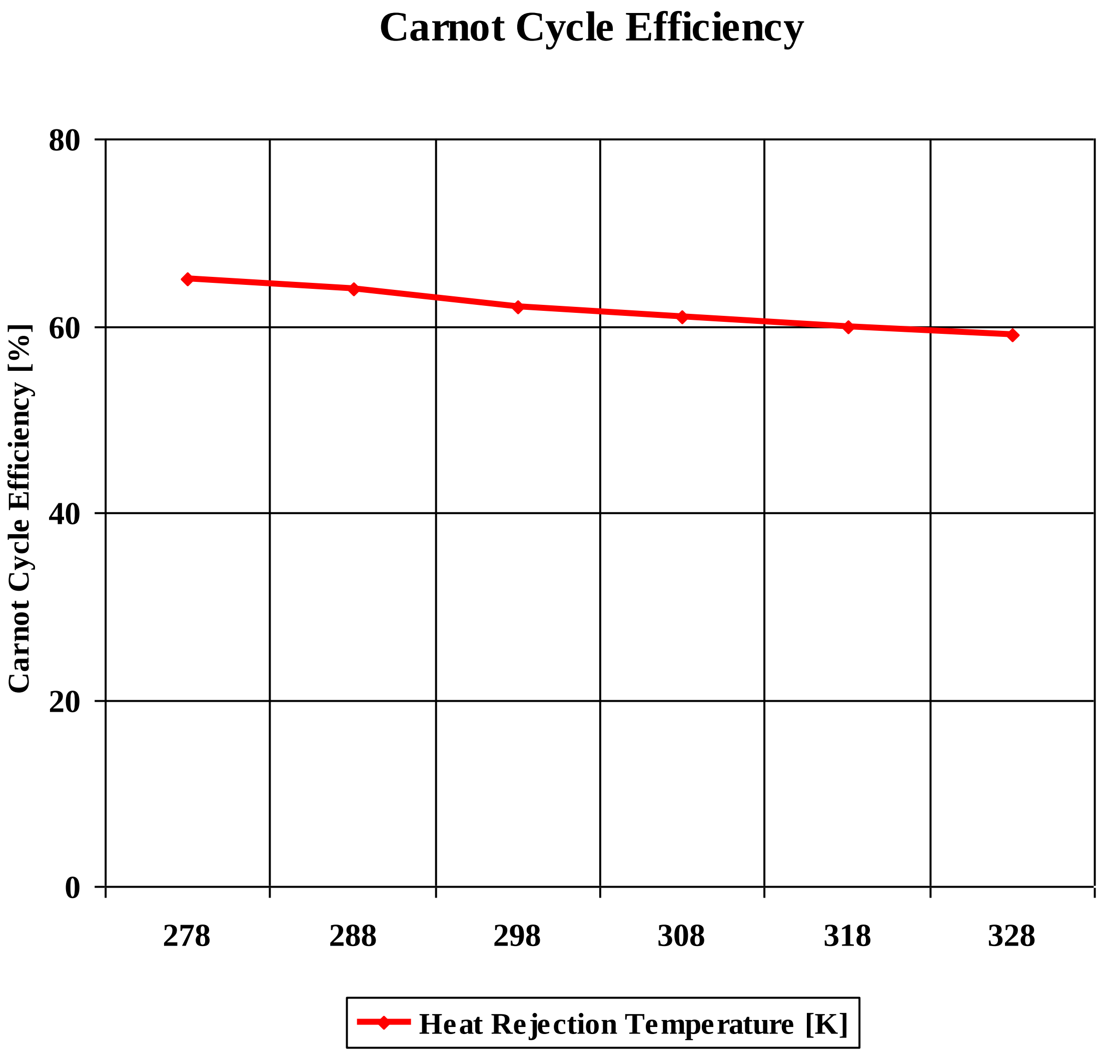
Carnot Cycle T - s Diagram

Carnot Cycle



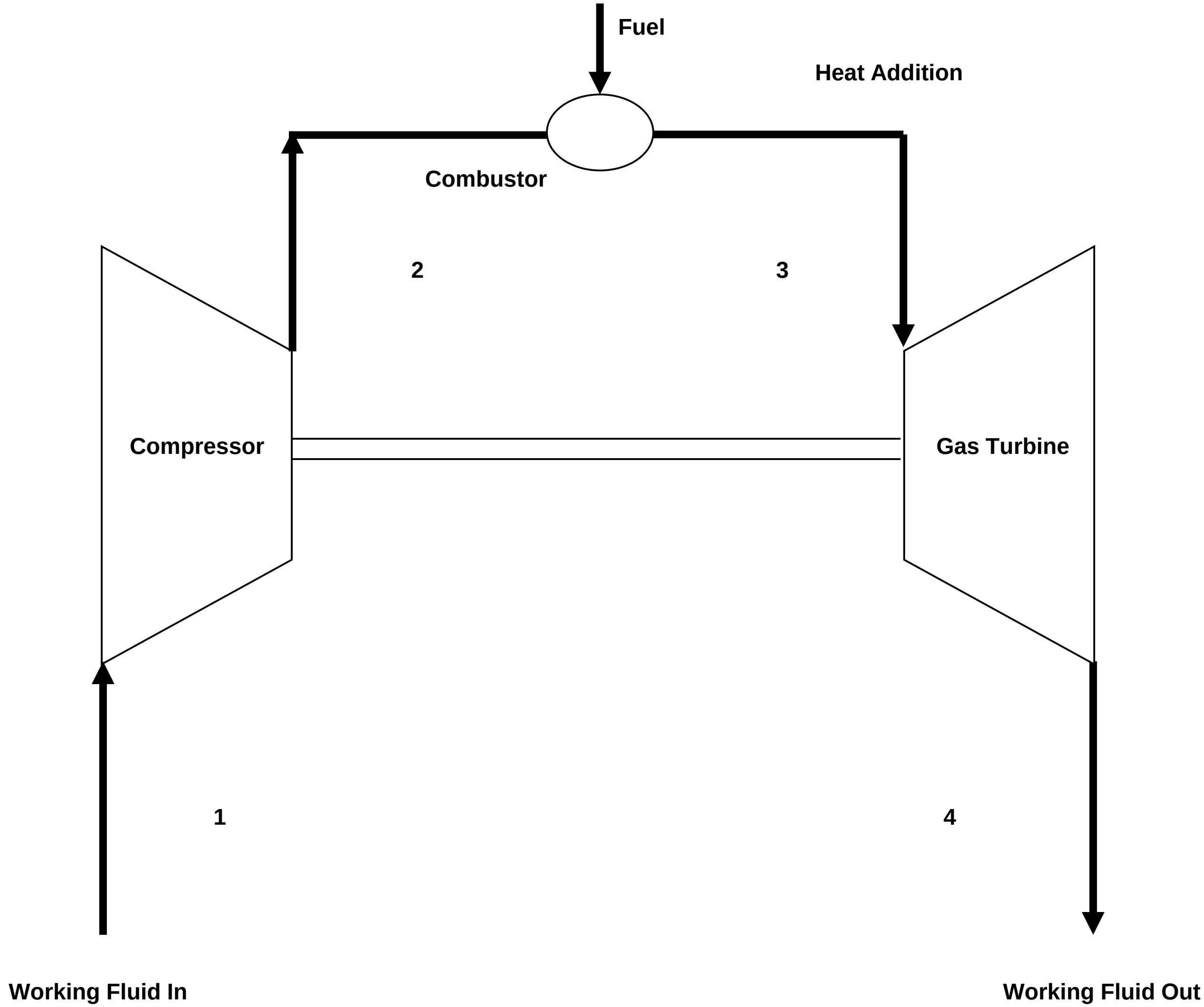
Compressor Inlet Temperature: 298 [K]

Carnot Cycle



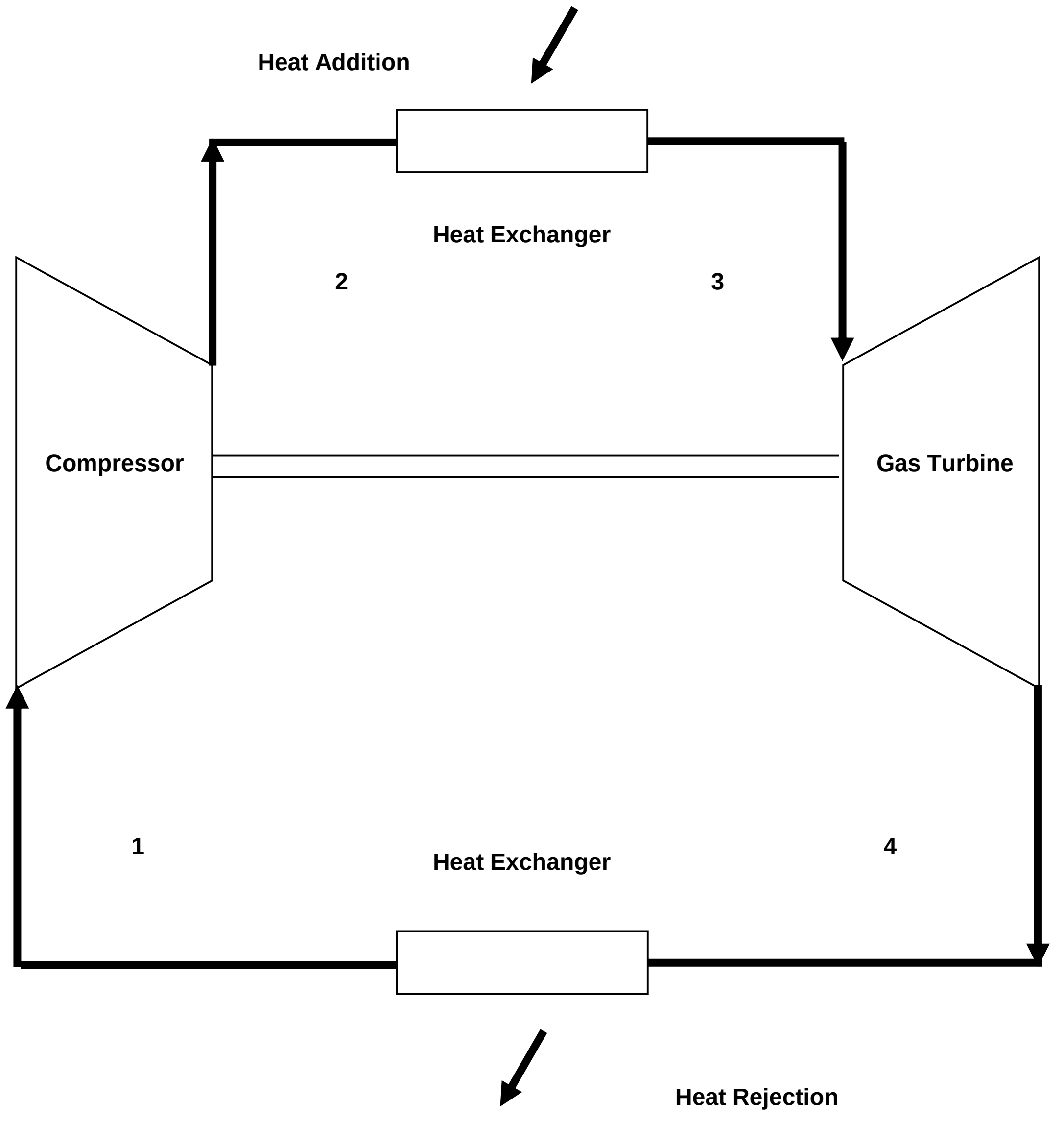
Turbine Inlet Temperature: 800 [K]

Brayton Cycle (Gas Turbine)



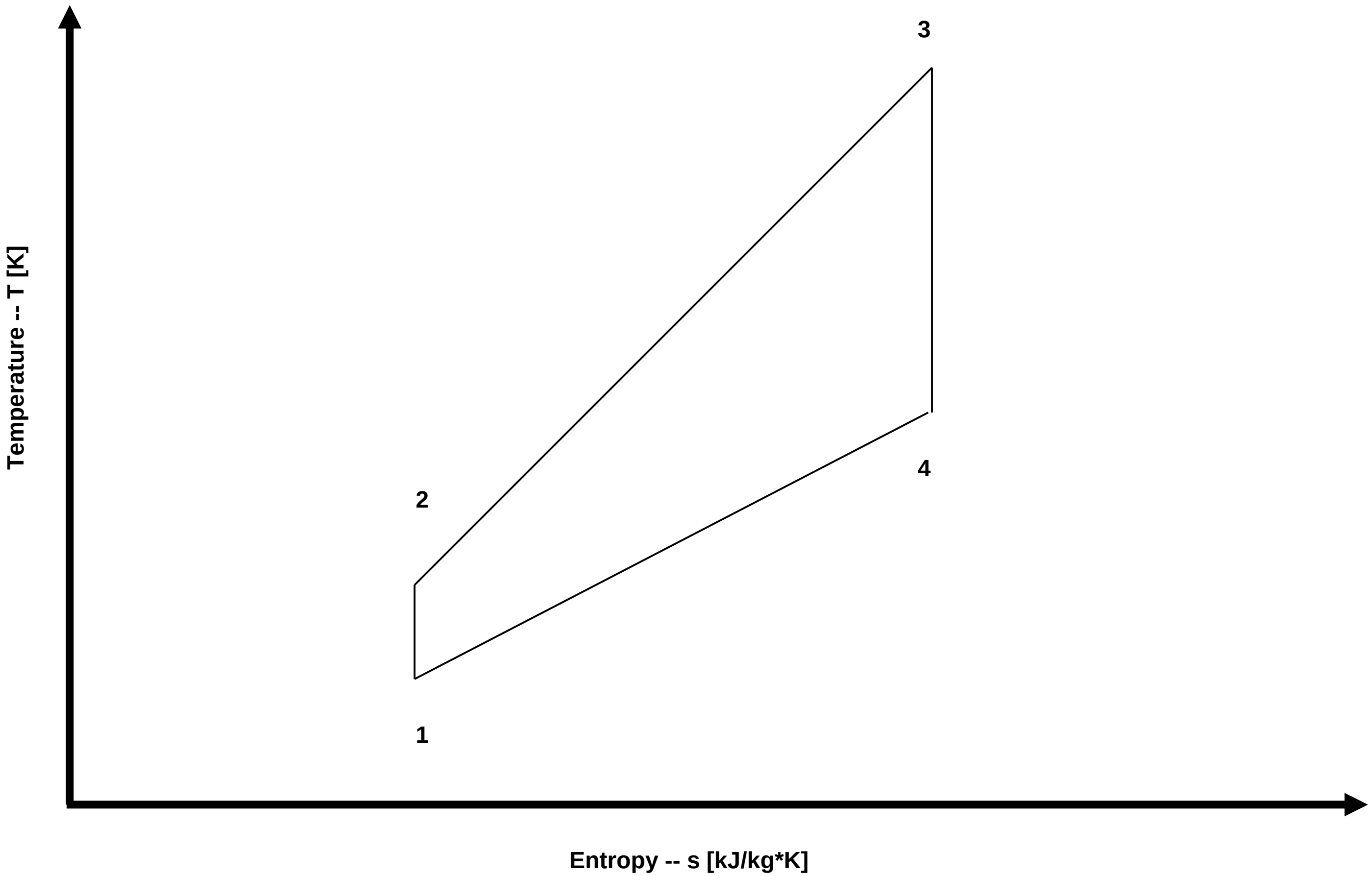
Brayton Cycle (Gas Turbine) Schematic Layout -- Open Cycle

Brayton Cycle (Gas Turbine)



Brayton Cycle Schematic Layout -- Closed Cycle

Brayton Cycle (Gas Turbine)



Brayton Cycle (Gas Turbine) T - s Diagram

Brayton Cycle (Gas Turbine)

Assumptions

Compressor Inlet Temperature: 298 [K]

Compressor Inlet Pressure: 1 [atm]

Turbine Inlet Temperature: 1,500 [K]

Turbine Inlet Pressure: 15 [atm]

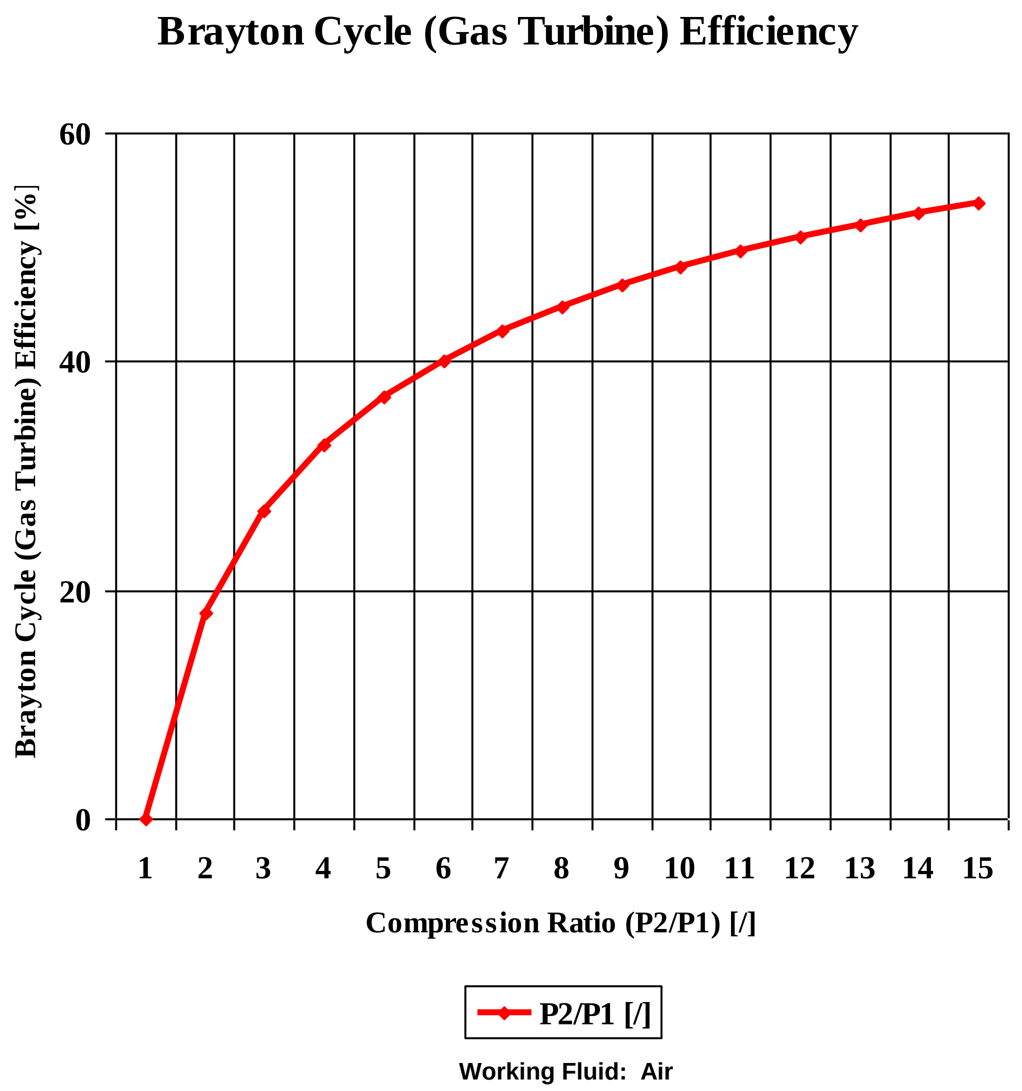
Working Fluid χ : 1.4 [/]

Working Fluid Specific Heat: 1.004 [kJ/kg*K]

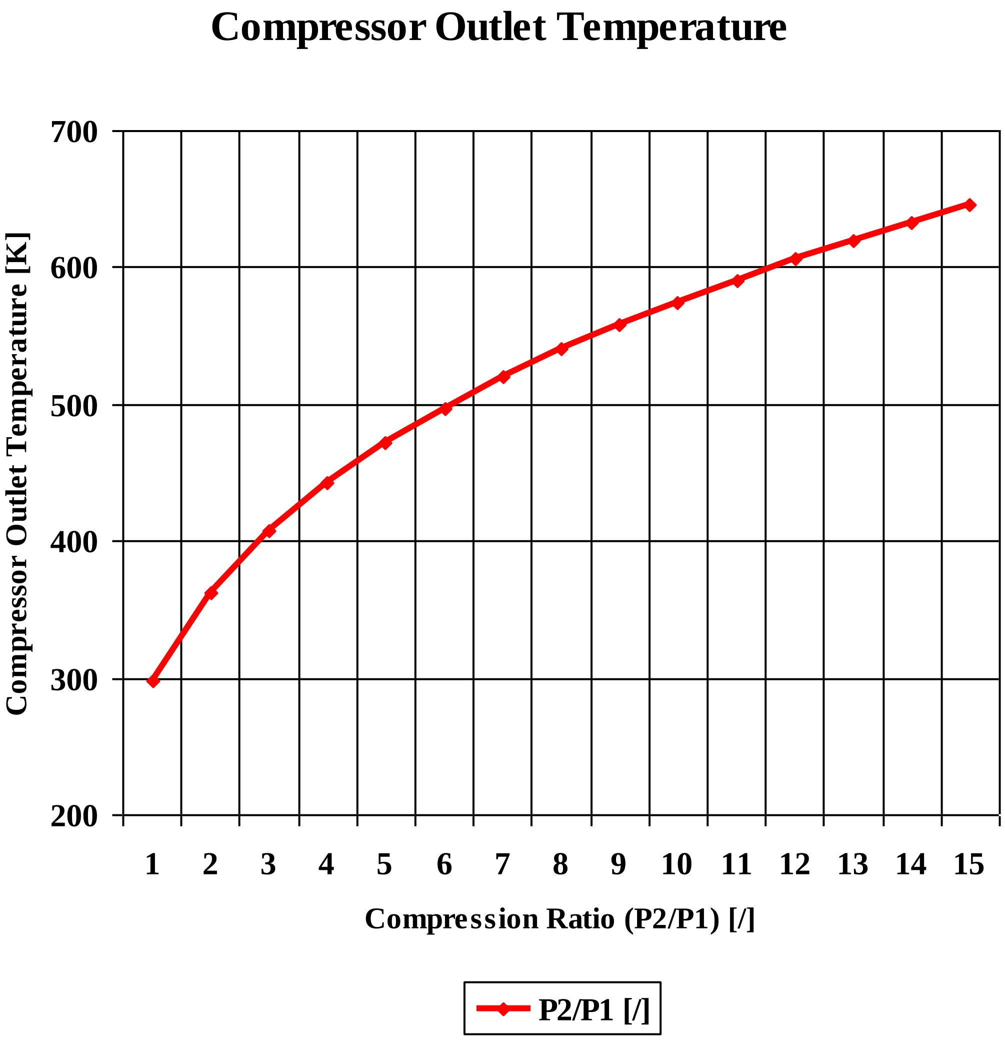
Working Fluid Mass Flow Rate: 1 [kg/s]

Fuel HHV: 24,000 [Btu/lbm]

Brayton Cycle (Gas Turbine)

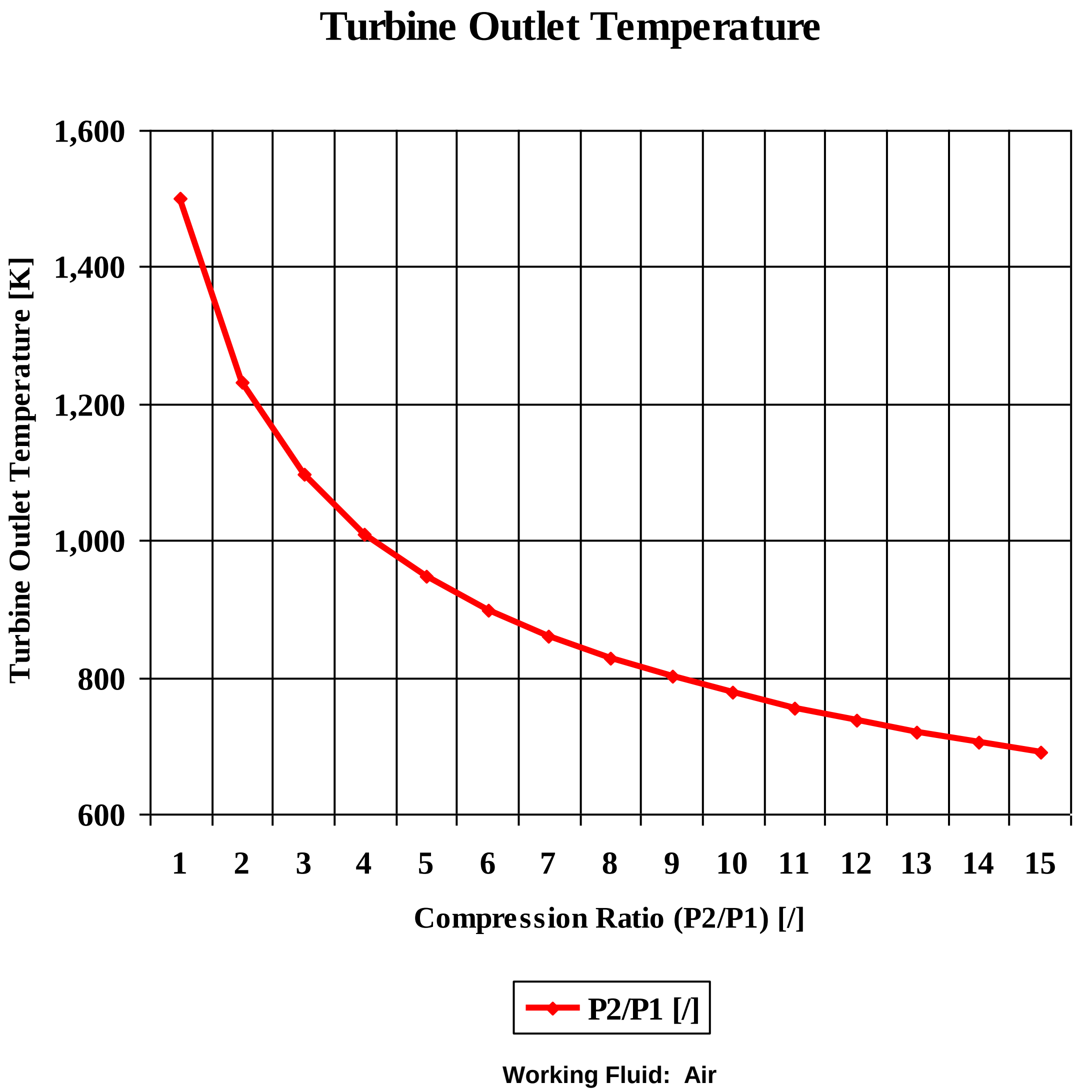


Brayton Cycle (Gas Turbine)

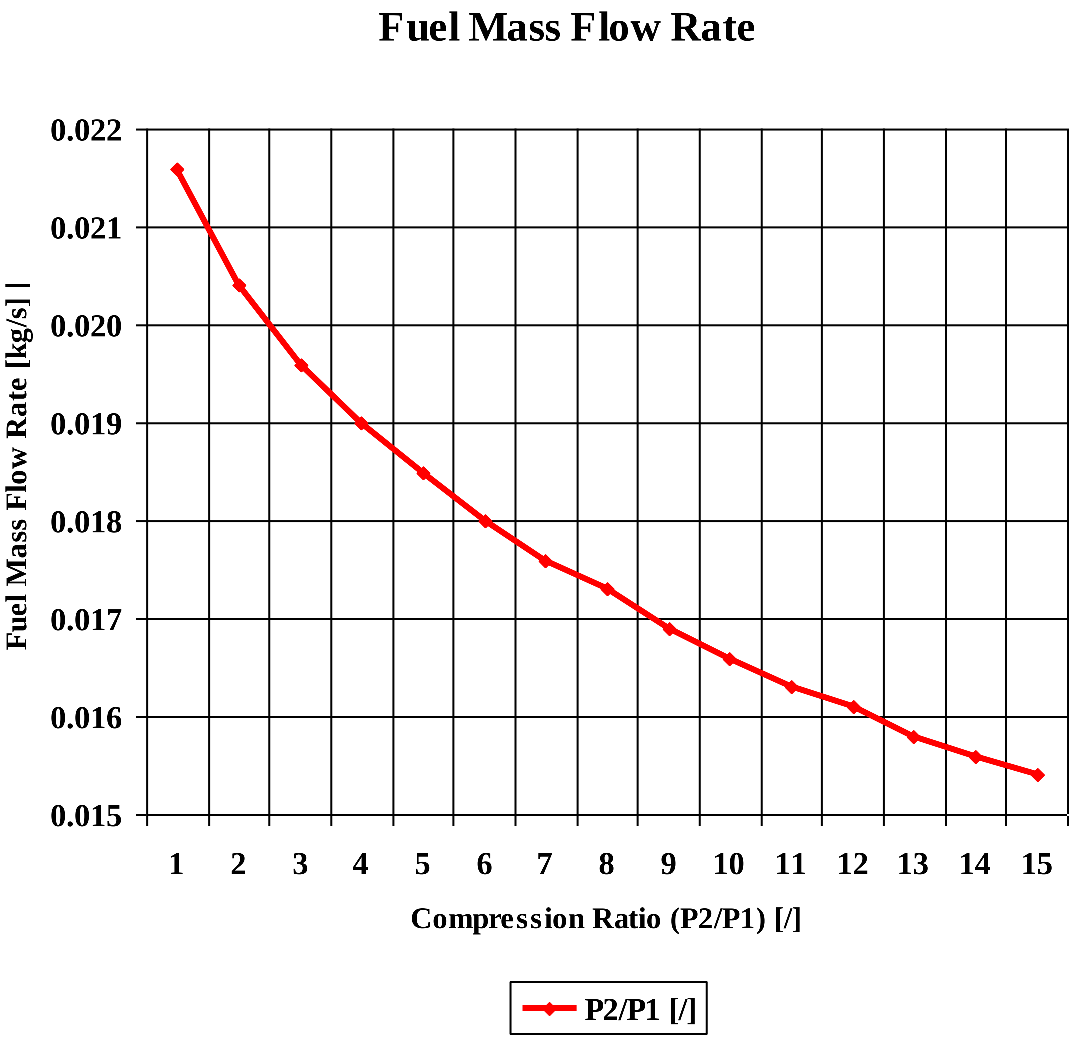


Working Fluid: Air

Brayton Cycle (Gas Turbine)

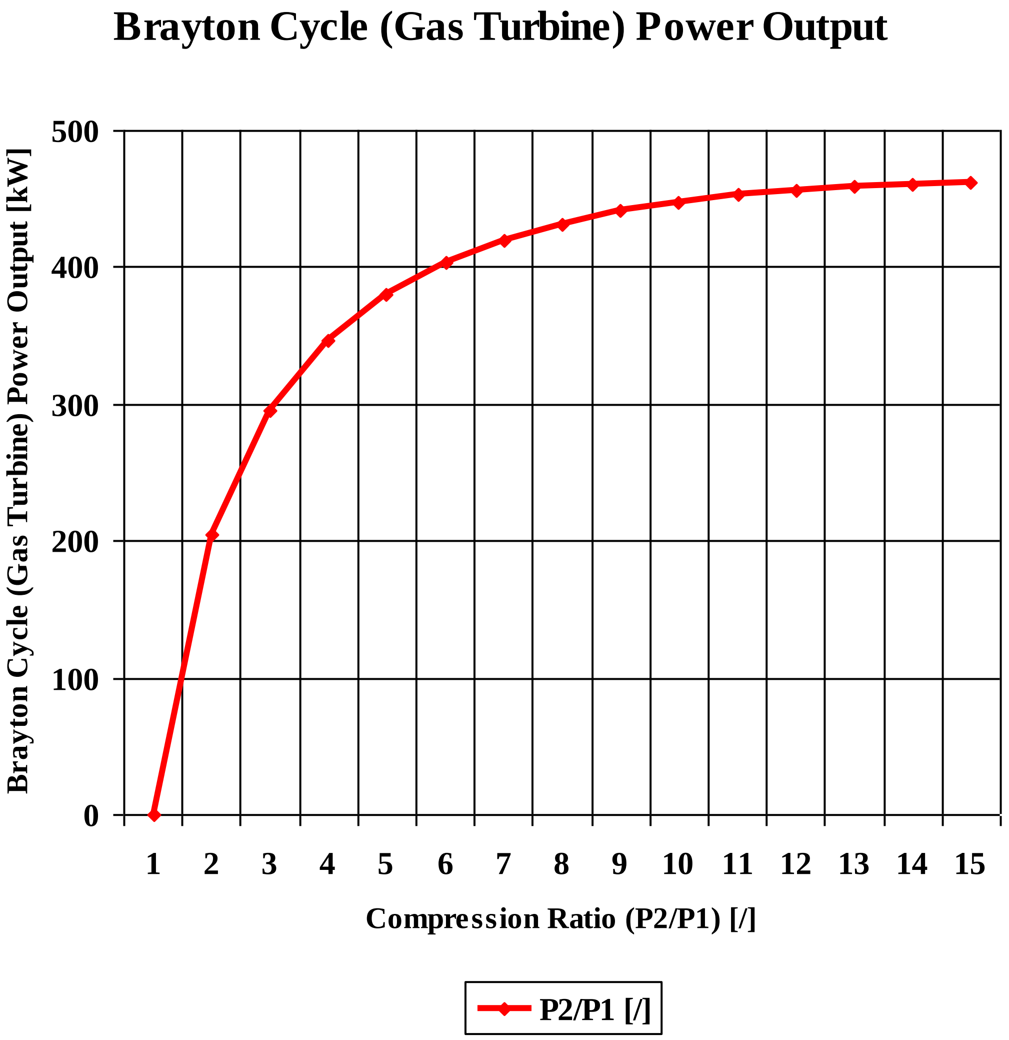


Brayton Cycle (Gas Turbine)



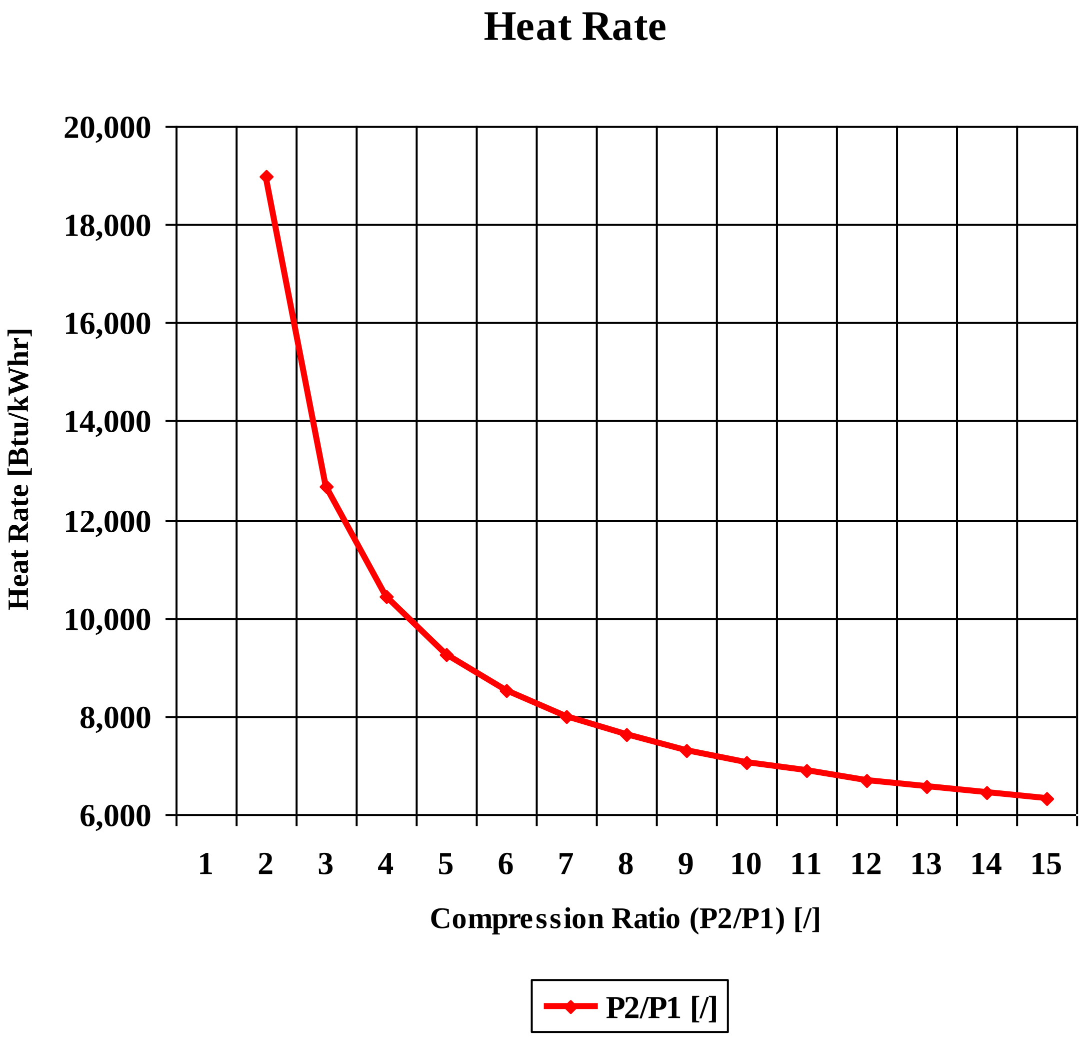
Working Fluid: Air

Brayton Cycle (Gas Turbine)



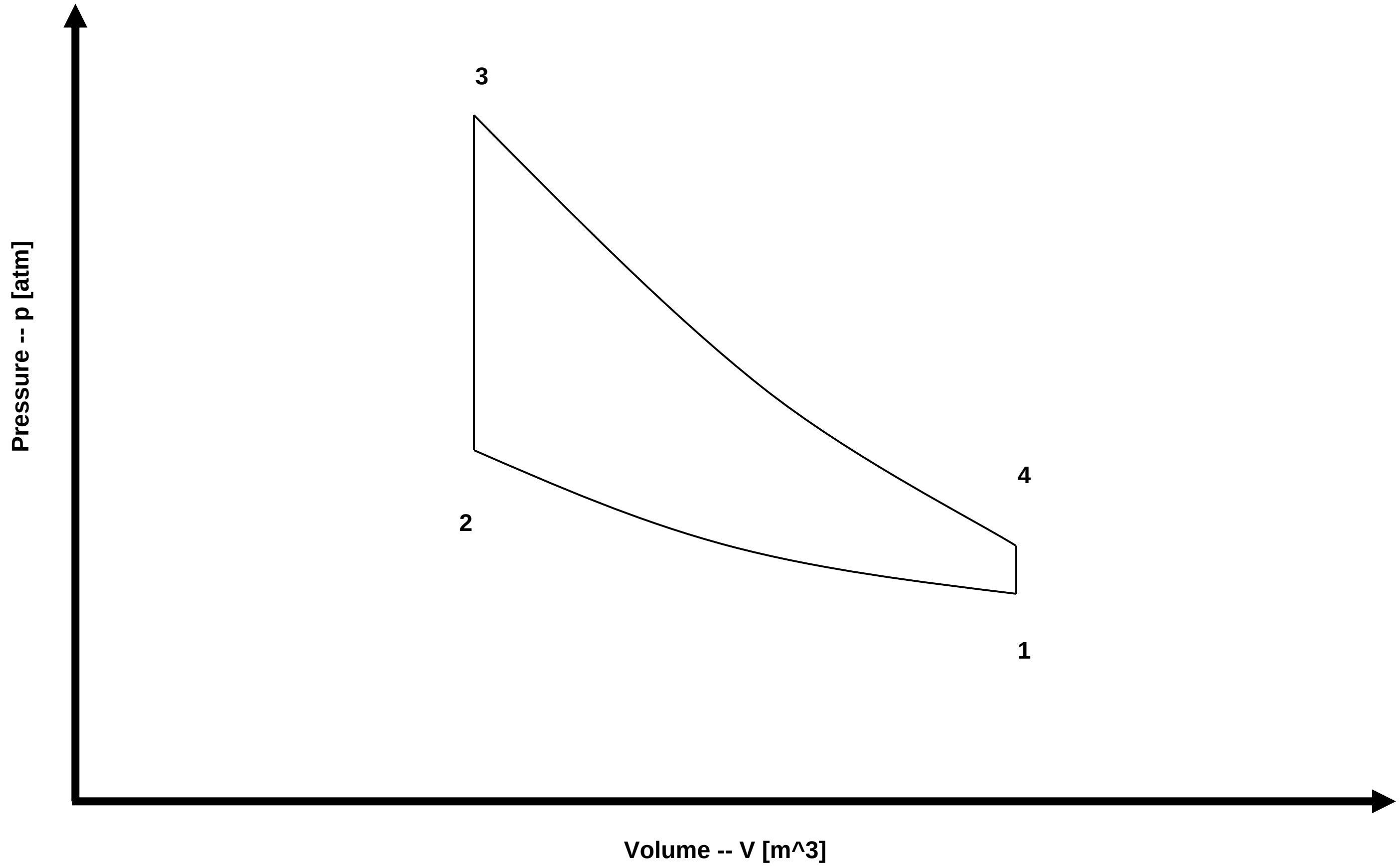
Working Fluid: Air

Brayton Cycle (Gas Turbine)



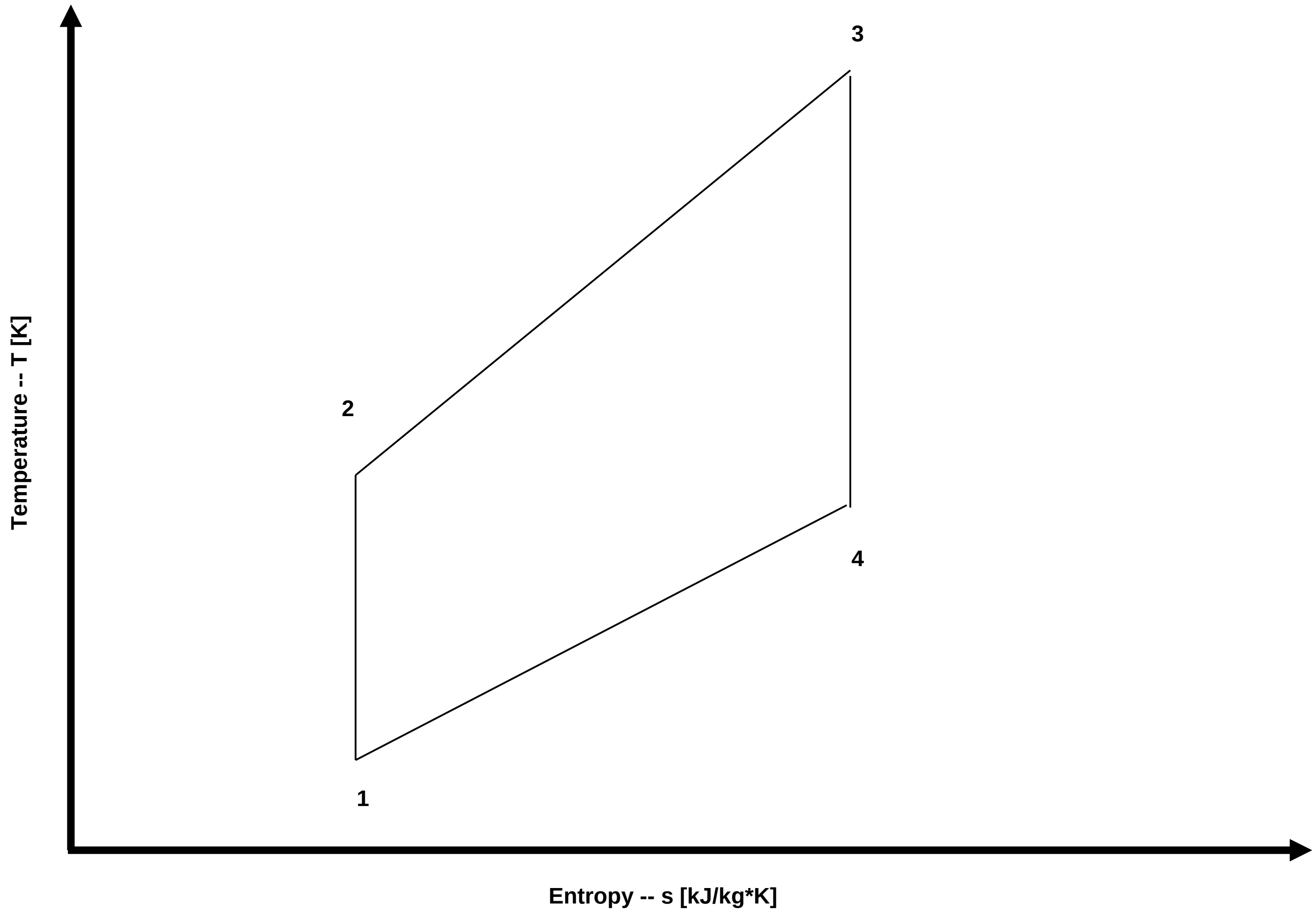
Working Fluid: Air

Otto Cycle



Otto Cycle p - V Diagram

Otto Cycle



Otto Cycle T - s Diagram

Otto Cycle

Assumptions

Ambient Temperature: 298 [K]

Ambient Pressure: 1 [atm]

Compression Ratio: 7 [/]

Combustion Temperature: 1,250 [K]

Working Fluid χ : 1.4 [/]

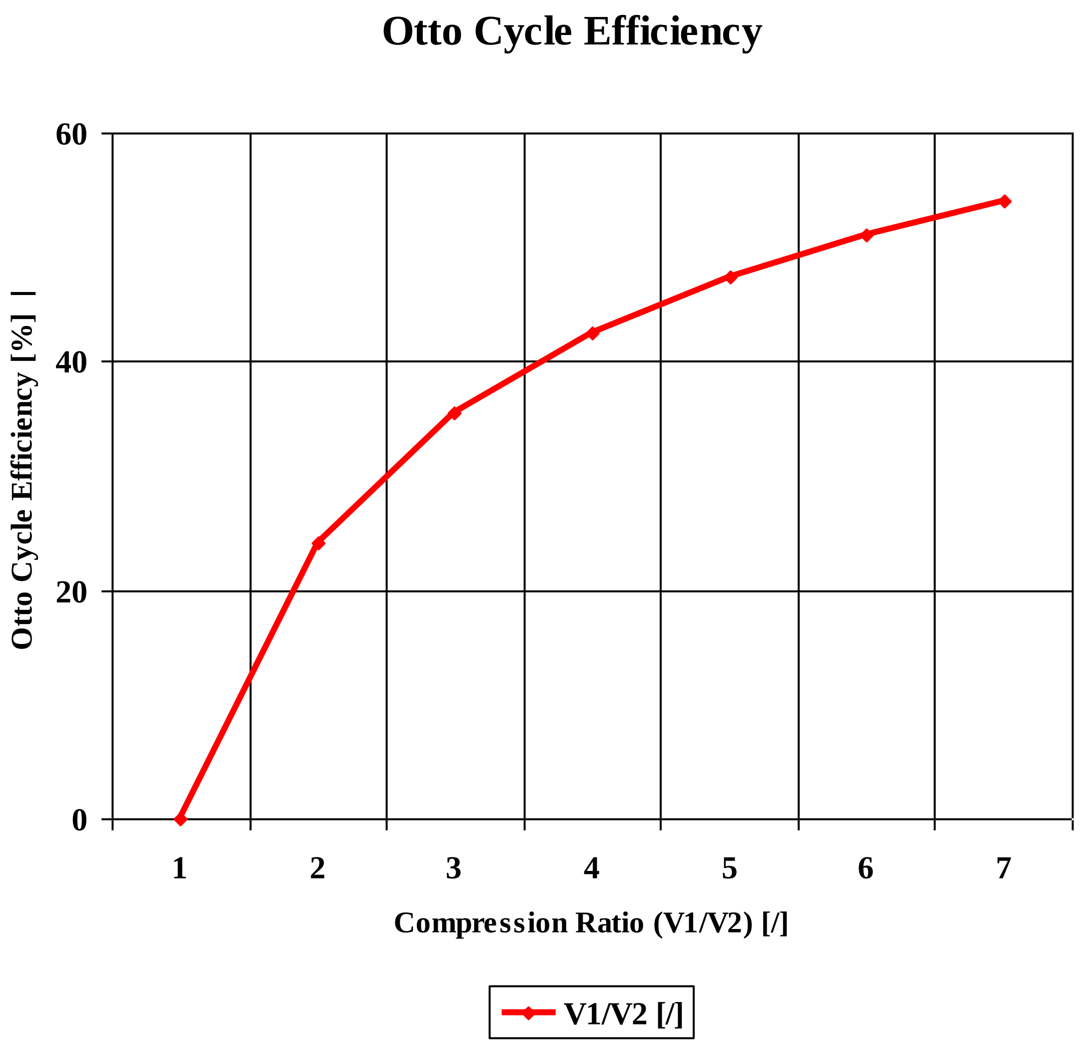
Working Fluid Gas Constant: 0.2867 [kJ/kg*K]

Working Fluid Specific Heat: 1.004 [kJ/kg*K]

Working Fluid Mass Flow Rate: 0.78 [kg/s]

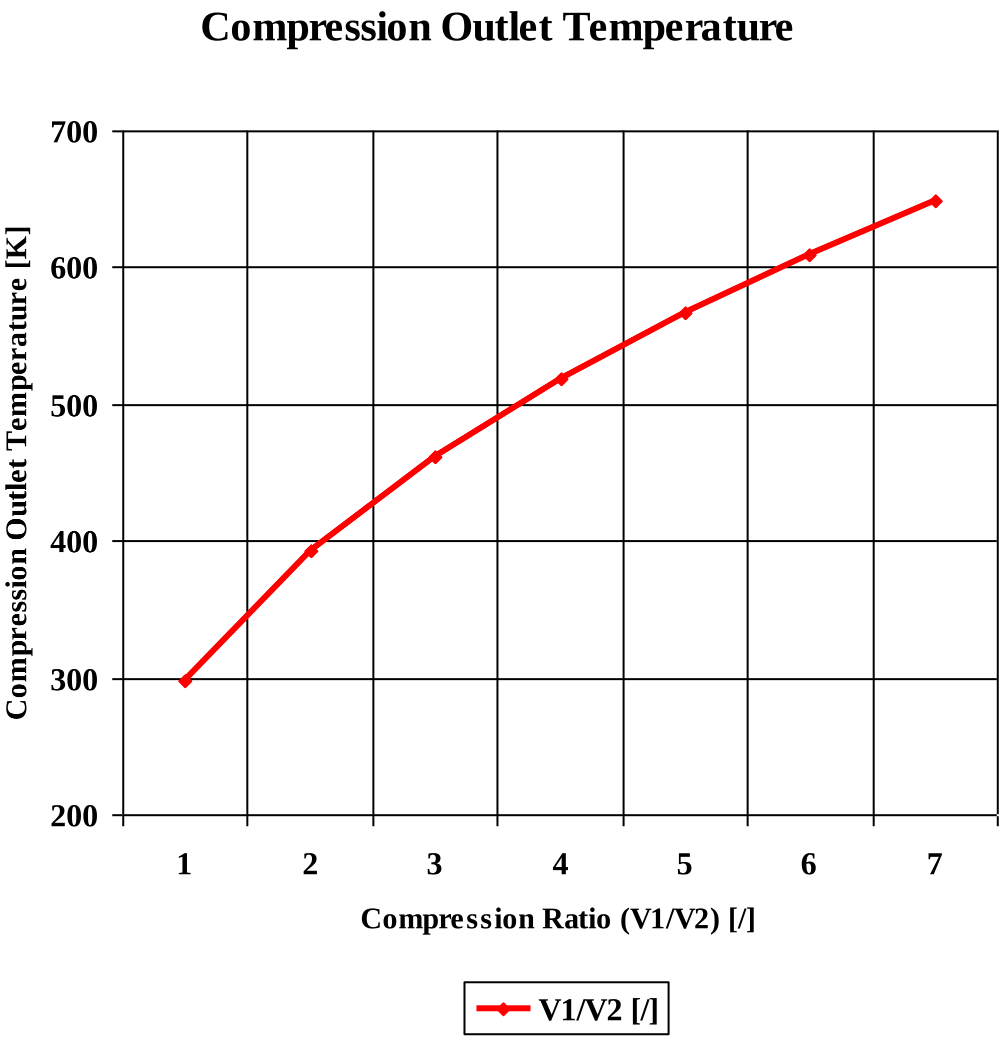
Fuel HHV: 18,000 [Btu/lbm]

Otto Cycle



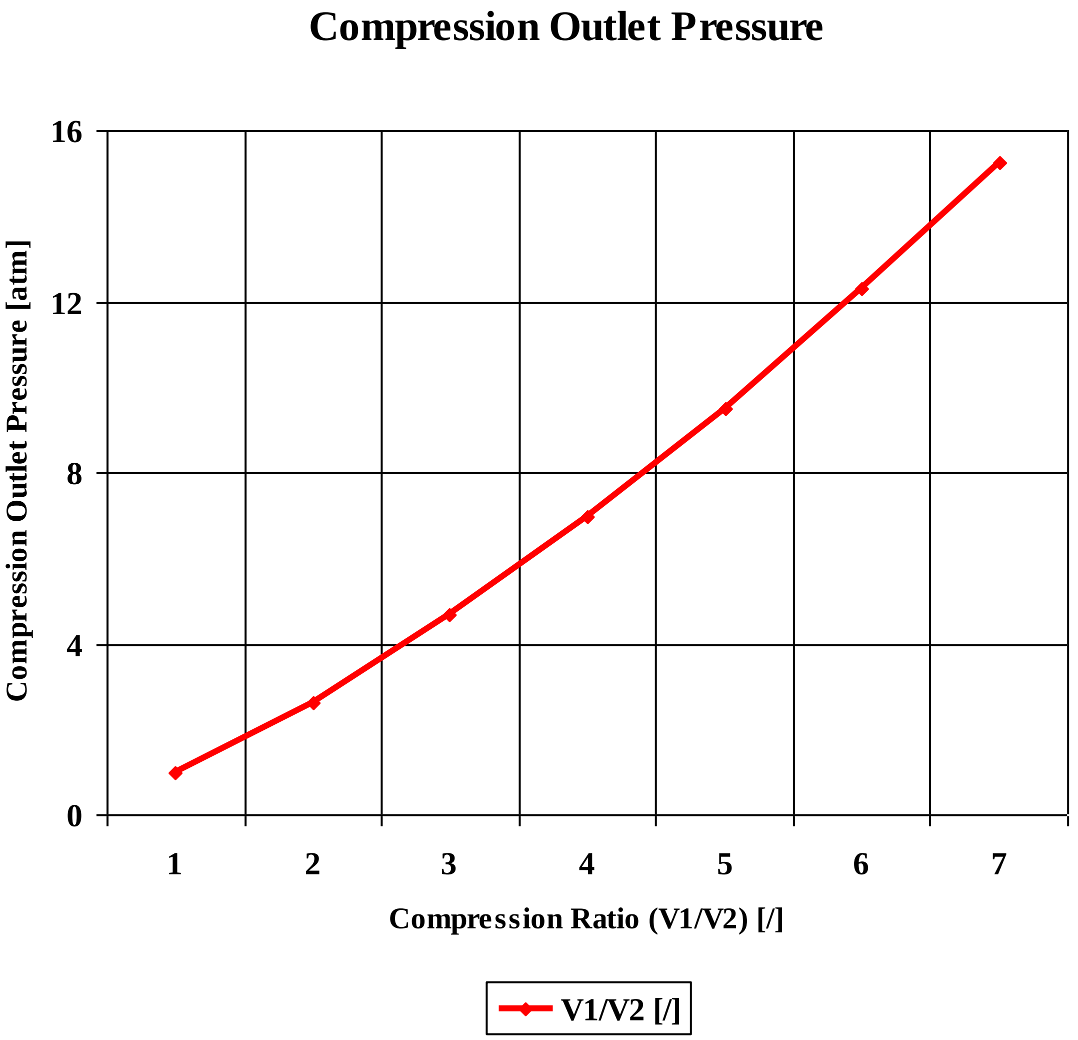
Working Fluid: Air

Otto Cycle



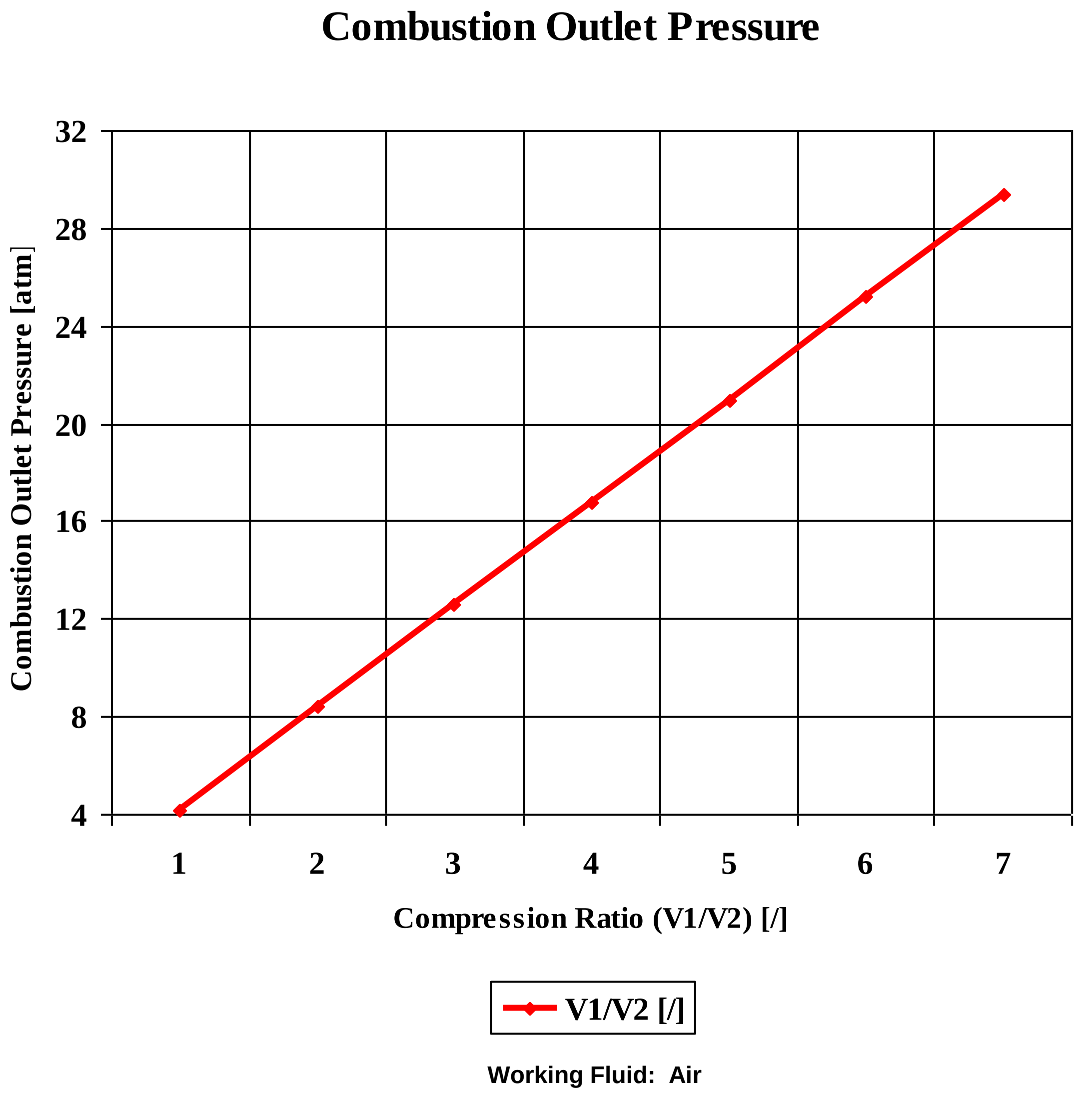
Working Fluid: Air

Otto Cycle



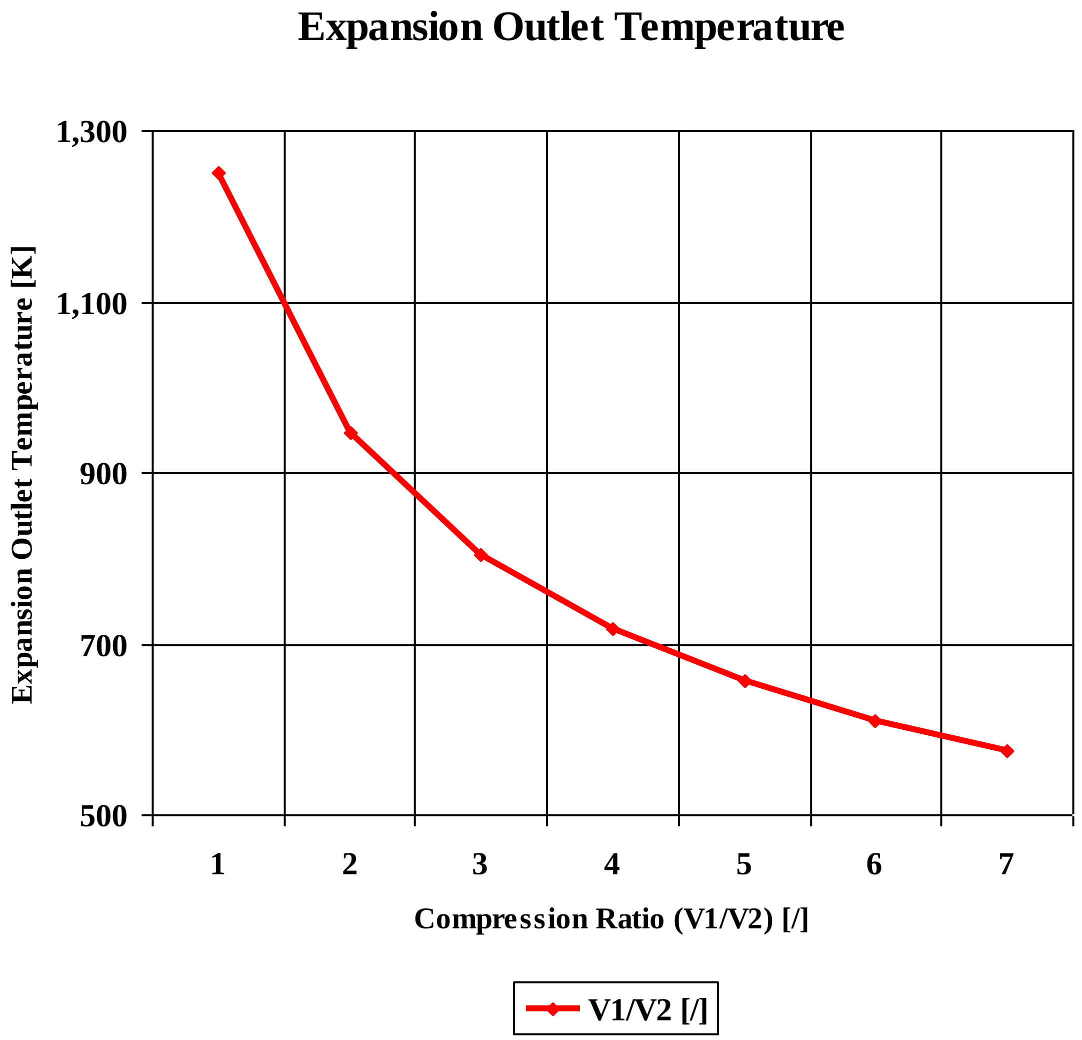
Working Fluid: Air

Otto Cycle



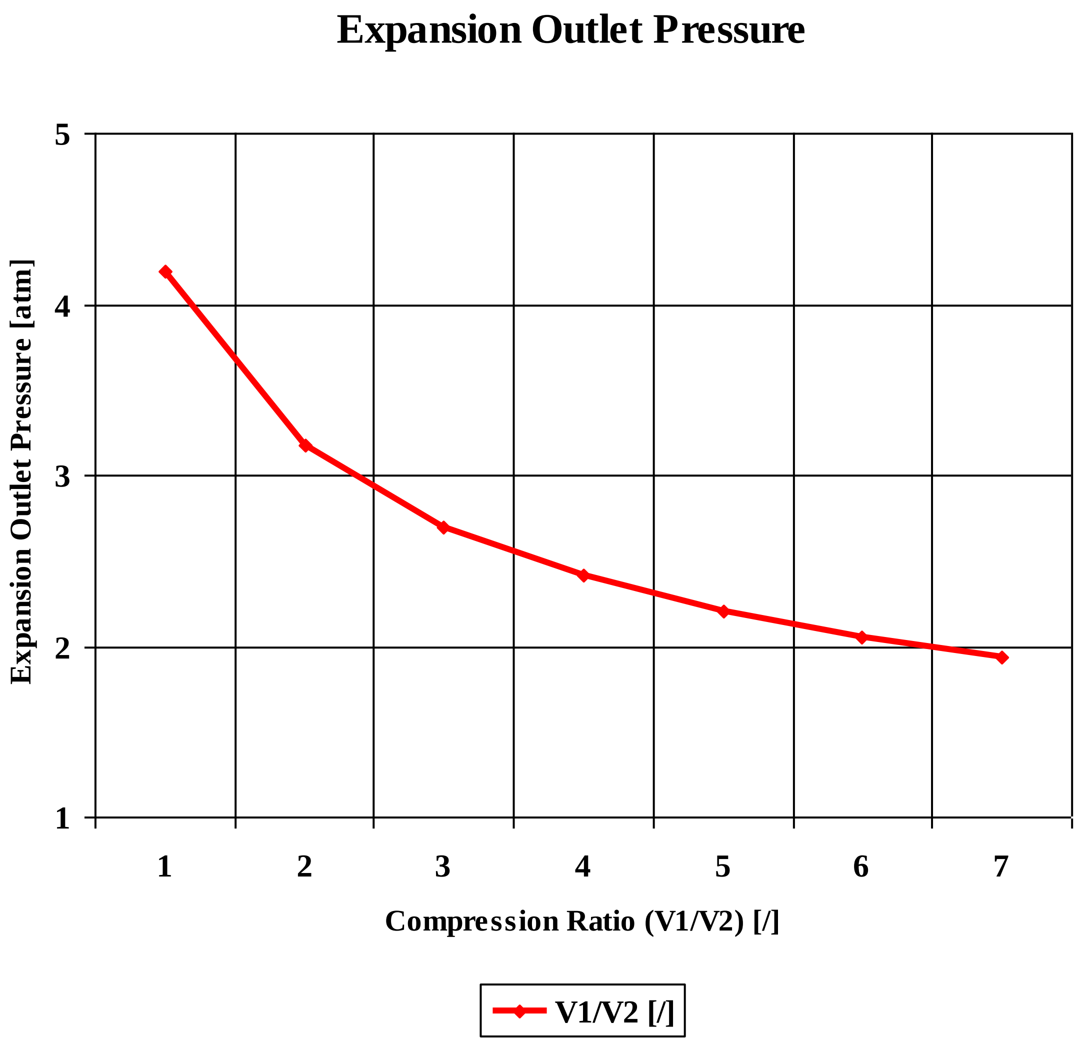
Combustion Outlet Pressure
32
28
24
20
16
12
8
4
Combustion Outlet Pressure [atm]
1
2
3
4
5
6
7
Compression Ratio (V1/V2) [/]
V1/V2 [/]
Working Fluid: Air

Otto Cycle



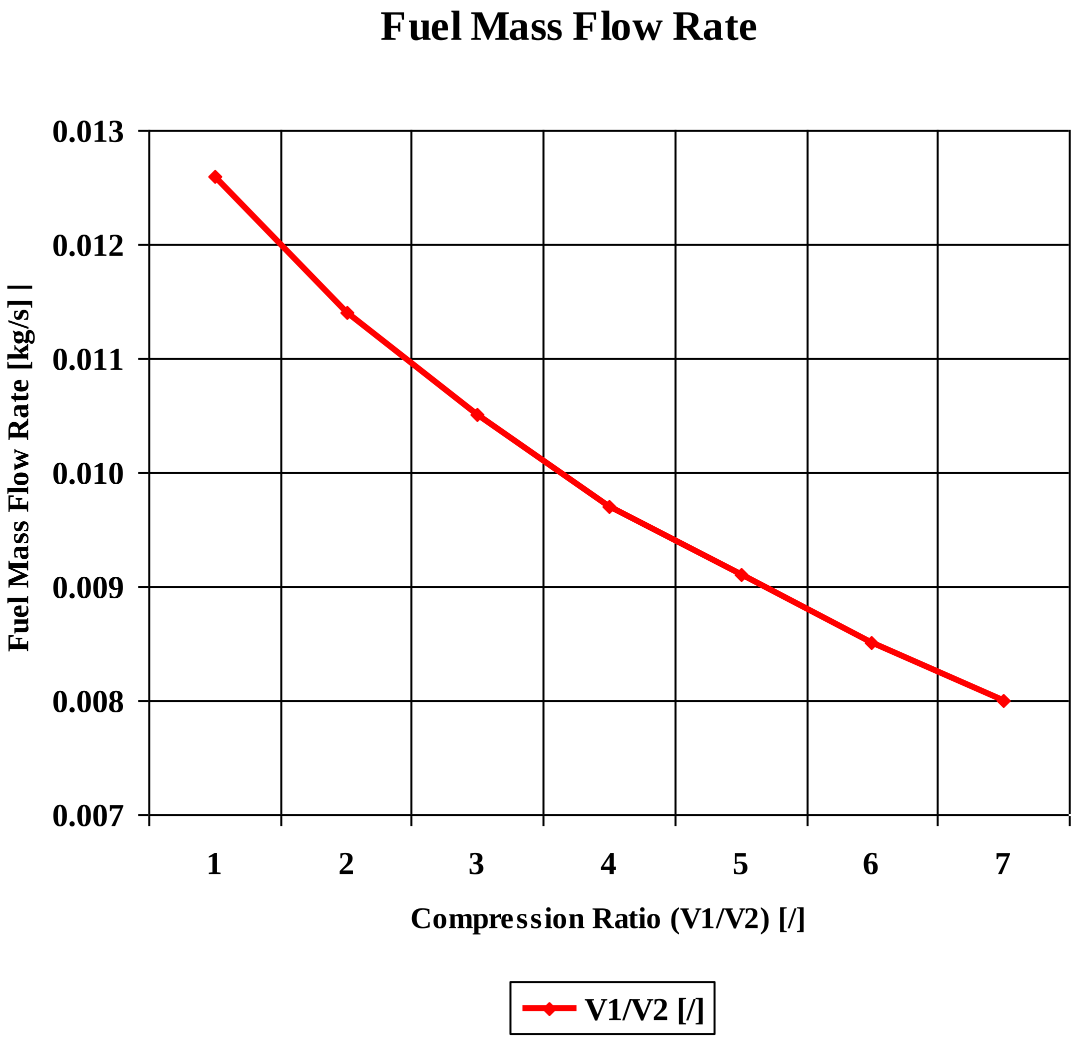
Working Fluid: Air

Otto Cycle



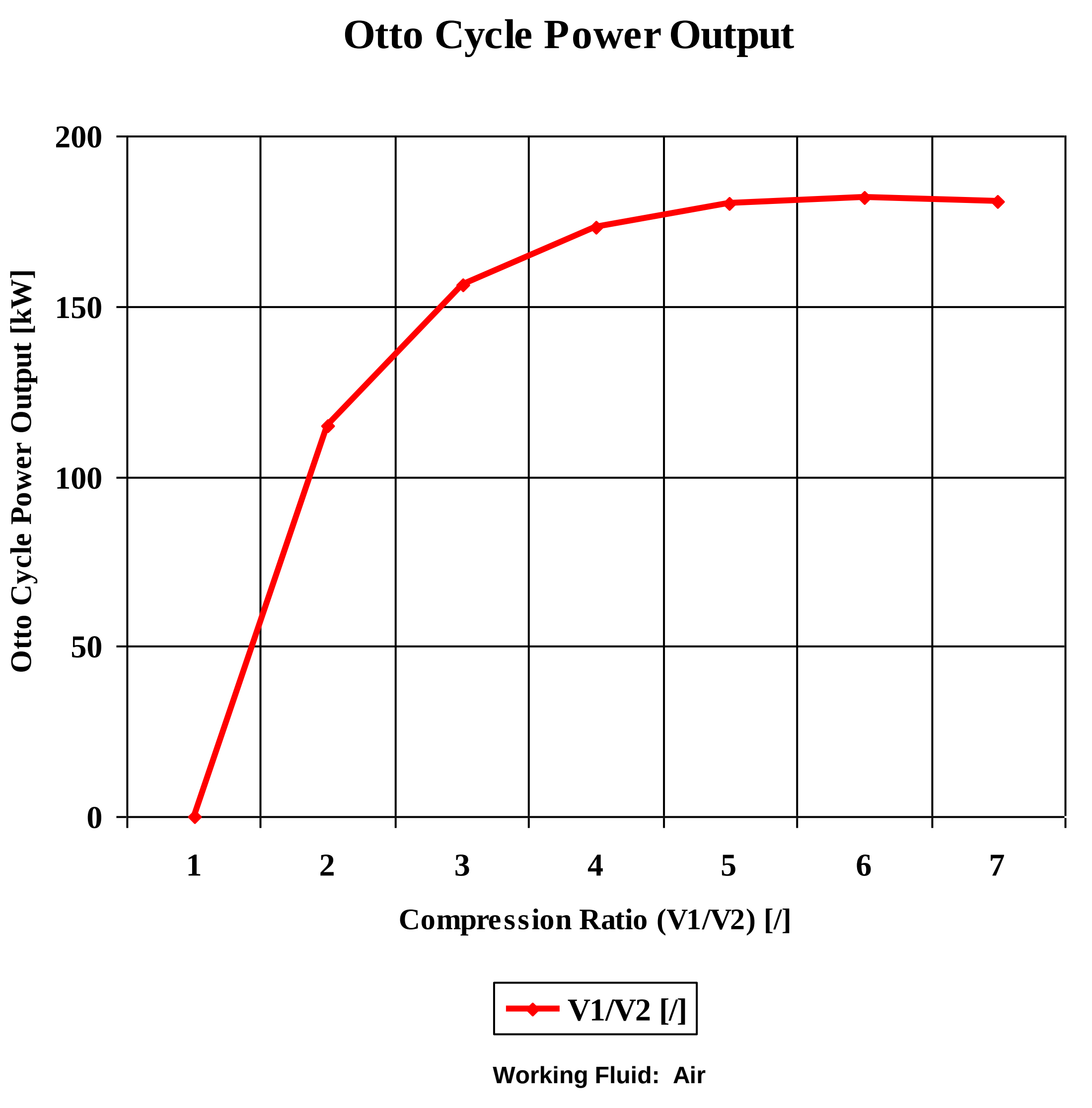
Working Fluid: Air

Otto Cycle

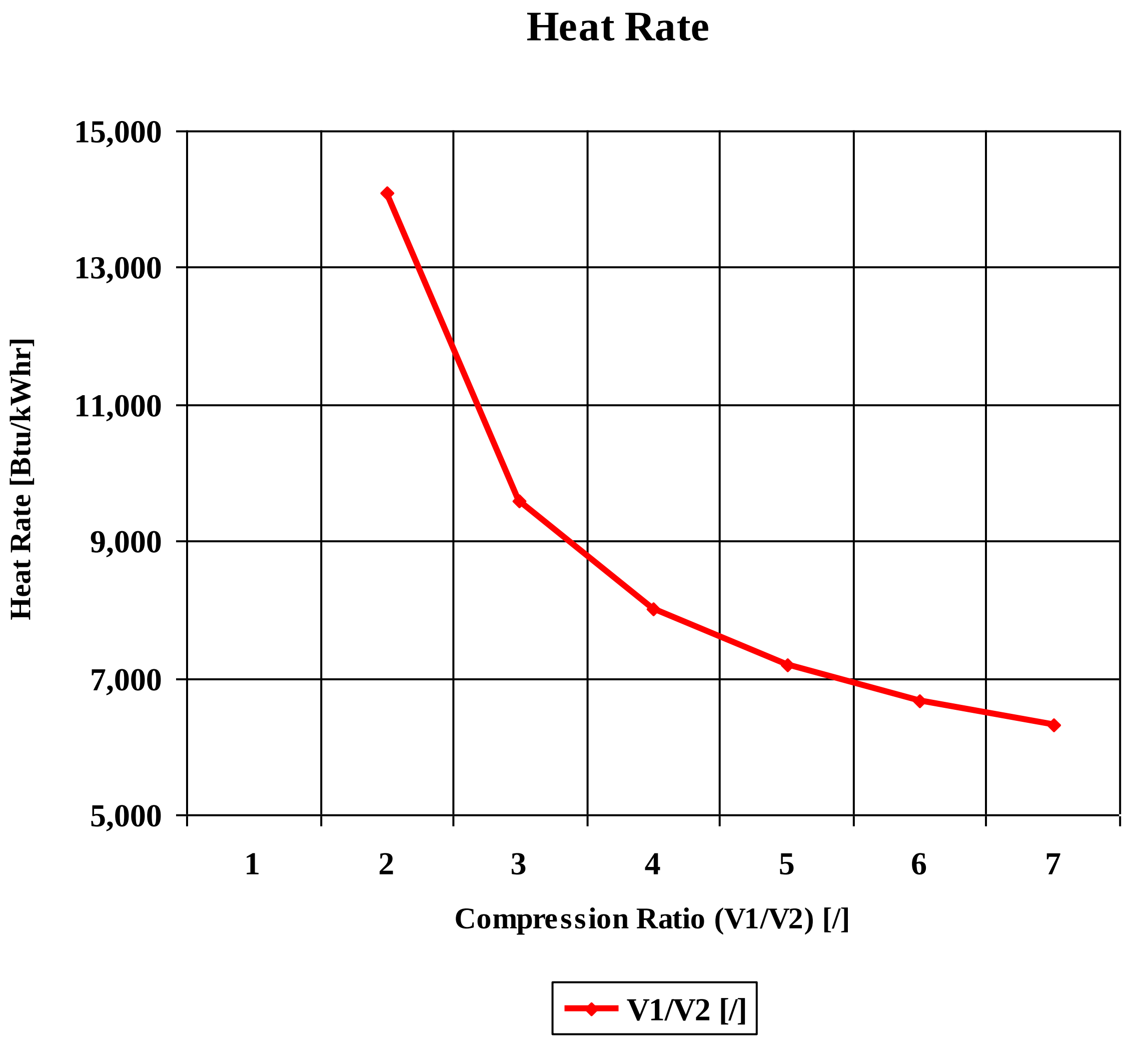


Working Fluid: Air

Otto Cycle

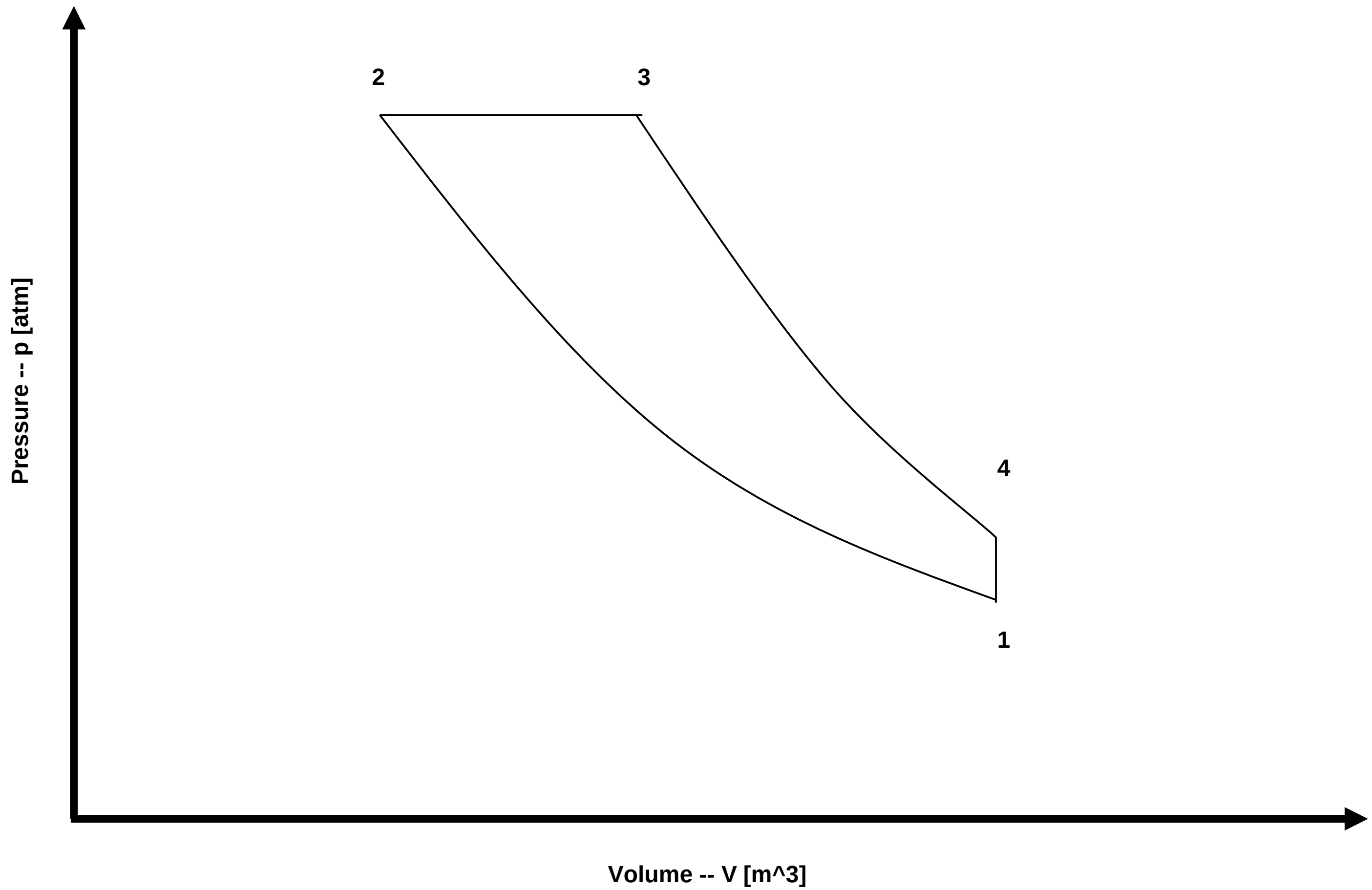

Otto Cycle Power Output
200
150
100
50
0
Otto Cycle Power Output [kW]
1
2
3
4
5
6
7
Compression Ratio (V1/V2) [/]
V1/V2 [/]
Working Fluid: Air

Otto Cycle



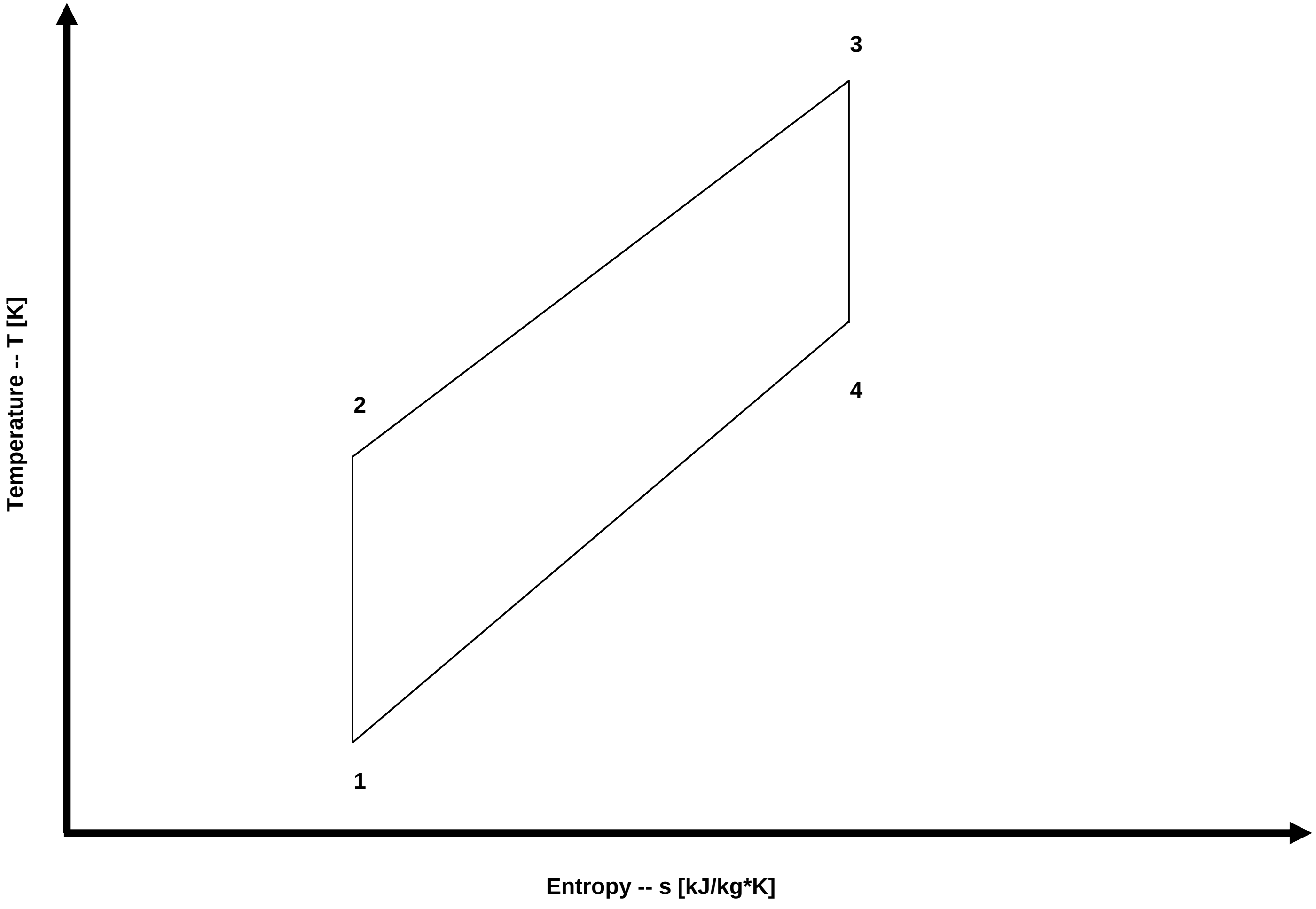
Working Fluid: Air

Diesel Cycle



Diesel Cycle p - V Diagram

Diesel Cycle



Diesel Cycle T - s Diagram

Diesel Cycle

Assumptions

Ambient Temperature: 298 [K]

Ambient Pressure: 1 [atm]

Compression Ratio: 15 [/]

Cut Off Ratio: 1.5 [/]

Working Fluid χ : 1.4 [/]

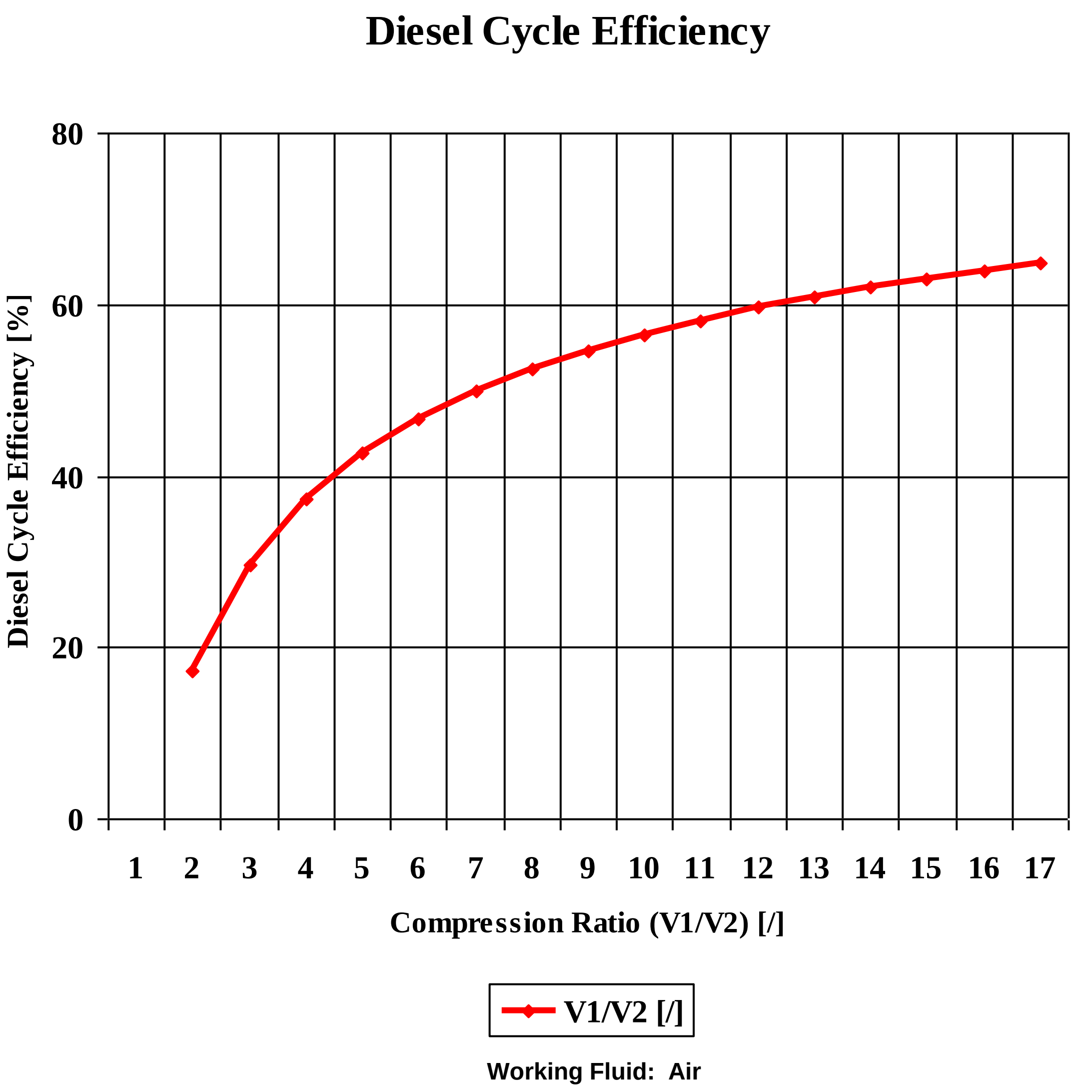
Working Fluid Gas Constant: 0.2867 [kJ/kg*K]

Working Fluid Specific Heat: 1.004 [kJ/kg*K]

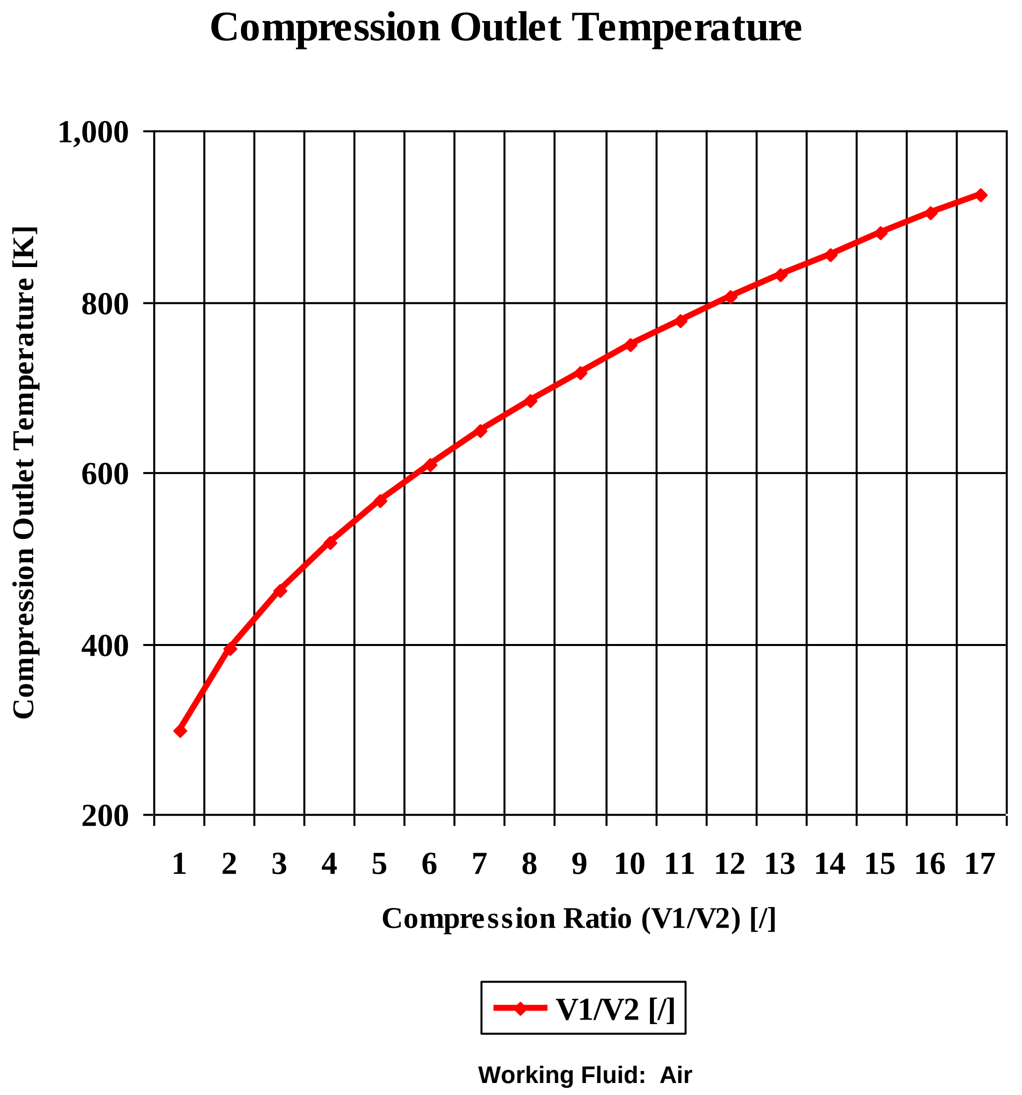
Working Fluid Mass Flow Rate: 0.78 [kg/s]

Fuel HHV: 18,000 [Btu/lbm]

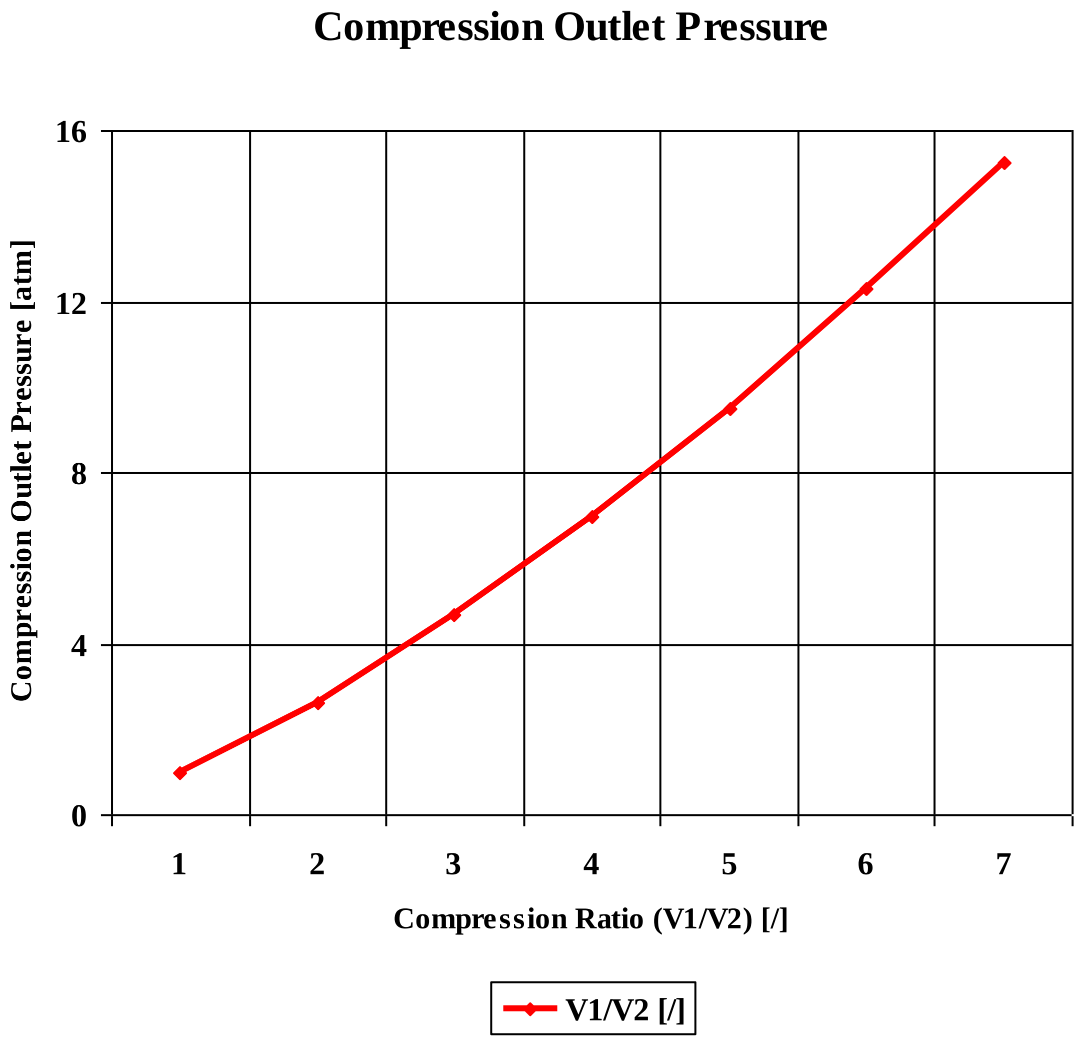
Diesel Cycle



Diesel Cycle

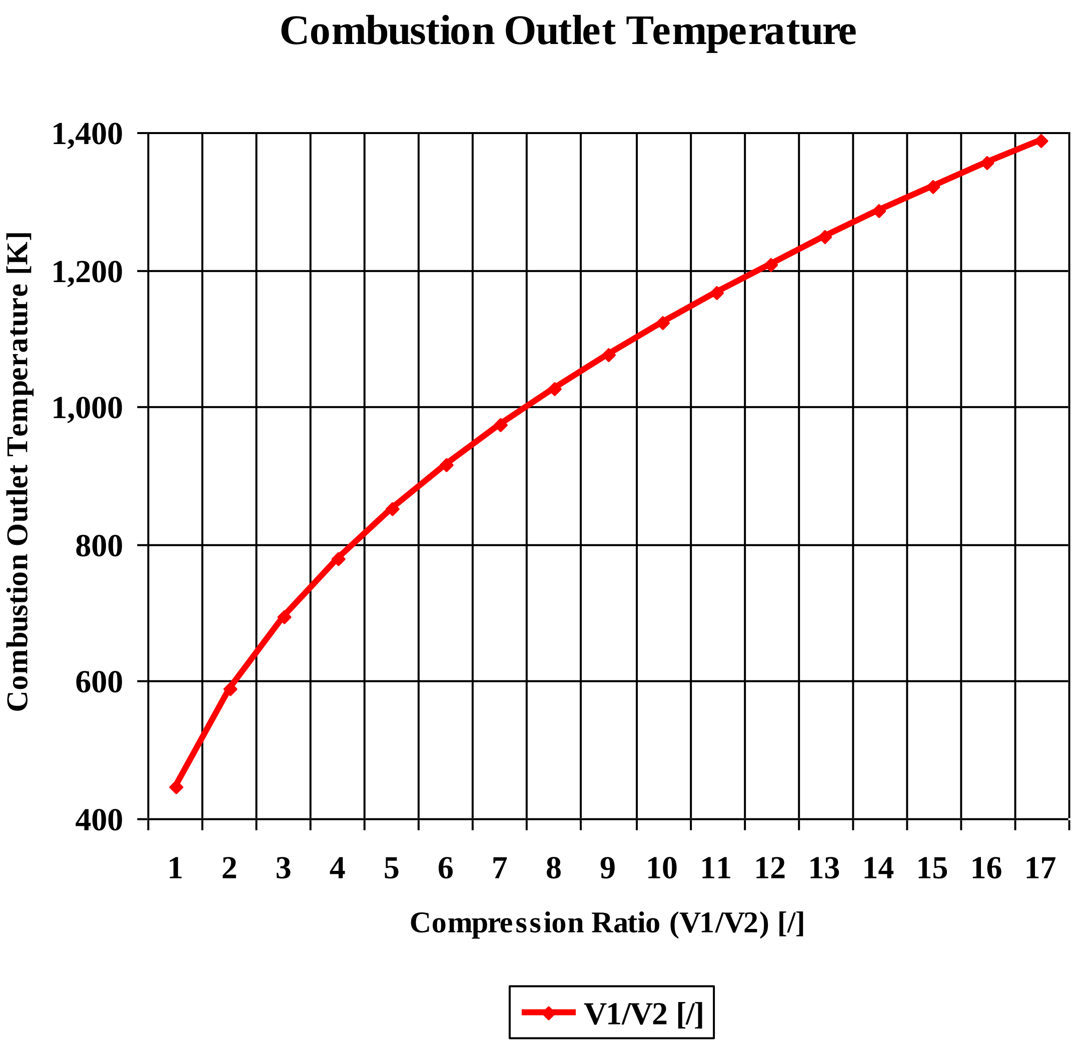


Diesel Cycle



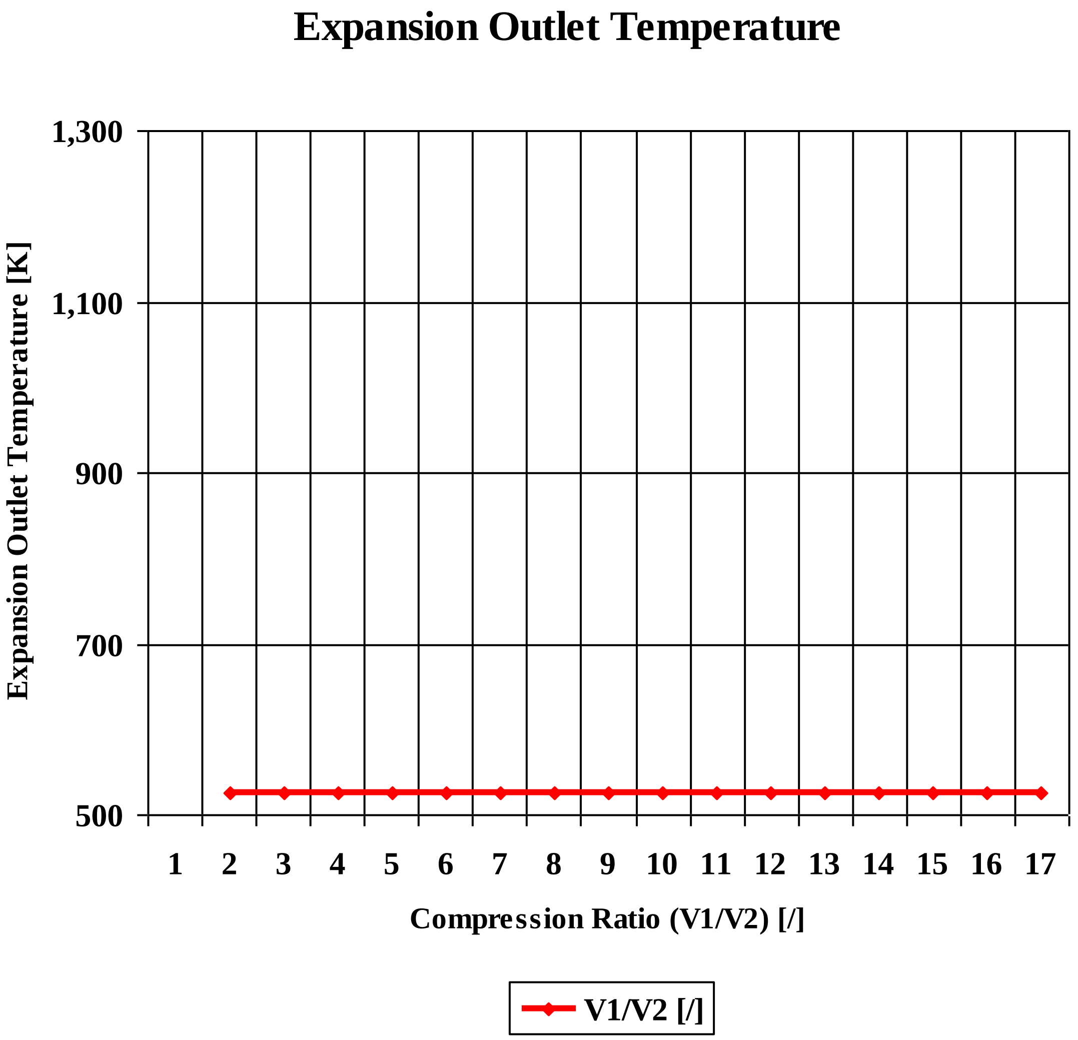
Working Fluid: Air

Diesel Cycle



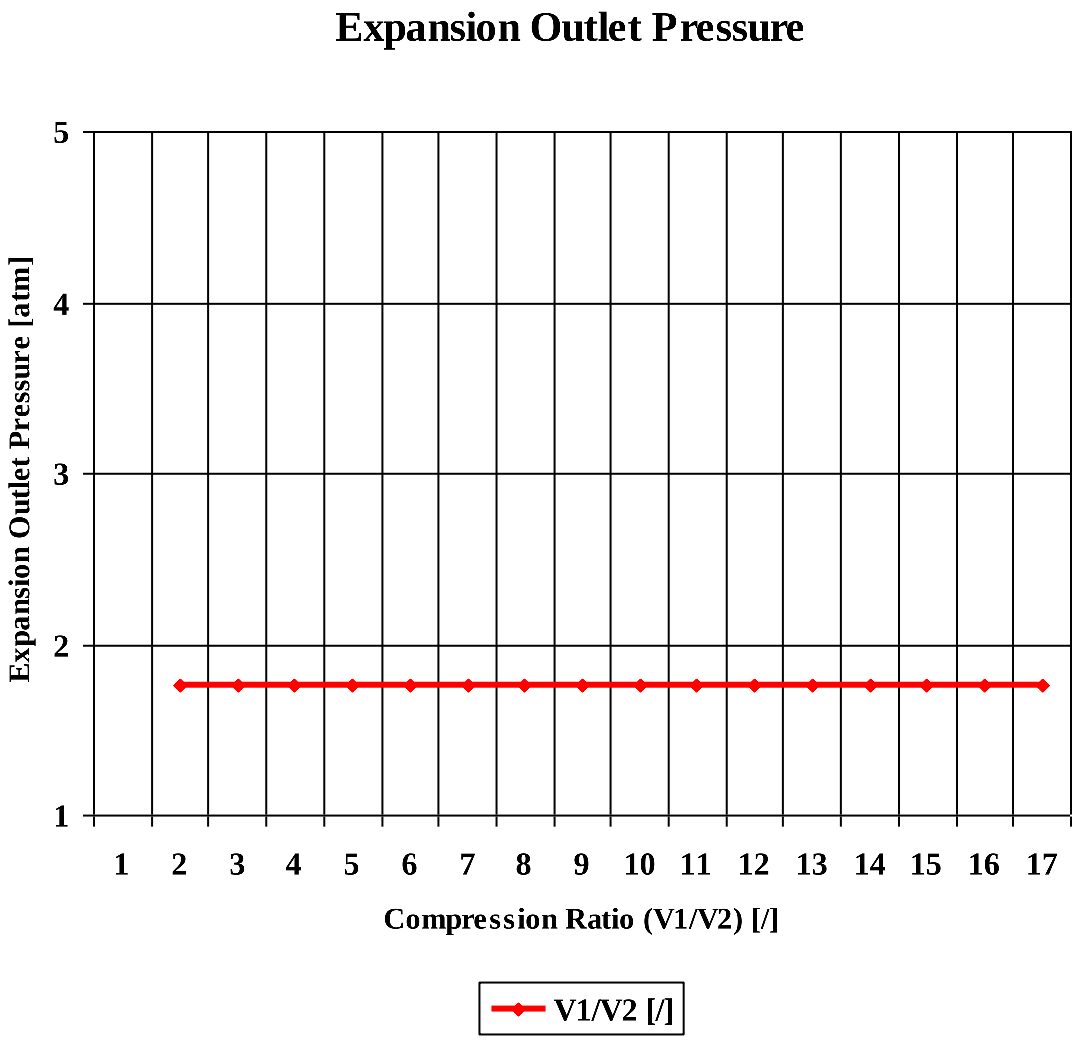
Working Fluid: Air

Diesel Cycle



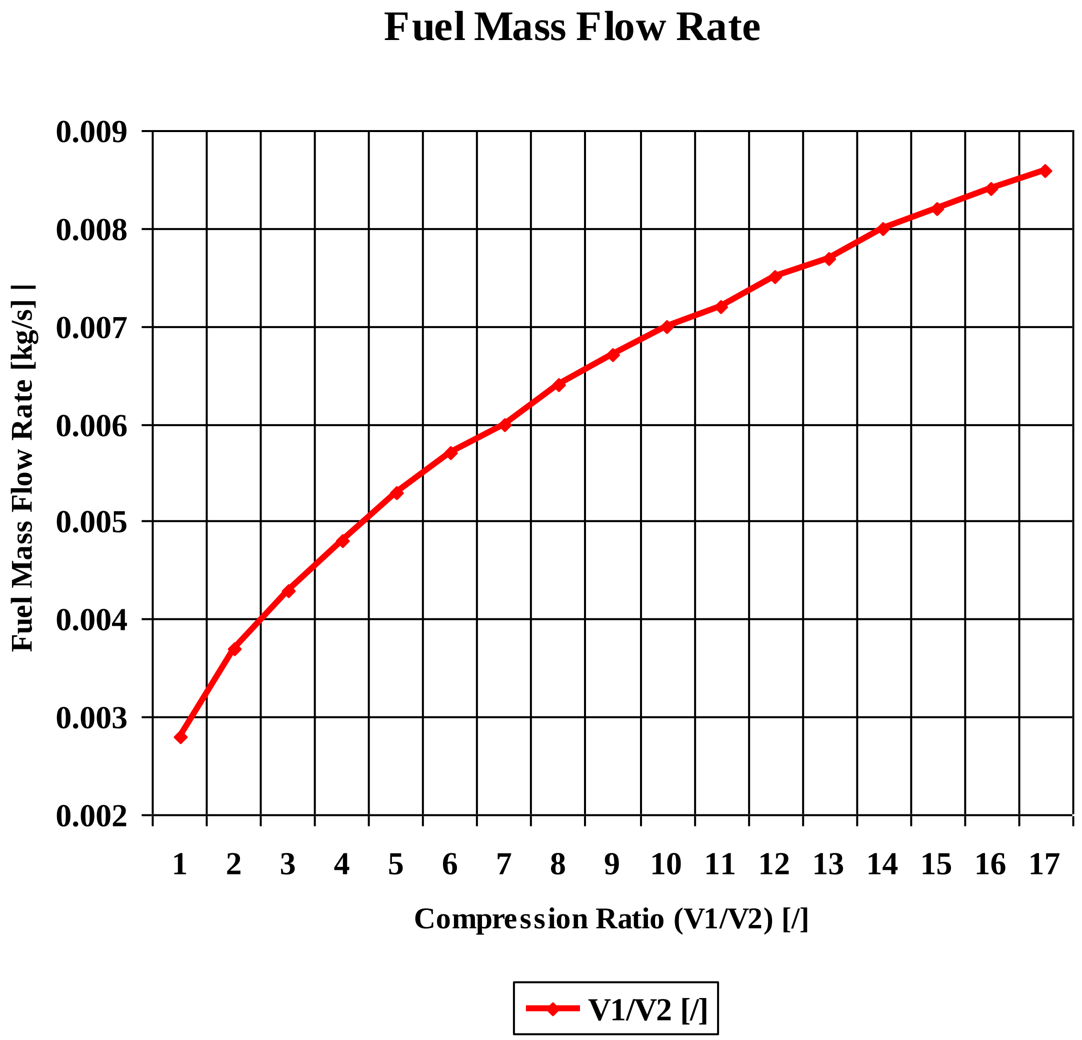
Working Fluid: Air

Diesel Cycle



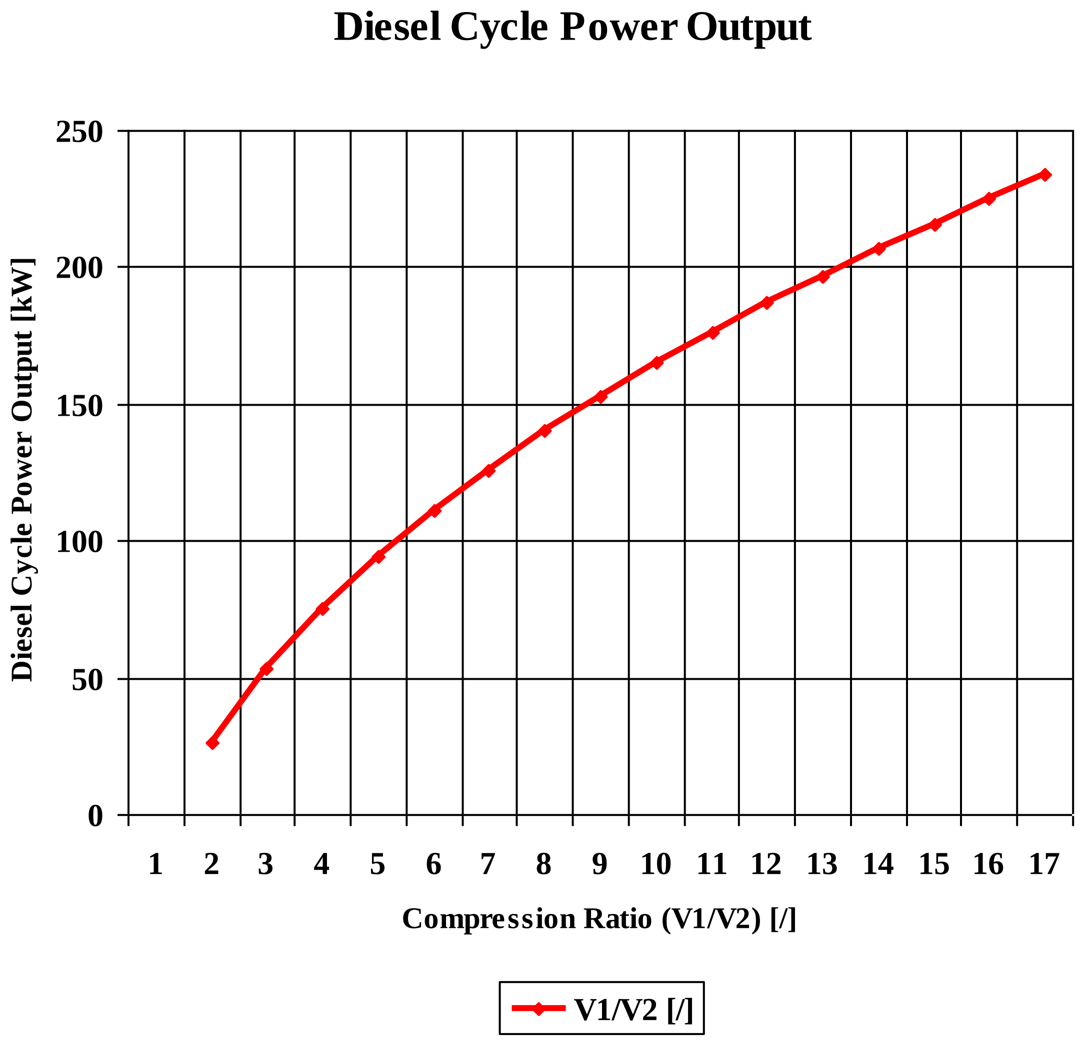
Working Fluid: Air

Diesel Cycle



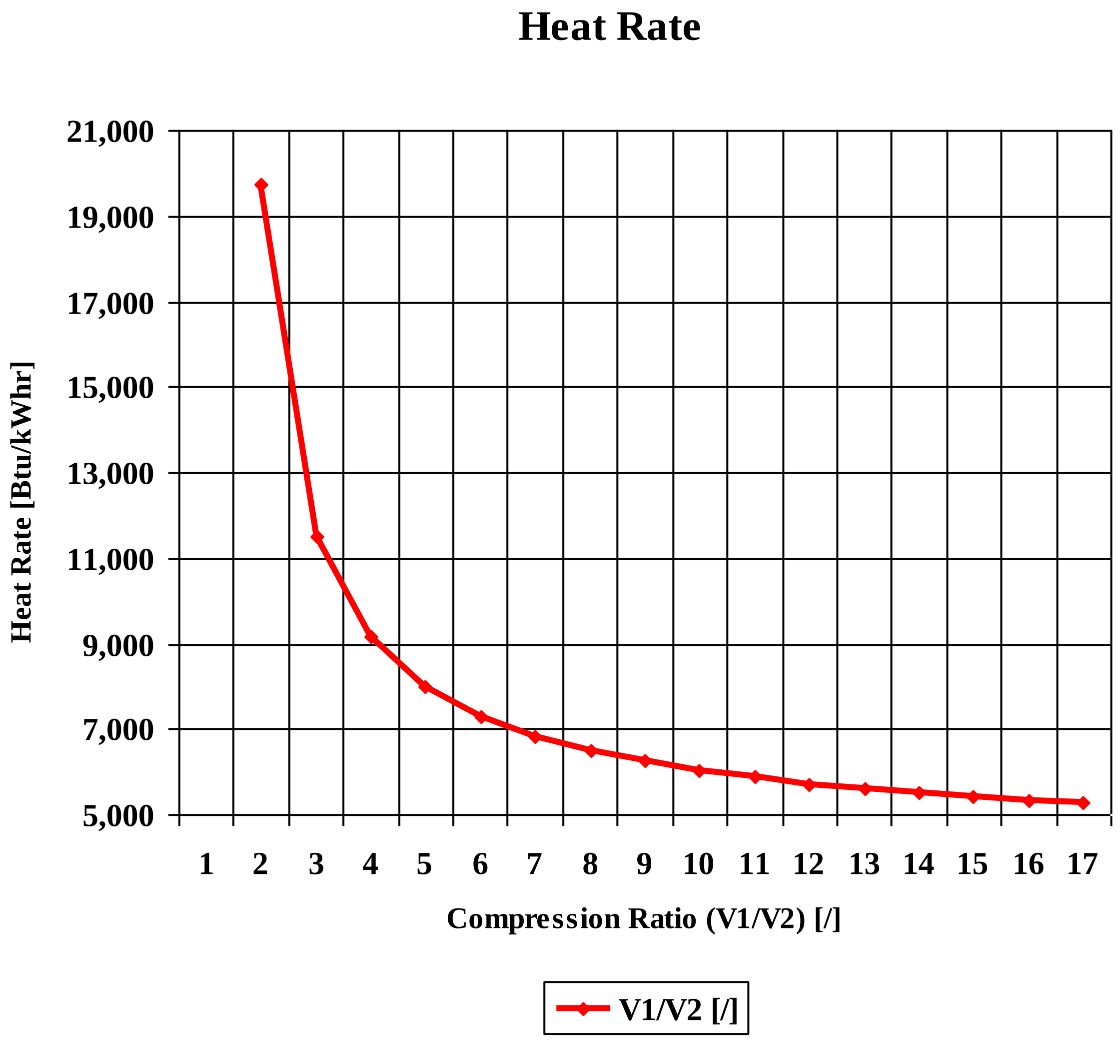
Working Fluid: Air

Diesel Cycle



Working Fluid: Air

Diesel Cycle



Working Fluid: Air

Power Cycles Analysis Conclusions

The Carnot Cycle efficiency increases with an increase in the heat addition temperature when the heat rejection temperature does not change at all. Furthermore, the Carnot Cycle efficiency decreases with an increase in the heat rejection temperature when the heat addition temperature does not change at all.

The Carnot Cycle efficiency is not dependent on the working fluid properties.

The Brayton Cycle specific power output increases with an increase in the gas turbine inlet temperature. Furthermore, the increase is greater for the higher compression ratio. The Brayton Cycle power output increases with an increase in the working fluid mass flow rate. The increase is greater for the higher compression ratio values.

The Otto Cycle efficiency increases with an increase in the compression ratio. Also, the Otto Cycle power output increases with an increase in the combustion temperature and the Otto Cycle power output is greater for higher compression ratio values.

The Diesel Cycle efficiency increases with an increase in the compression ratio and with a decrease in the cut off ratio values. Also, the Diesel Cycle power output increases with an increase in the compression ratio and the combustion temperature -- the Diesel Cycle power output is greater for lower cut off ratio values for given combustion temperature values.