Engineering Software

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

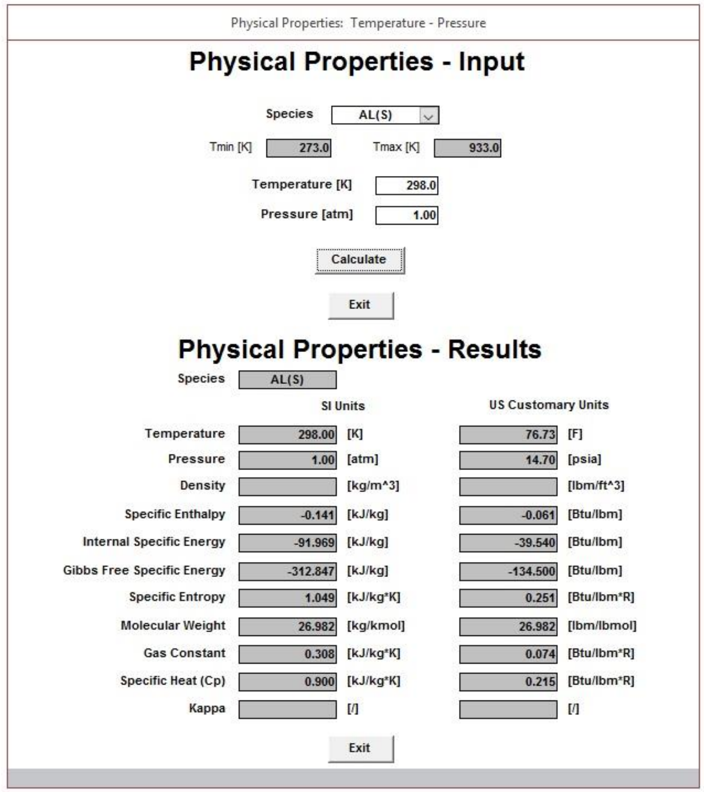
Product Line

Engineering Software has developed a new Windows based product line that quickly, easily and reliably calculates thermodynamic and transport properties of gaseous, liquid and solid species, contains coefficients for the calculation of physical properties -- the user has the capability to use the coefficients to carry out independent engineering calculations involving physical properties of various species, steam approximations for both saturated and superheated areas, analyzes power cycles, power cycle components/processes and compressible flow.

Benefits

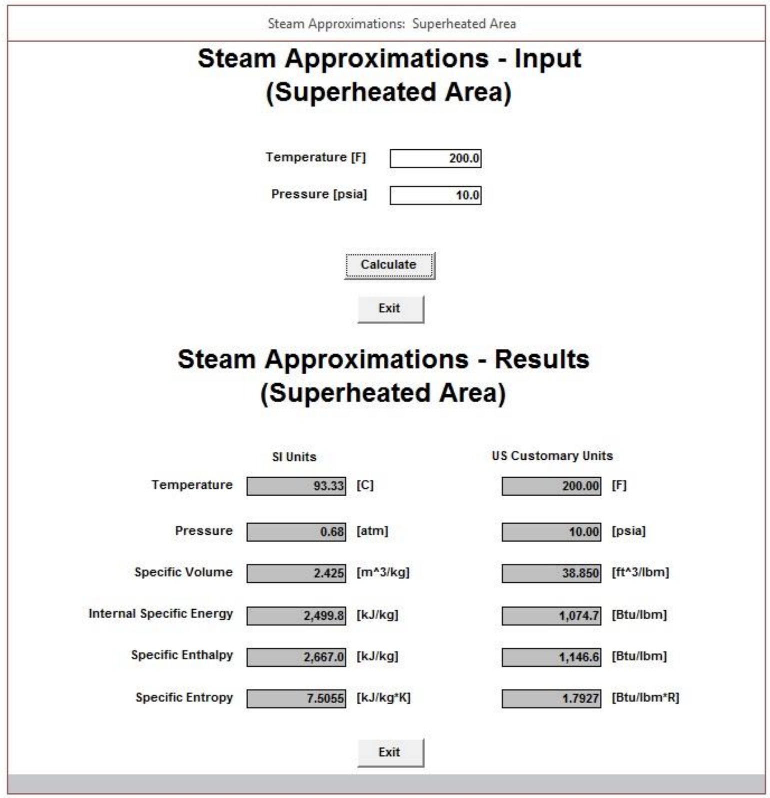
The **Engineering Software** product line should prove to be a good tool for those who are involved at various levels with design, operation and management of energy conversion systems. It should provide the user with the opportunity to more quickly, easily and effectively do his/her work, explore more options, save time and give more confidence in carrying out engineering calculations.

Physical Properties



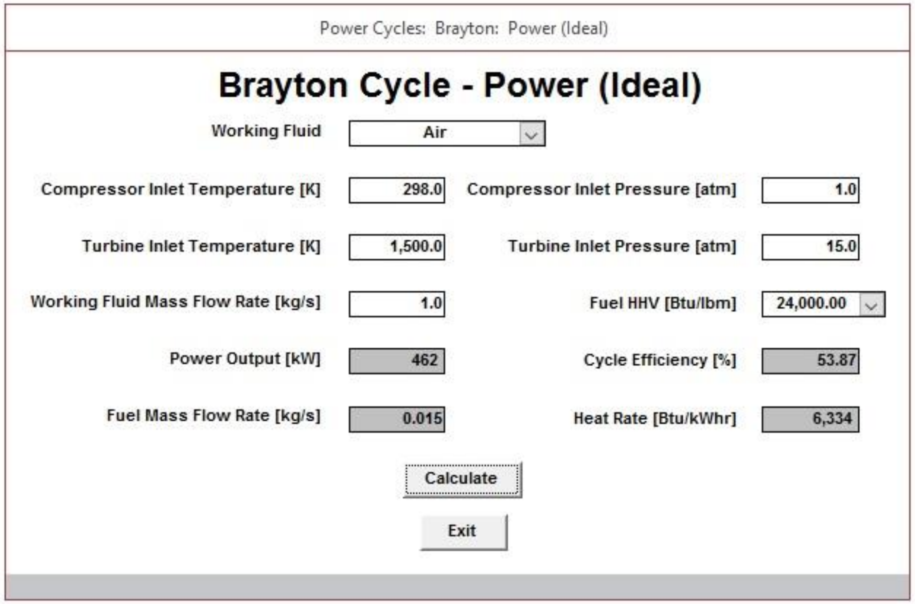
Physical properties of available species are provided for assigned two state values such as: temperature and pressure, enthalpy and pressure and entropy and pressure. Physical properties are given in both U.S. Customary and International Units.

Steam Approximations



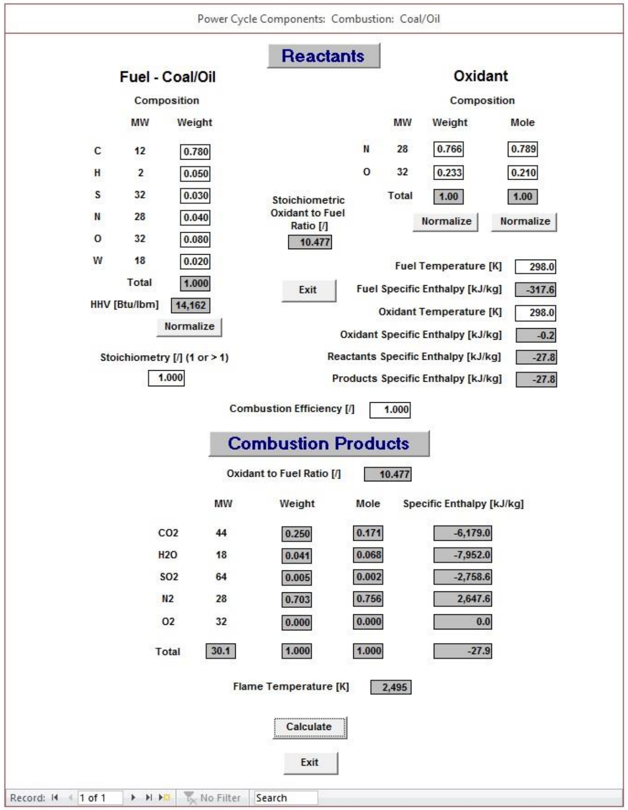
Provides steam approximations, steam table calculations are available for both saturated and superheated areas.

Power Cycle Analysis



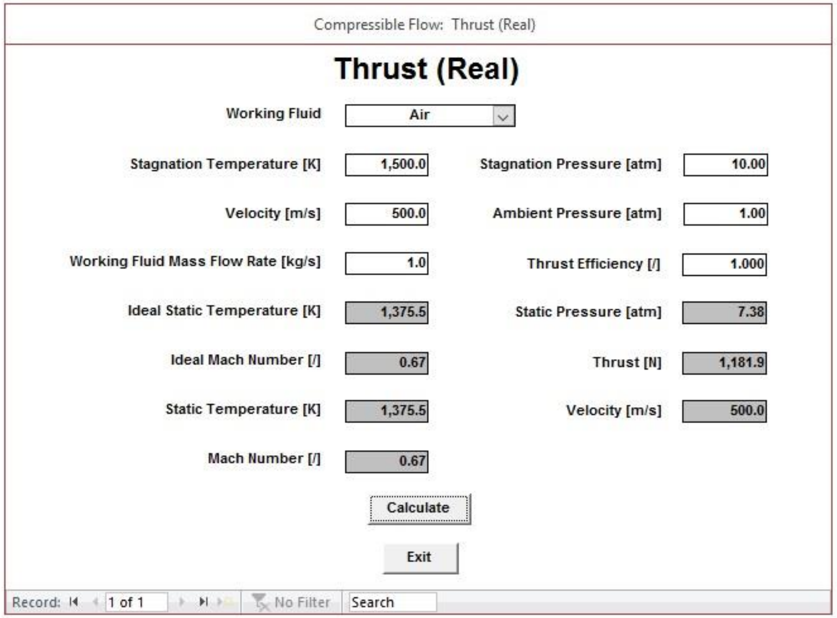
Provides analysis of a few power cycles (Carnot, Brayton, Rankine, Otto, Diesel, Magnetohydrodynamics and Fuel Cell).

Power Cycle Components/Processes



Provides analysis of power cycle components/processes (compression, combustion, expansion, heat transfer and mixing).

Compressible Flow



Provides analysis of compressible flow (velocity of sound, Mach number, stagnation and static properties, nozzle, diffuser, normal shock and thrust).

Claim Sheet

Engineering Software product line allows quick and reliable calculation of thermodynamic and transport properties of gaseous, liquid and solid species, contains coefficients for the calculation of physical properties, steam approximations for both saturated and superheated areas, provides analyses of power cycles, power cycle components/processes and compressible flow.

The aforementioned engineering calculations are valid under the following assumptions:

Thermodynamic and Transport Properties
- Single species consideration
- Ideal gas approach is used (pv=RT)
- Specific heat is not constant
- Coefficients describing thermodynamic and transport properties were obtained from the NASA Glenn Research Center at Lewis Field in Cleveland, OH -- such coefficients conform with the standard reference temperature of 298.15 K (77 F) and the JANAF Tables

Power Cycles
- Single species consideration -- fuel mass flow rate 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

Compressible Flow
- Single species consideration
- Basic equations hold (continuity, momentum and energy equations)
- Specific heat is constant

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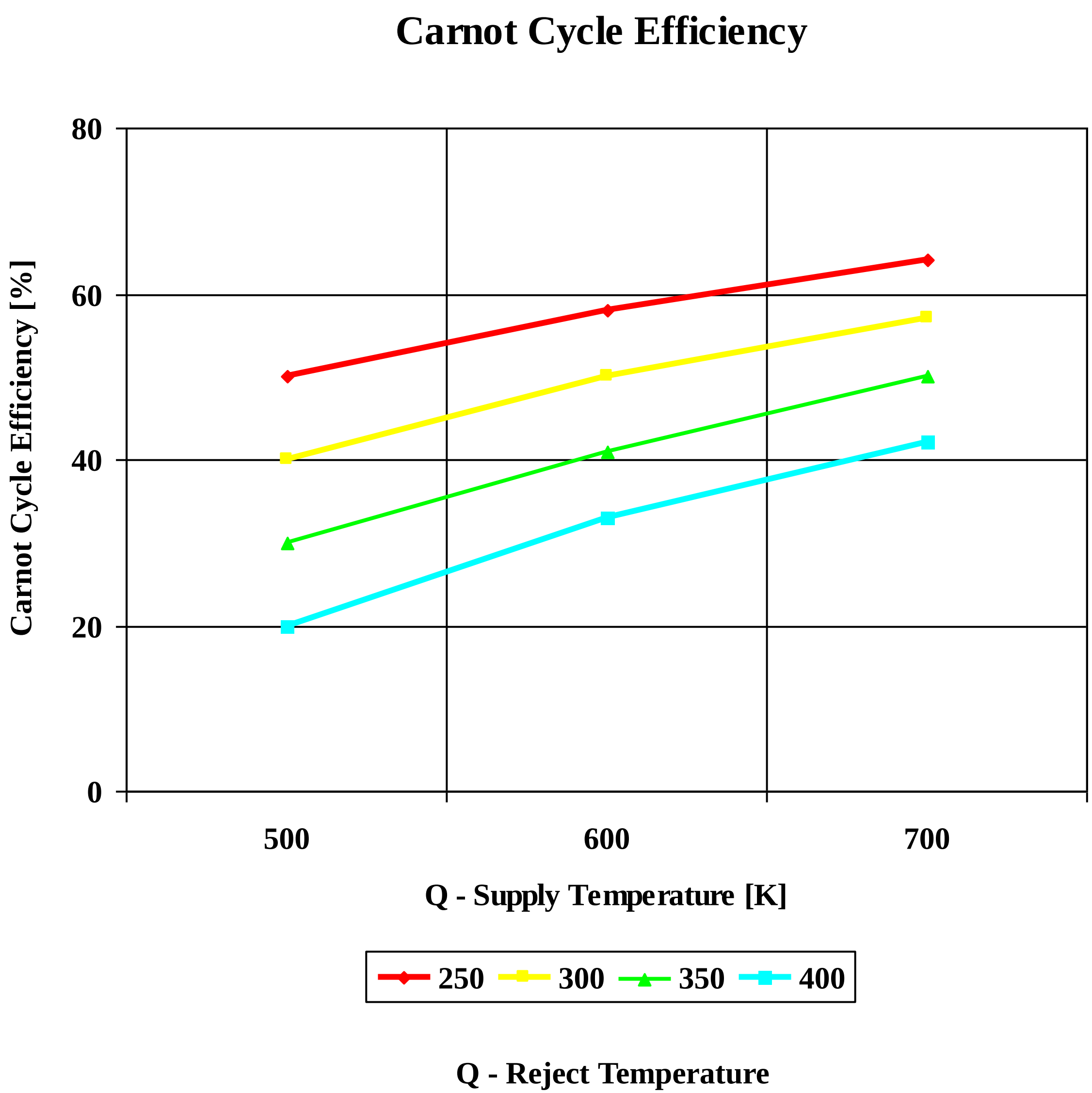
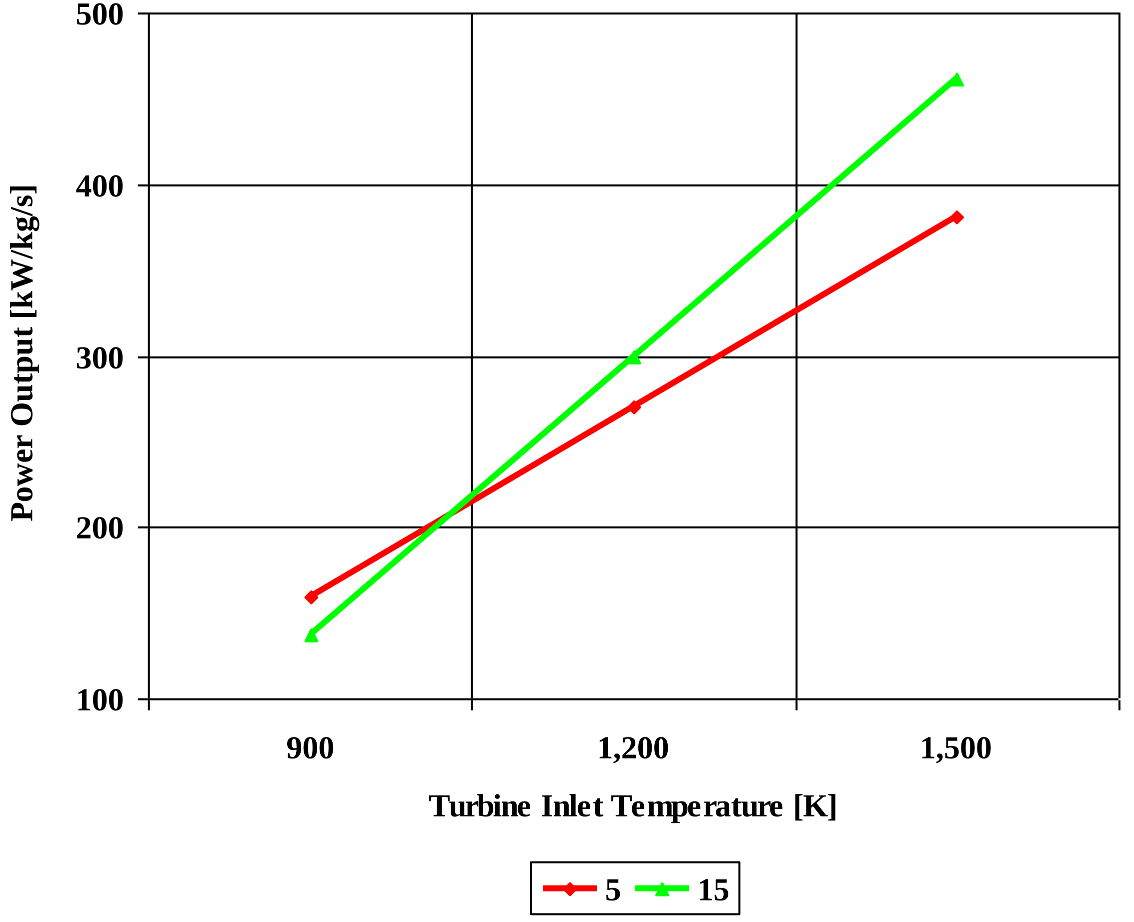
Engineering Plots

Here are some of the basic engineering plots related to energy conversion systems -- the engineering plots have been generated by the **Engineering Software** product line.

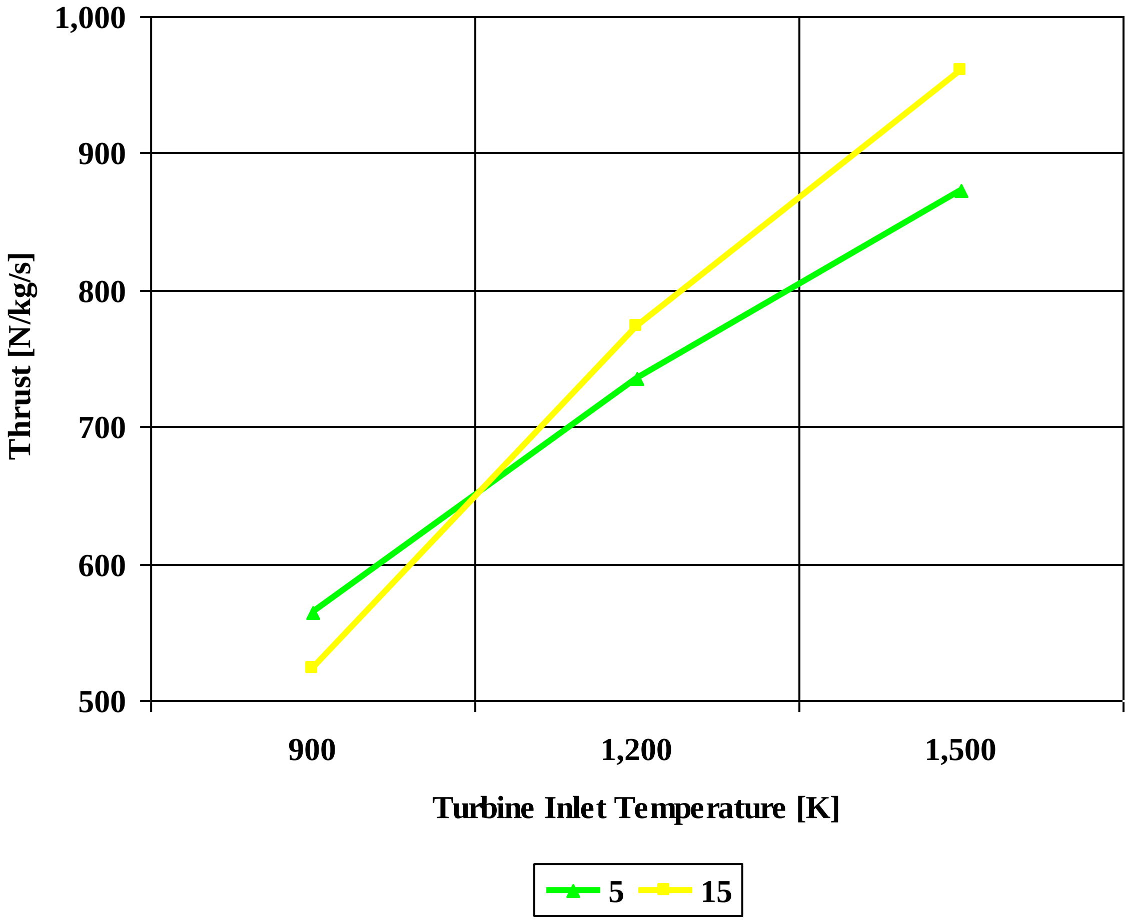

Carnot Cycle Efficiency
80
60
40
20
0
Carnot Cycle Efficiency [%]
500
600
700
Q - Supply Temperature [K]
250
300
350
400
Q - Reject Temperature

Brayton Cycle (Power)

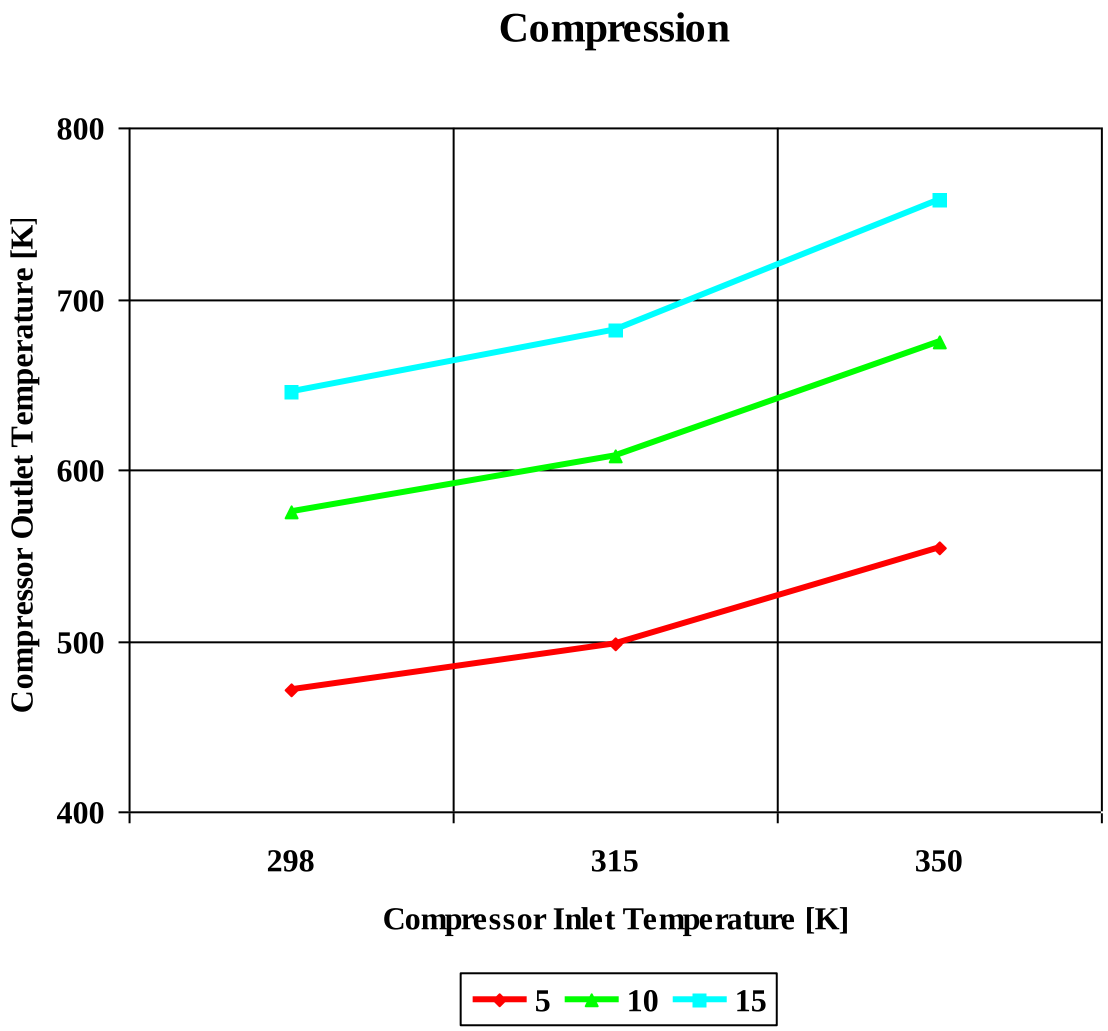


Compression Ratio (P2/P1) [/]
Working Fluid: Air
Isentropic Compression and Expansion

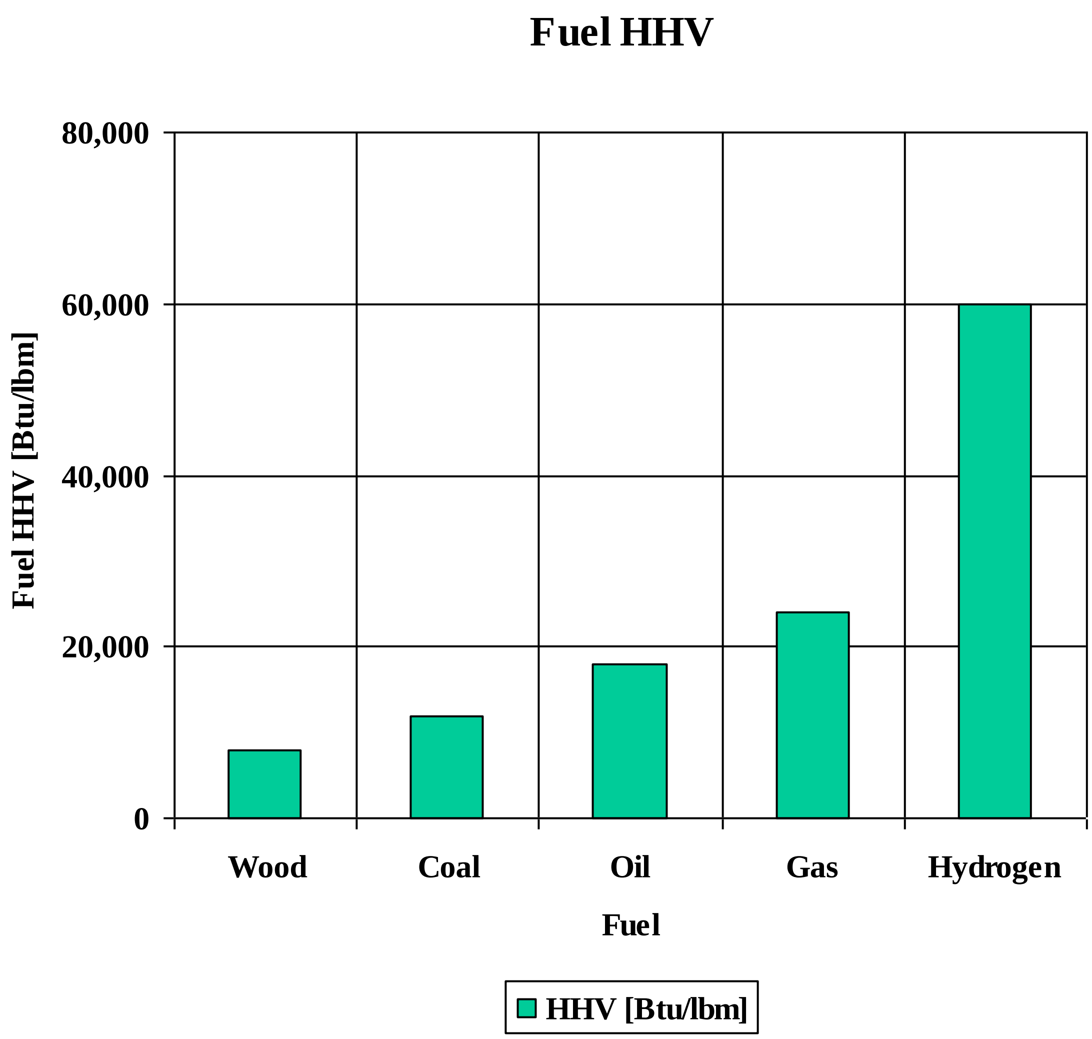
Brayton Cycle (Propulsion)



Compression Ratio (P2/P1) [/]
Working Fluid: Air
Isentropic Compression and Expansion



Compression Ratio (P2/P1) [/]
Working Fluid: Air
Isentropic Compression


Fuel HHV
80,000
60,000
40,000
20,000
0
Fuel HHV [Btu/lbm]
Wood
Coal
Oil
Gas
Hydrogen
Fuel
HHV [Btu/lbm]

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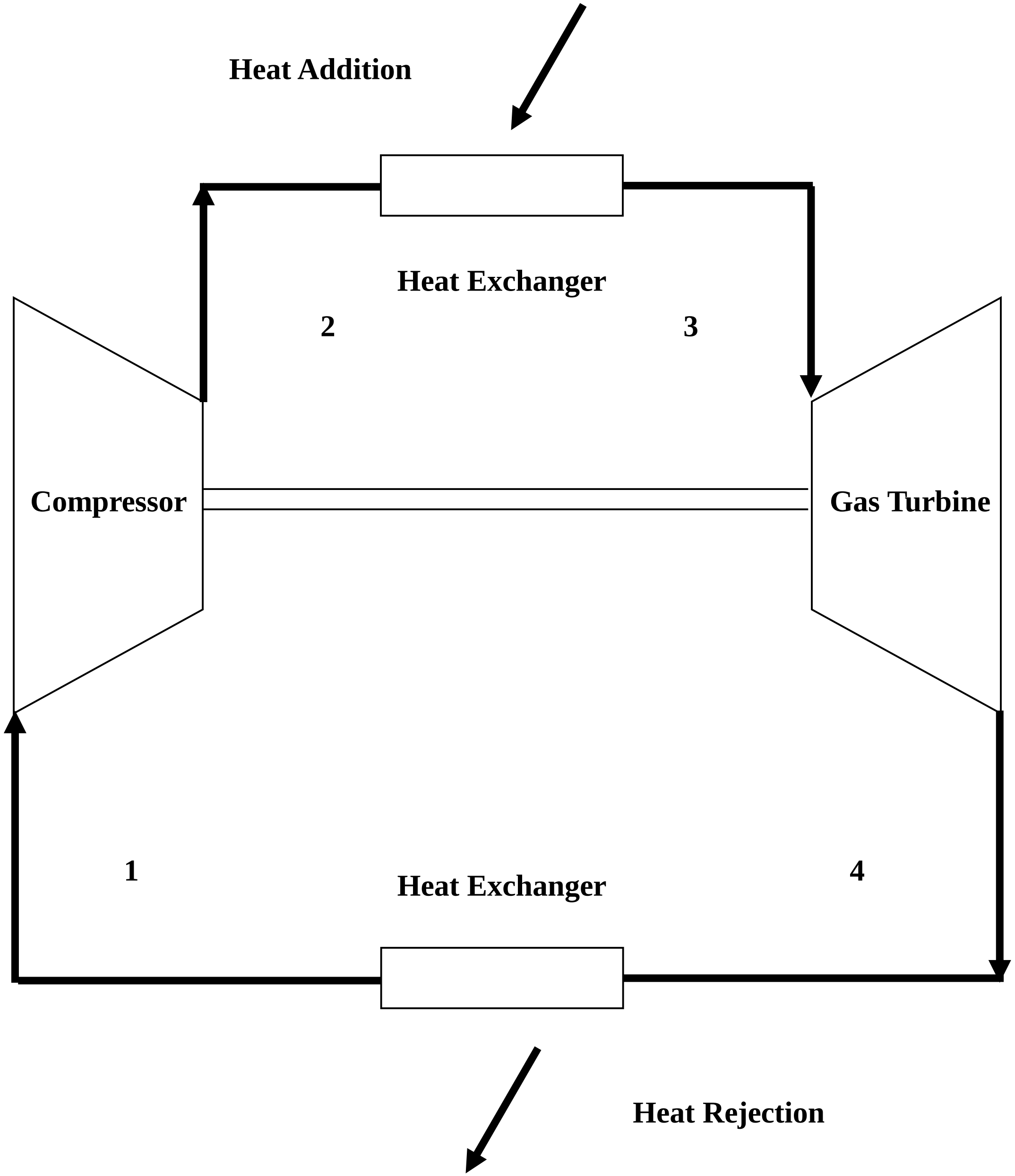
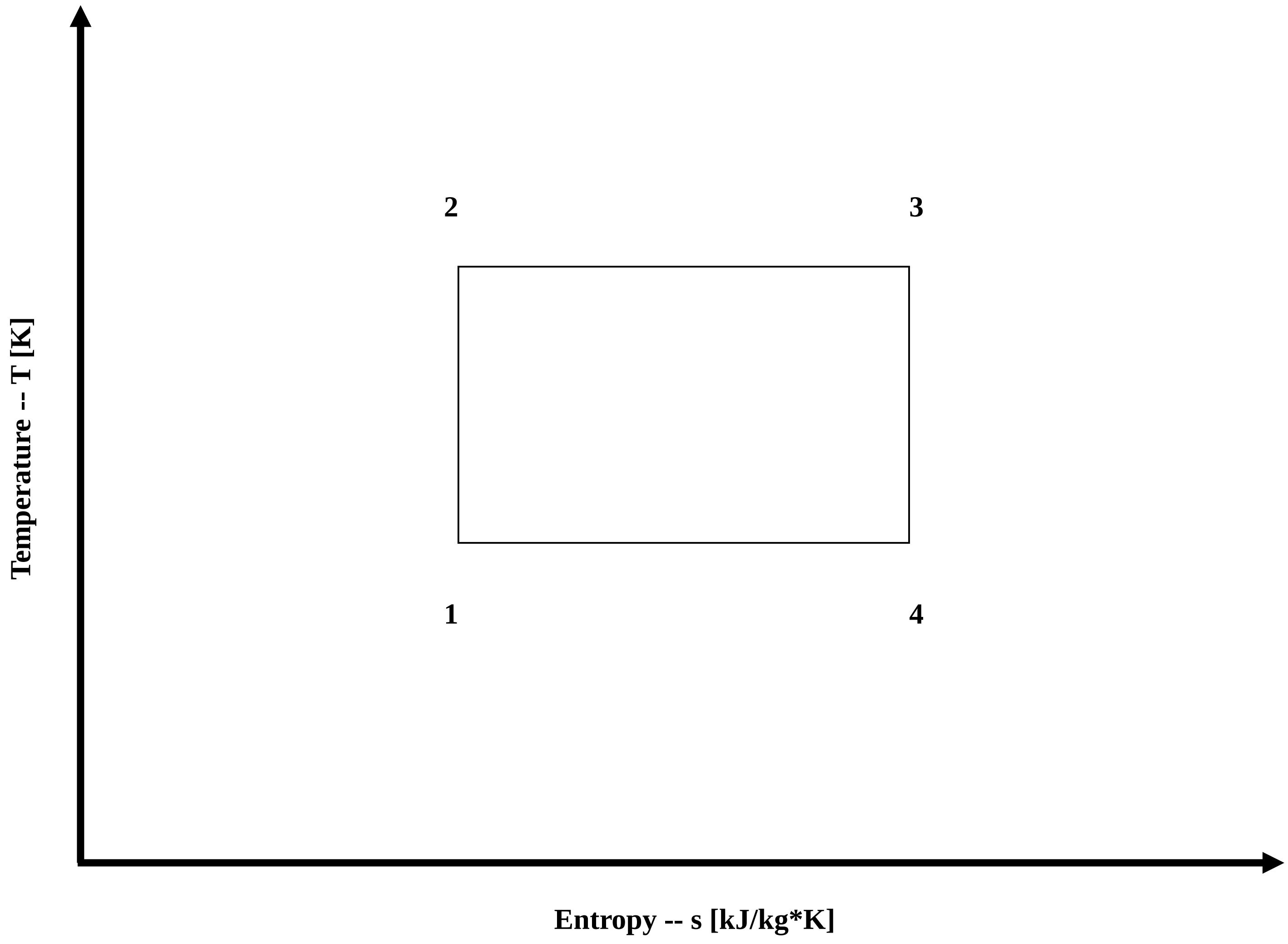
Carnot Cycle Analysis

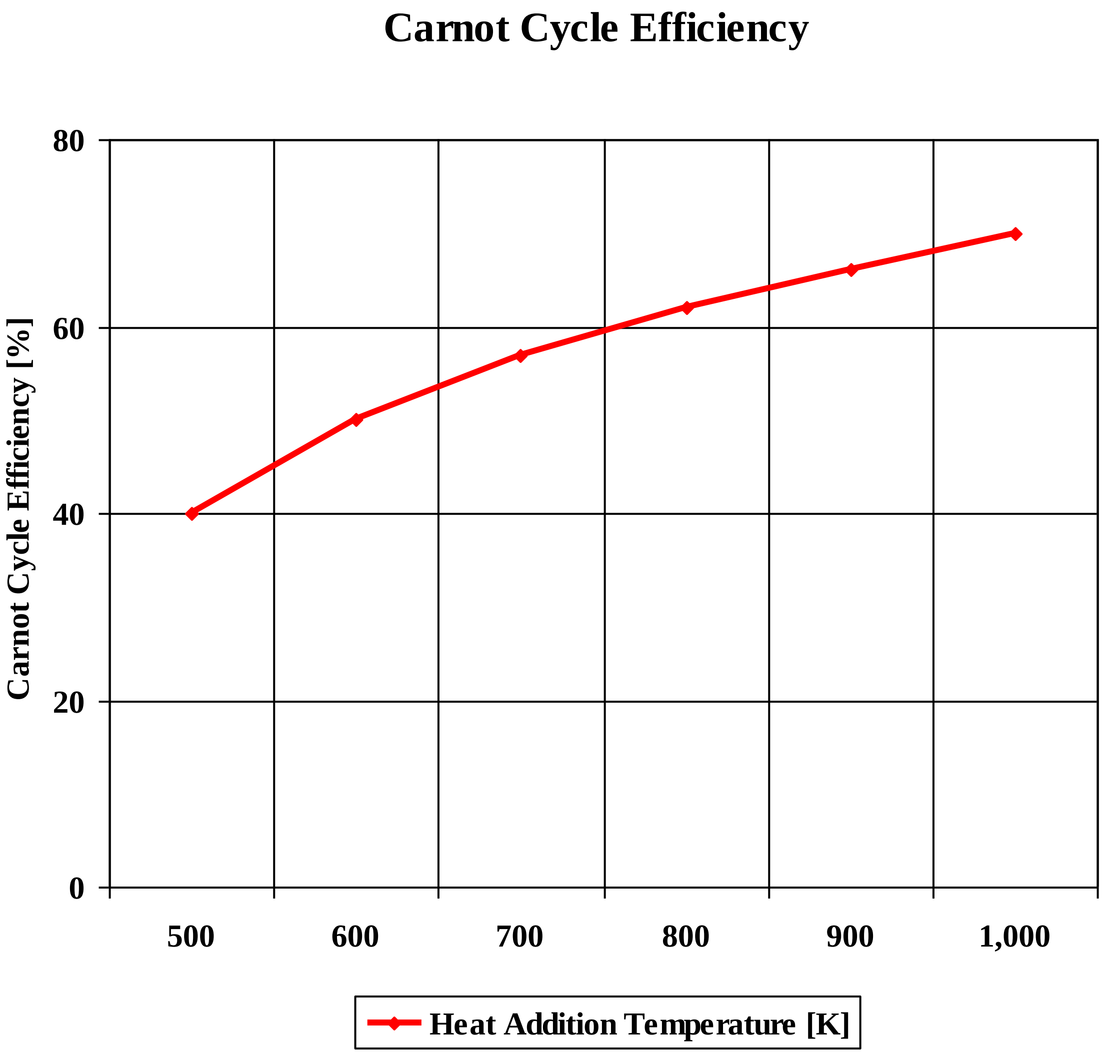
Here are some of the basic Carnot Cycle plots.

Carnot Cycle Schematic Layout

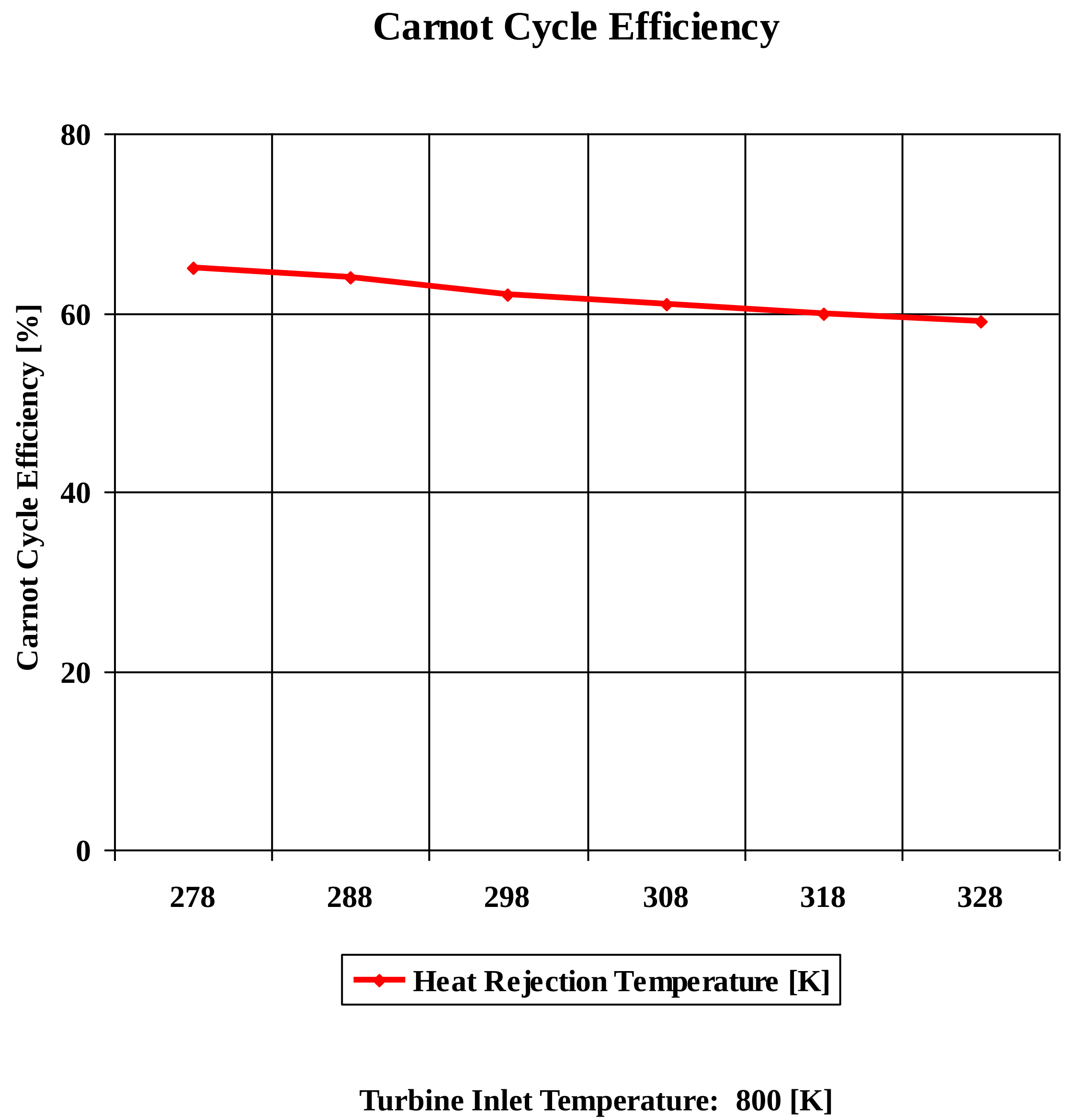




Carnot Cycle T - s Diagram



Compressor Inlet Temperature: 298 [K]


Carnot Cycle Efficiency
Carnot Cycle Efficiency [%]
80
60
40
20
0
278
288
298
308
318
328
Heat Rejection Temperature [K]
Turbine Inlet Temperature: 800 [K]

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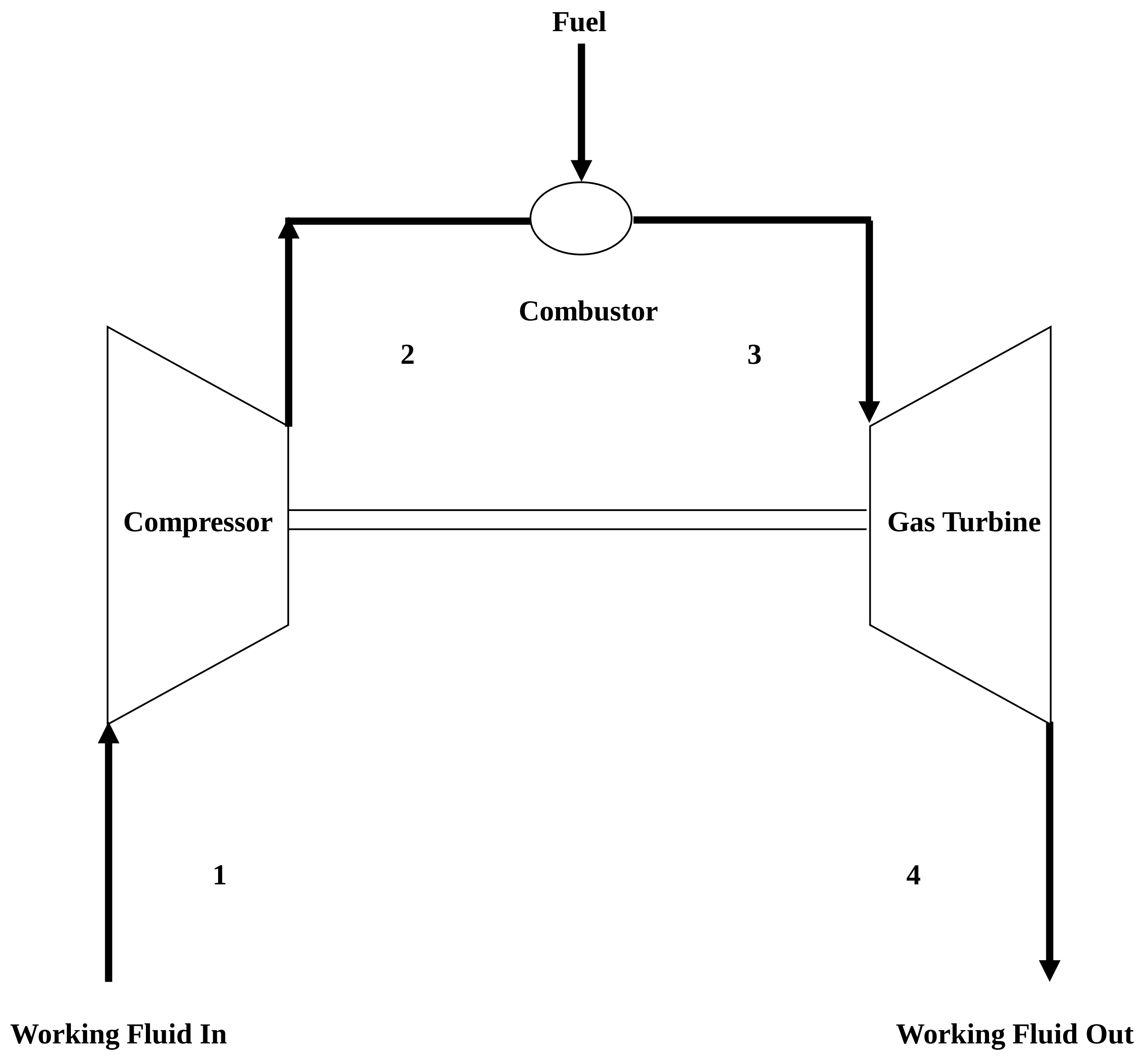
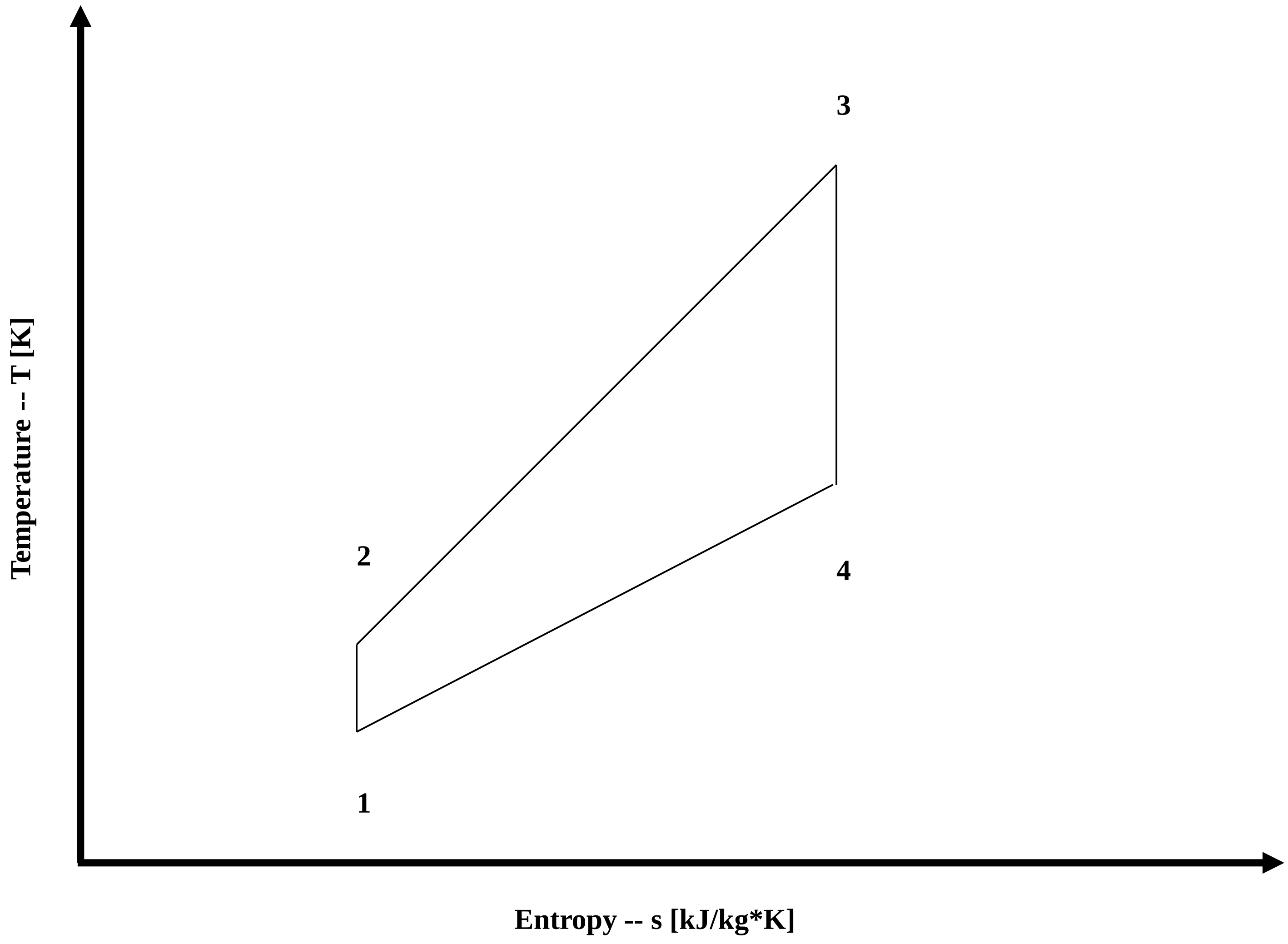
Brayton Cycle (Gas Turbine) Analysis

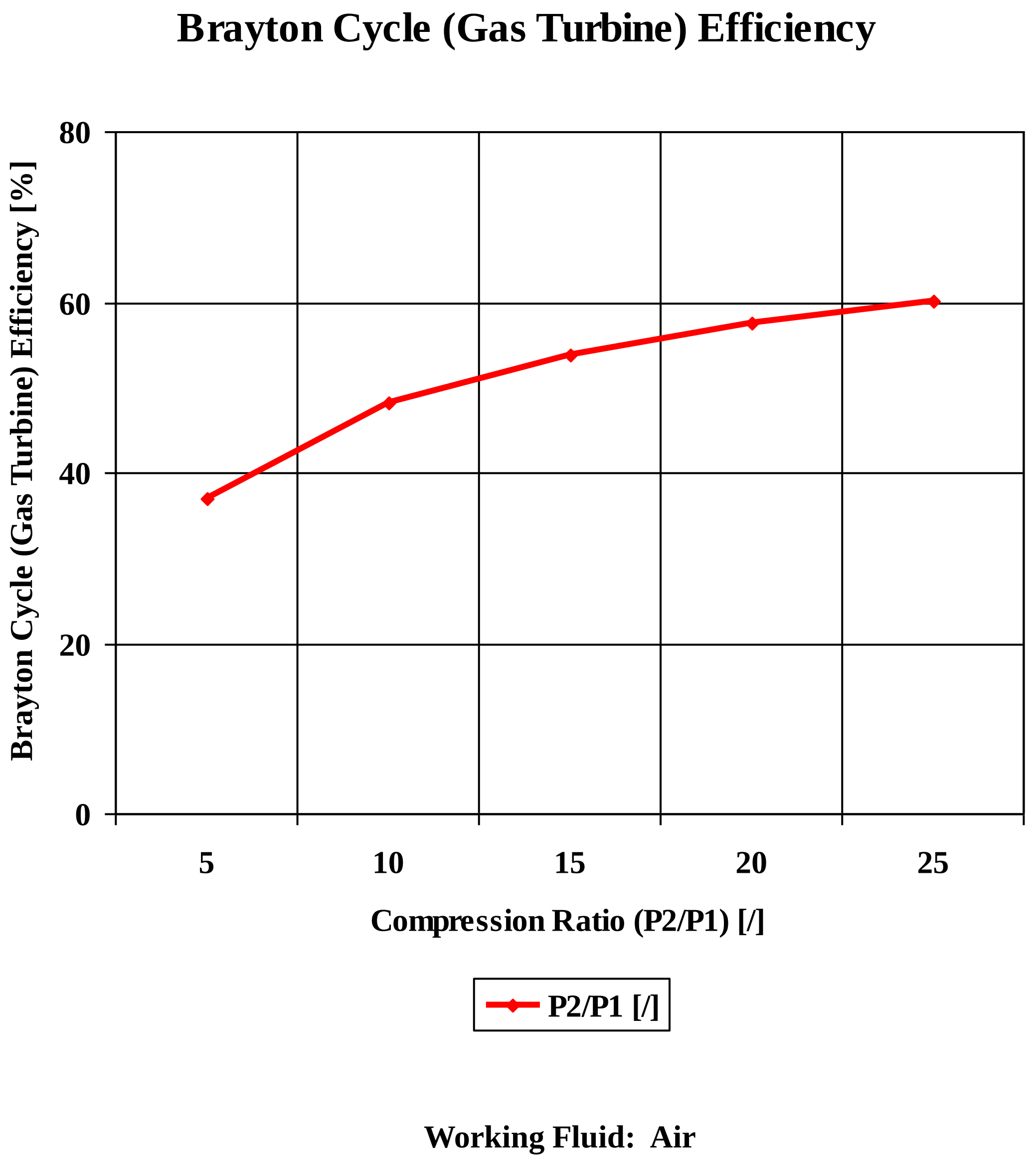
Here are some of the basic Brayton Cycle (Gas Turbine) plots for power and propulsion applications.

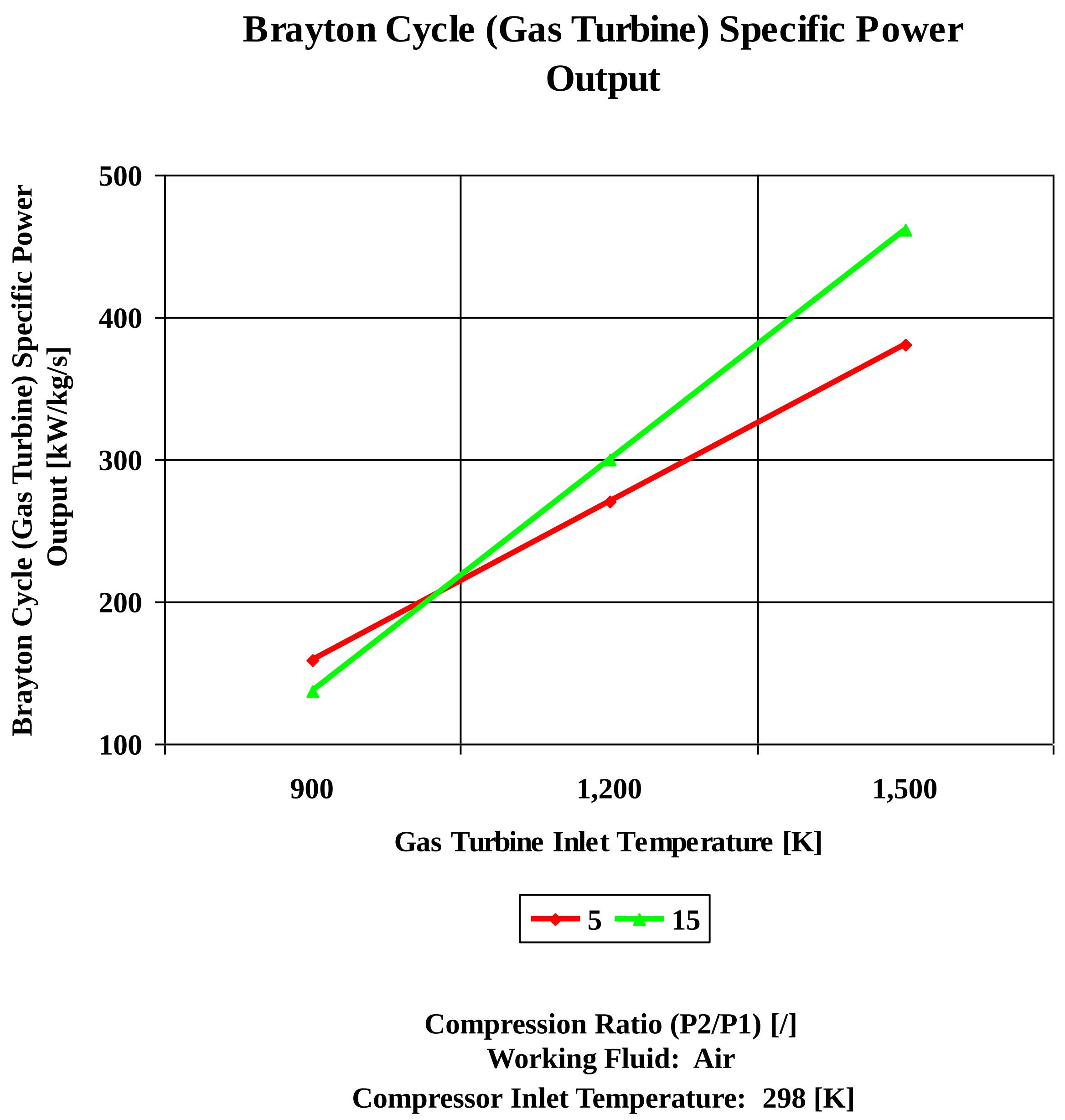


Brayton Cycle (Gas Turbine) Schematic Layout

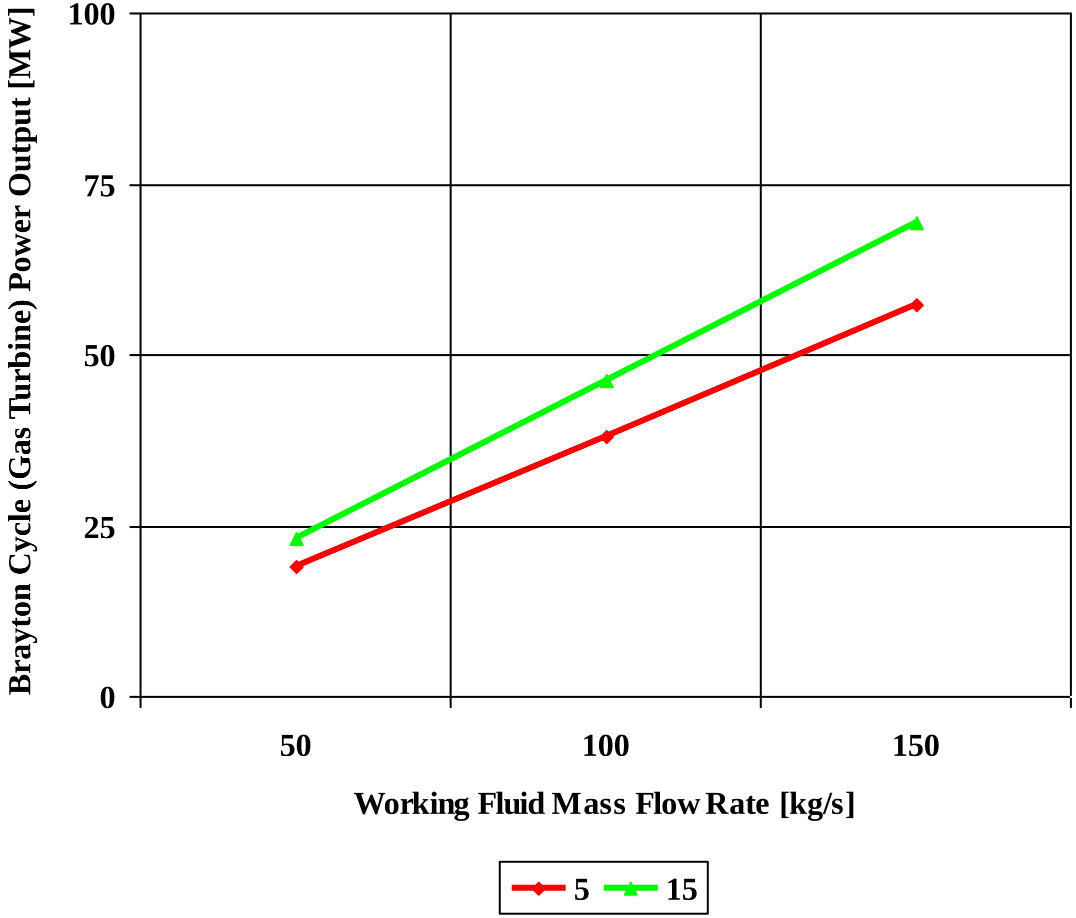


Brayton Cycle (Gas Turbine) T - s Diagram

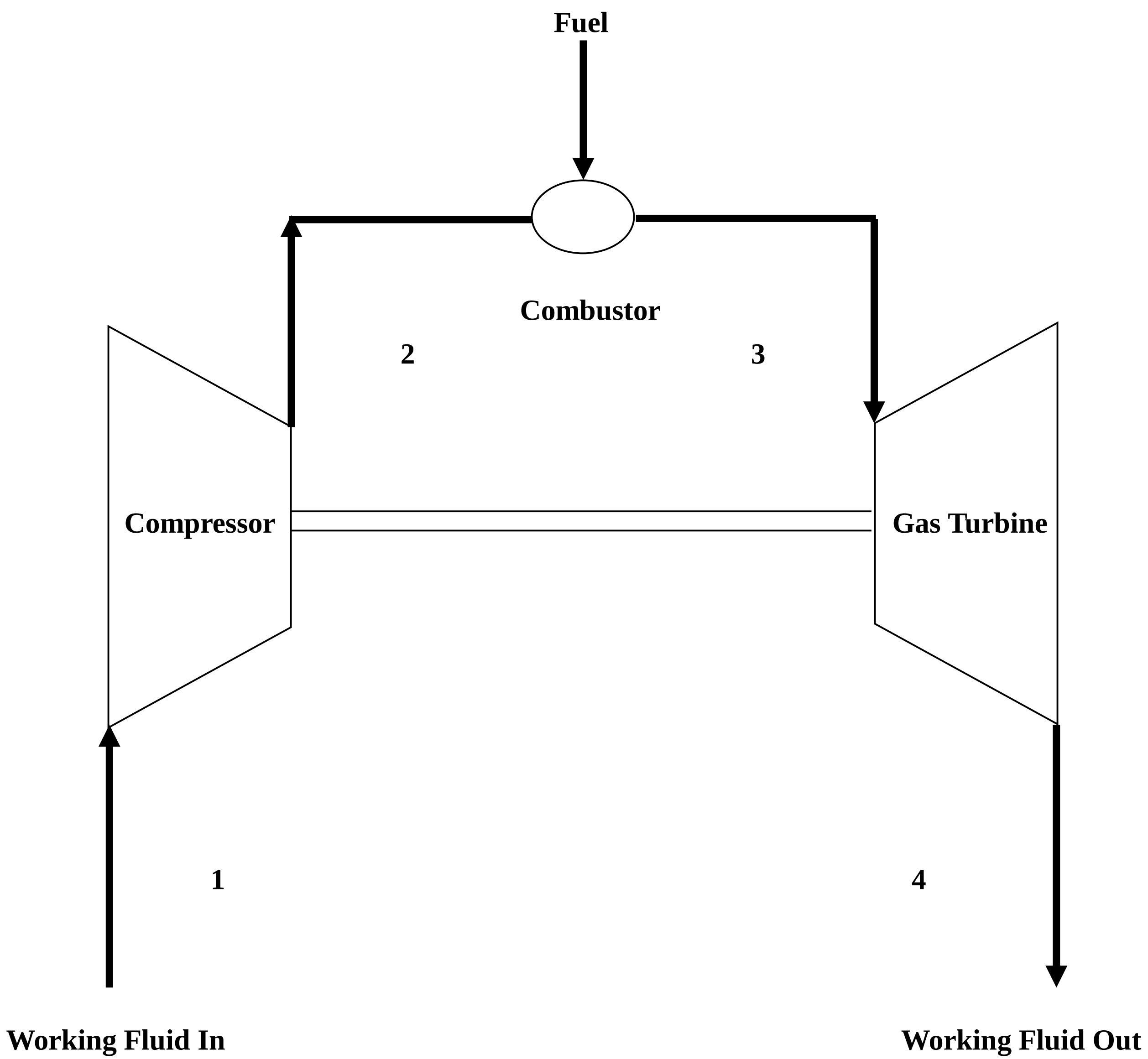

Brayton Cycle (Gas Turbine) Efficiency
Brayton Cycle (Gas Turbine) Efficiency [%]
0
20
40
60
80
5
10
15
20
25
Compression Ratio (P2/P1) [/]
P2/P1 [/]
Working Fluid: Air


Brayton Cycle (Gas Turbine) Specific Power Output
Brayton Cycle (Gas Turbine) Specific Power Output [kW/kg/s]
500
400
300
200
100
900
1,200
1,500
Gas Turbine Inlet Temperature [K]
5
15
Compression Ratio (P2/P1) [/]
Working Fluid: Air
Compressor Inlet Temperature: 298 [K]

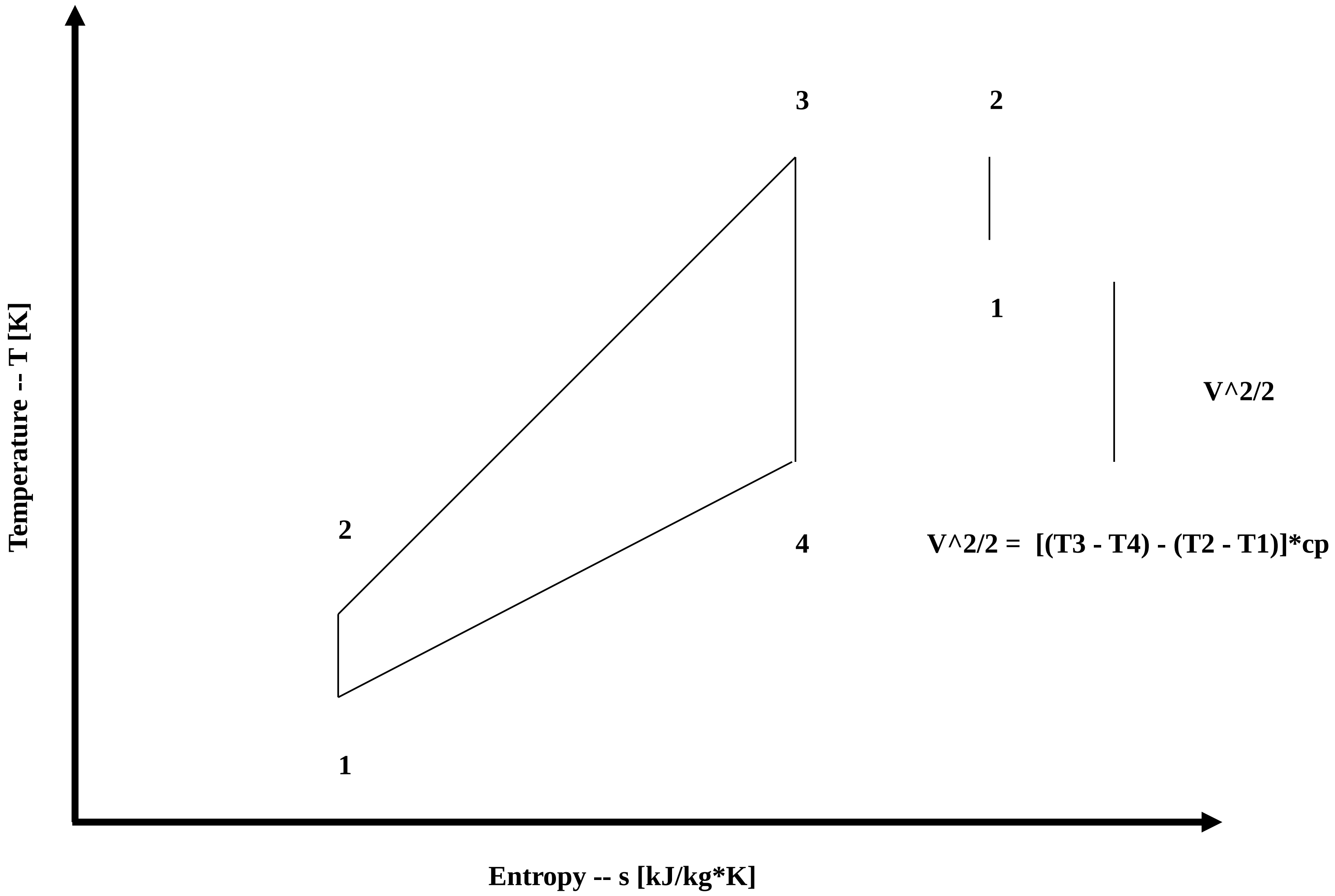
Brayton Cycle (Gas Turbine) Power Output



Compression Ratio (P2/P1) [/]
Working Fluid: Air
Compressor Inlet Temperature: 298 [K] -- Gas Turbine Inlet Temperature: 1,500 [K]

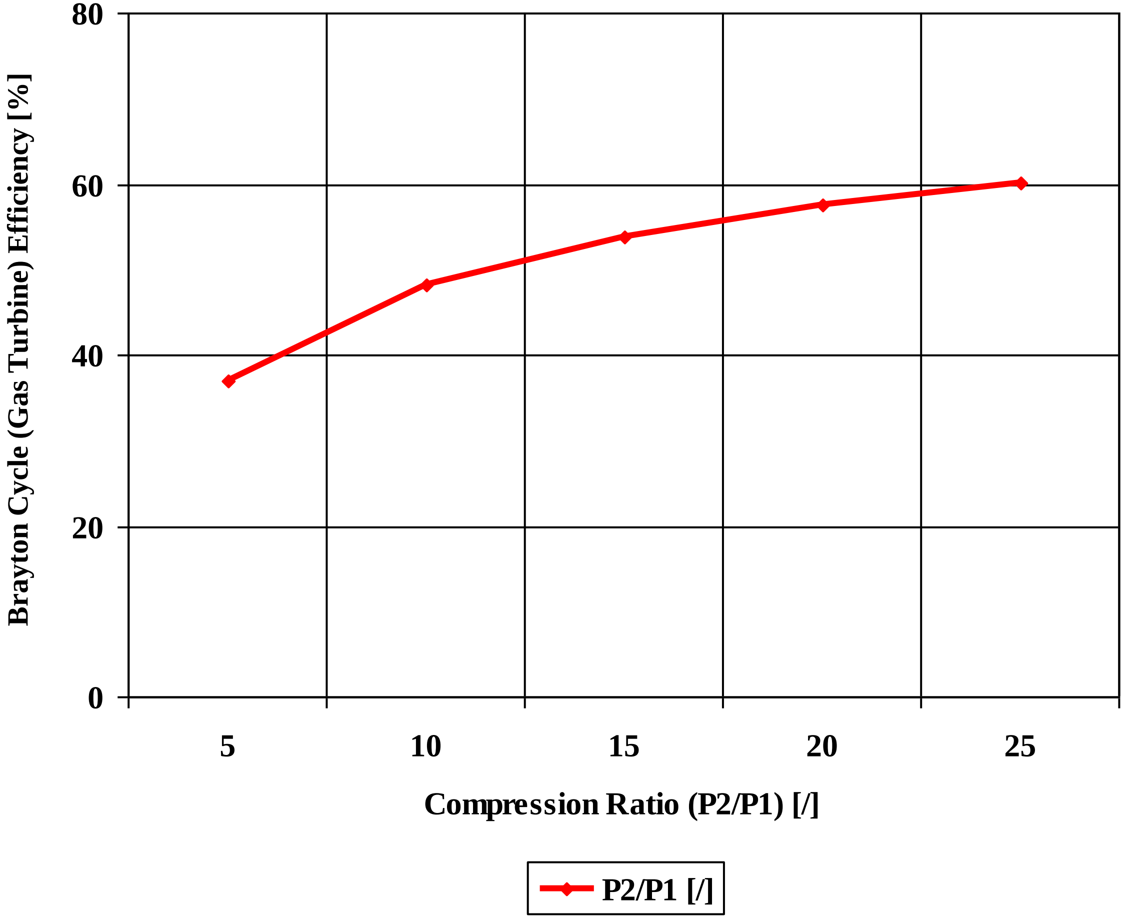


Brayton Cycle (Gas Turbine) Schematic Layout



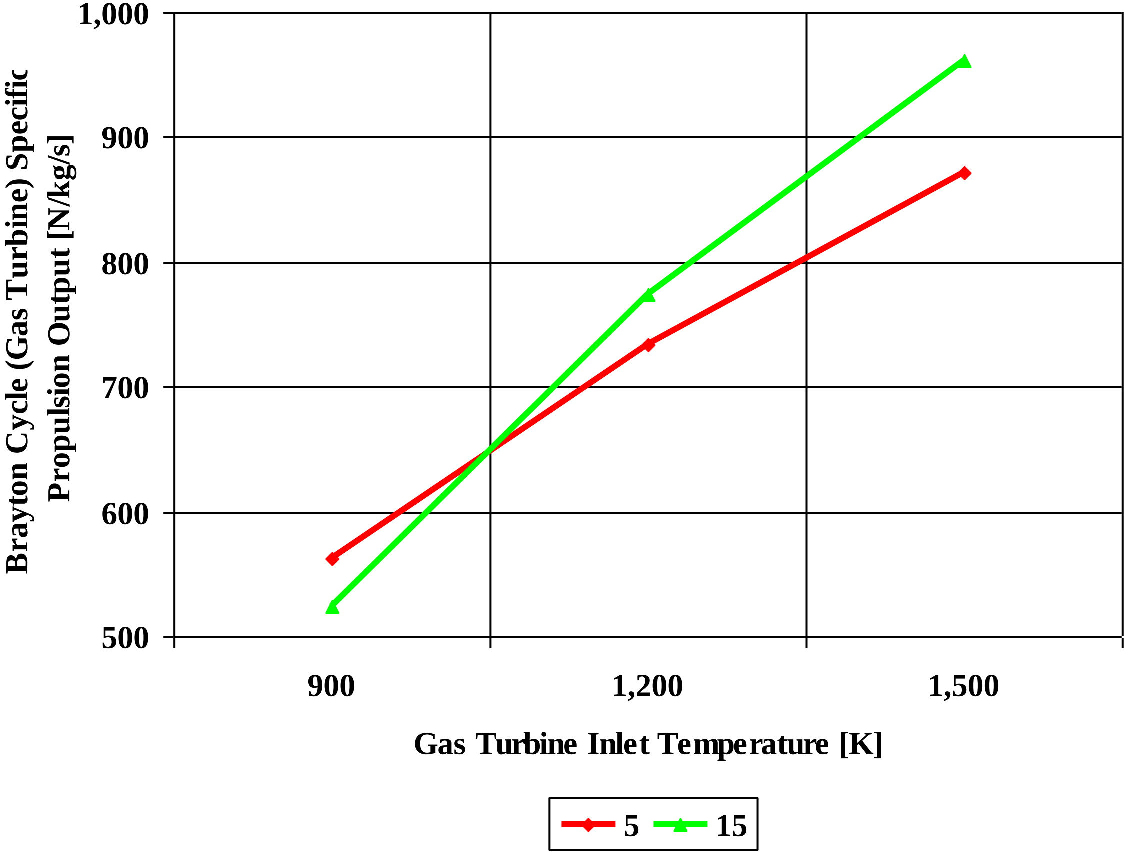
Brayton Cycle (Gas Turbine) T - s Diagram

Brayton Cycle (Gas Turbine) Efficiency



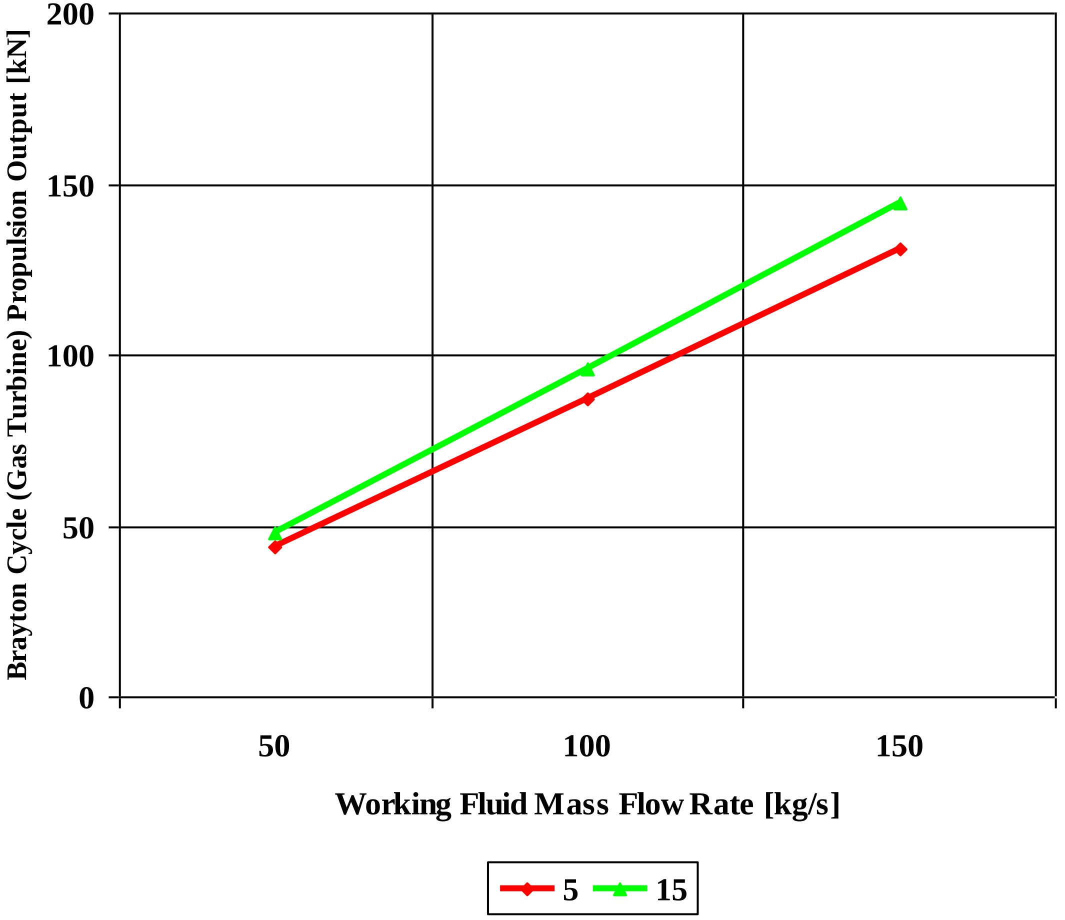
Working Fluid: Air

Brayton Cycle (Gas Turbine) Specific Propulsion Output



Compression Ratio (P2/P1) [/]
Working Fluid: Air
Compressor Inlet Temperature: 298 [K]

Brayton Cycle (Gas Turbine) Propulsion Output



Compression Ratio (P2/P1) [/]
Working Fluid: Air
Compressor Inlet Temperature: 298 [K] -- Gas Turbine Inlet Temperature: 1,500 [K]

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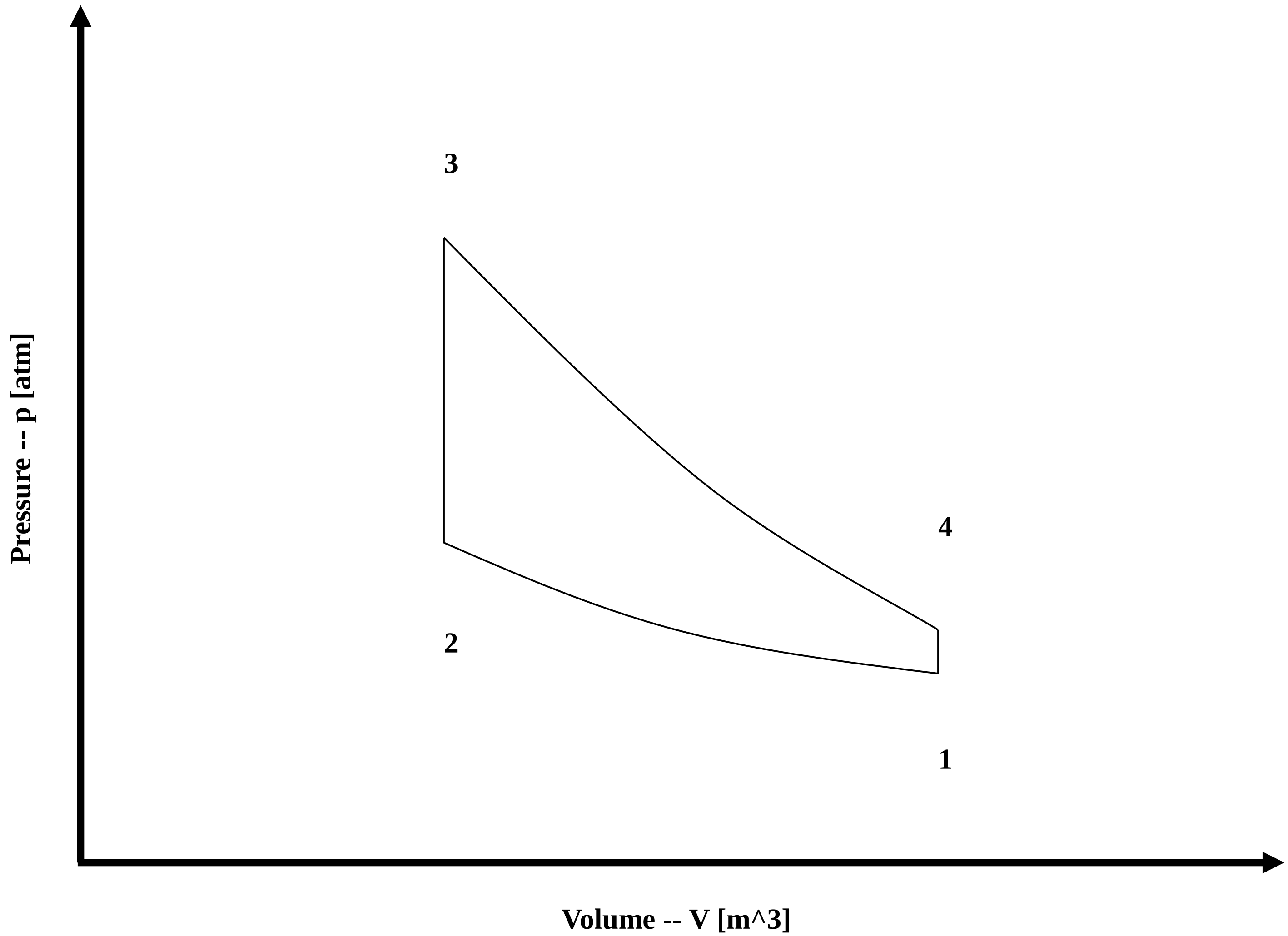
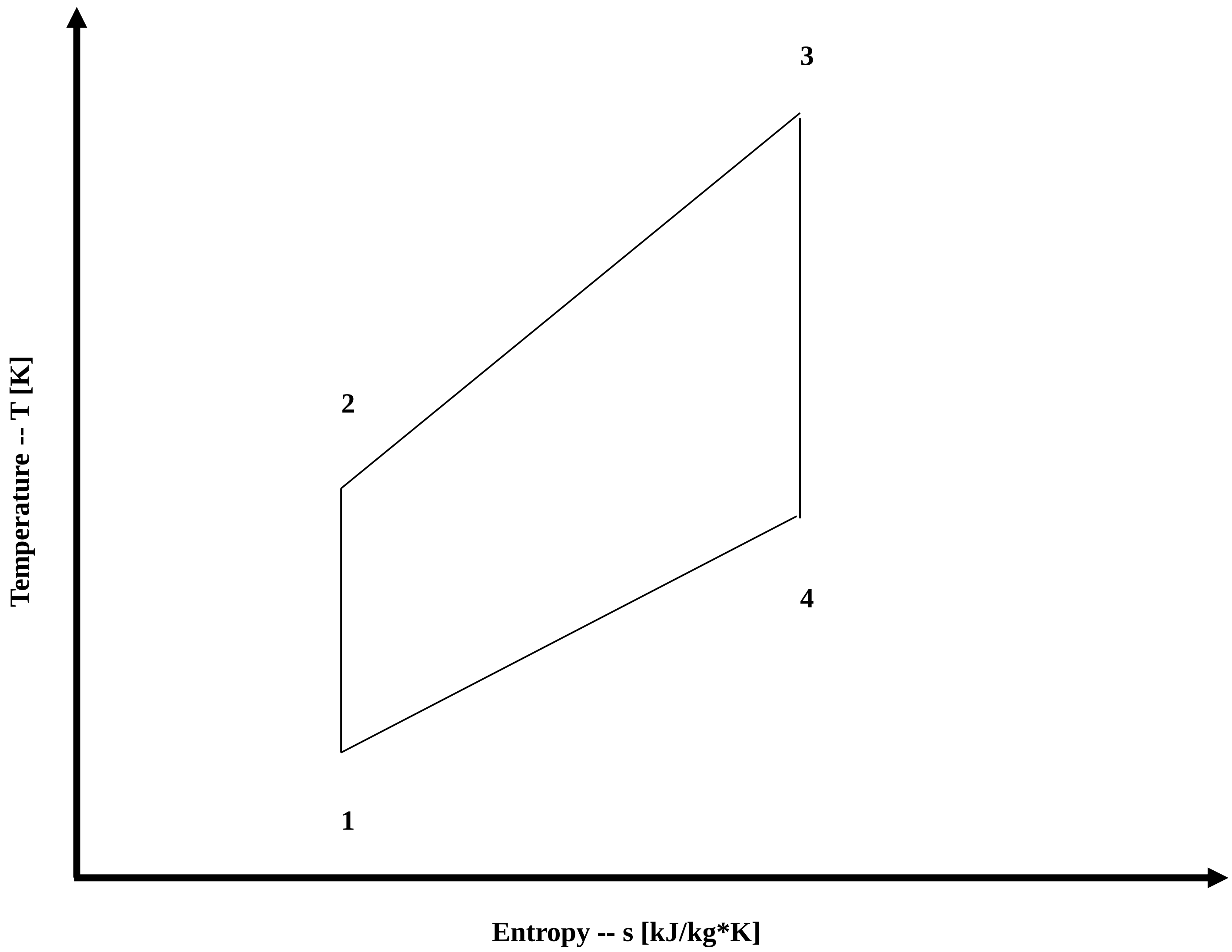
Otto Cycle Analysis

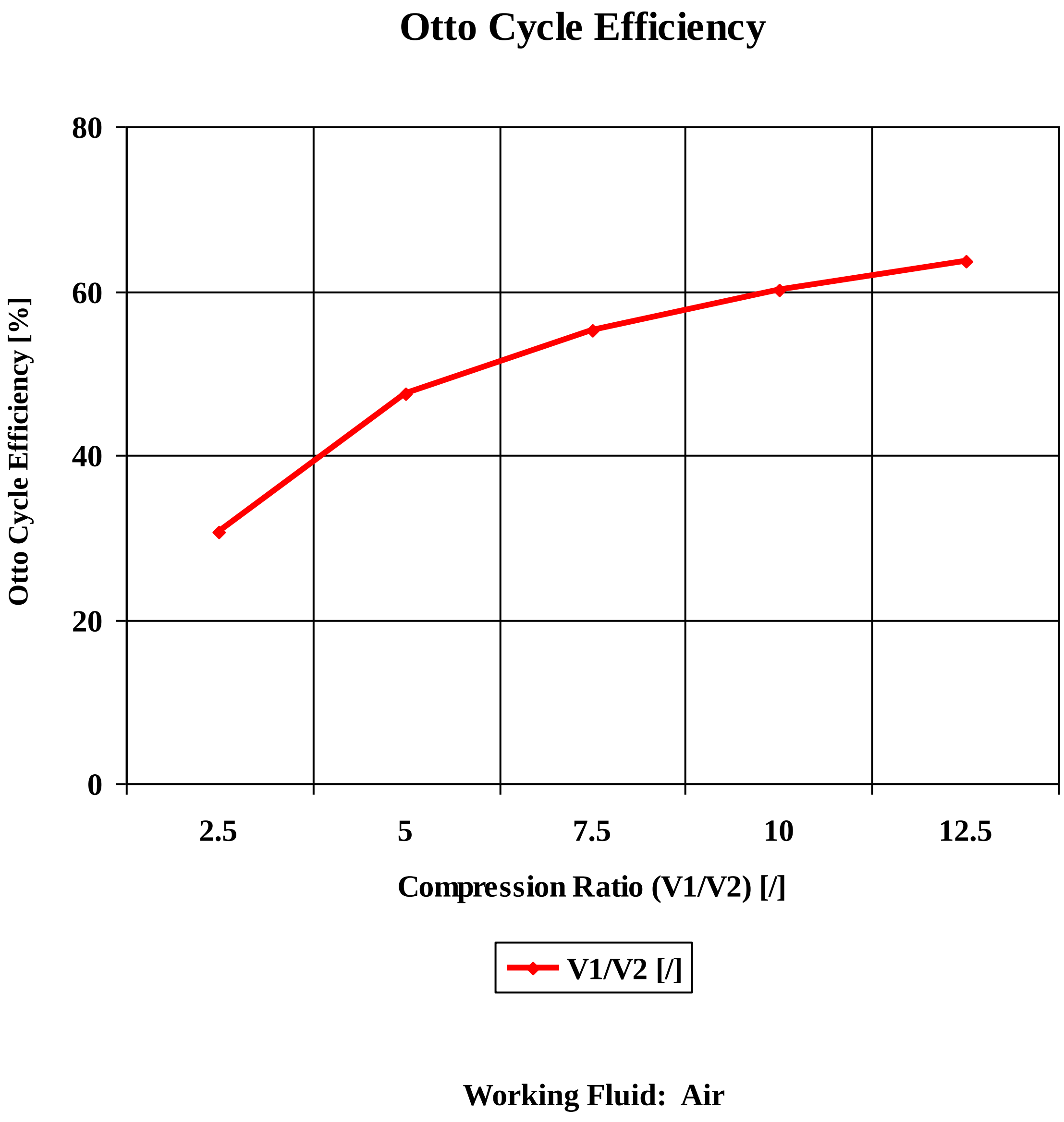
Here are some of the basic Otto Cycle plots.

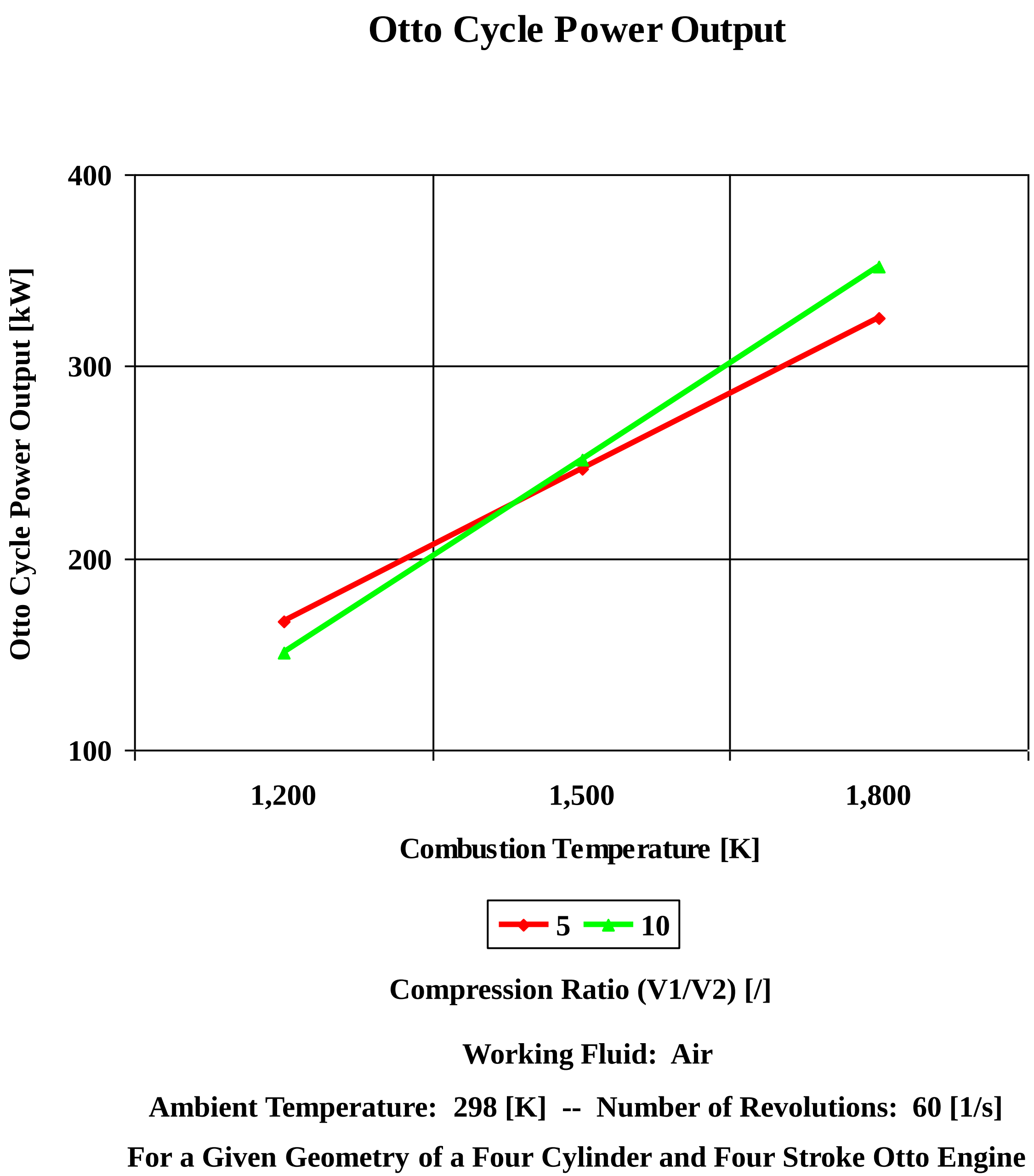


Otto Cycle p - V Diagram



Otto Cycle T - s Diagram


Otto Cycle Efficiency
80
60
40
20
0
Otto Cycle Efficiency [%]
2.5
5
7.5
10
12.5
Compression Ratio (V1/V2) [/]
V1/V2 [/]
Working Fluid: Air


Otto Cycle Power Output
400
300
200
100
Otto Cycle Power Output [kW]
1,200
1,500
1,800
Combustion Temperature [K]
5
10
Compression Ratio (V1/V2) [/]
Working Fluid: Air
Ambient Temperature: 298 [K] -- Number of Revolutions: 60 [1/s]
For a Given Geometry of a Four Cylinder and Four Stroke Otto Engine

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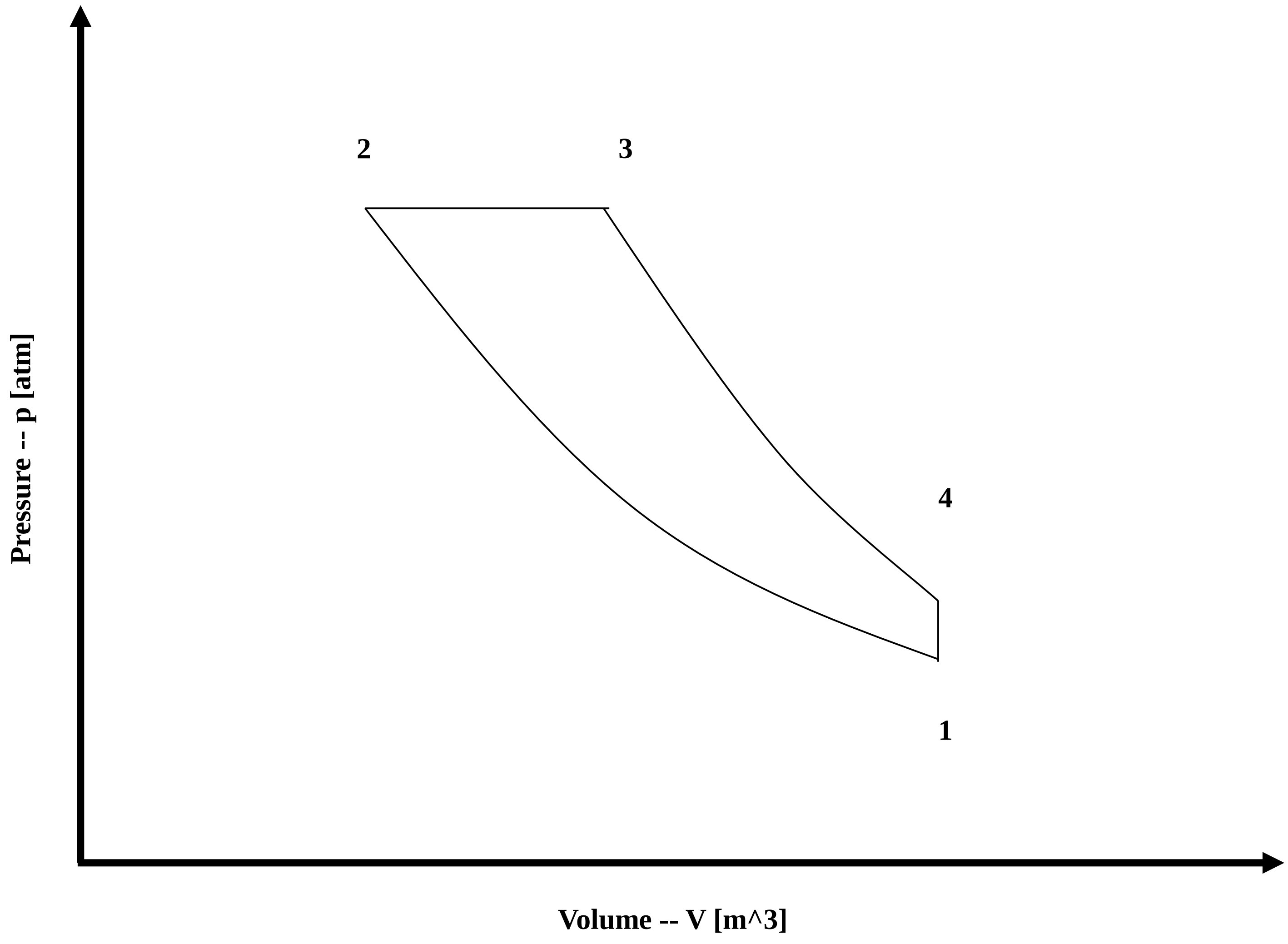
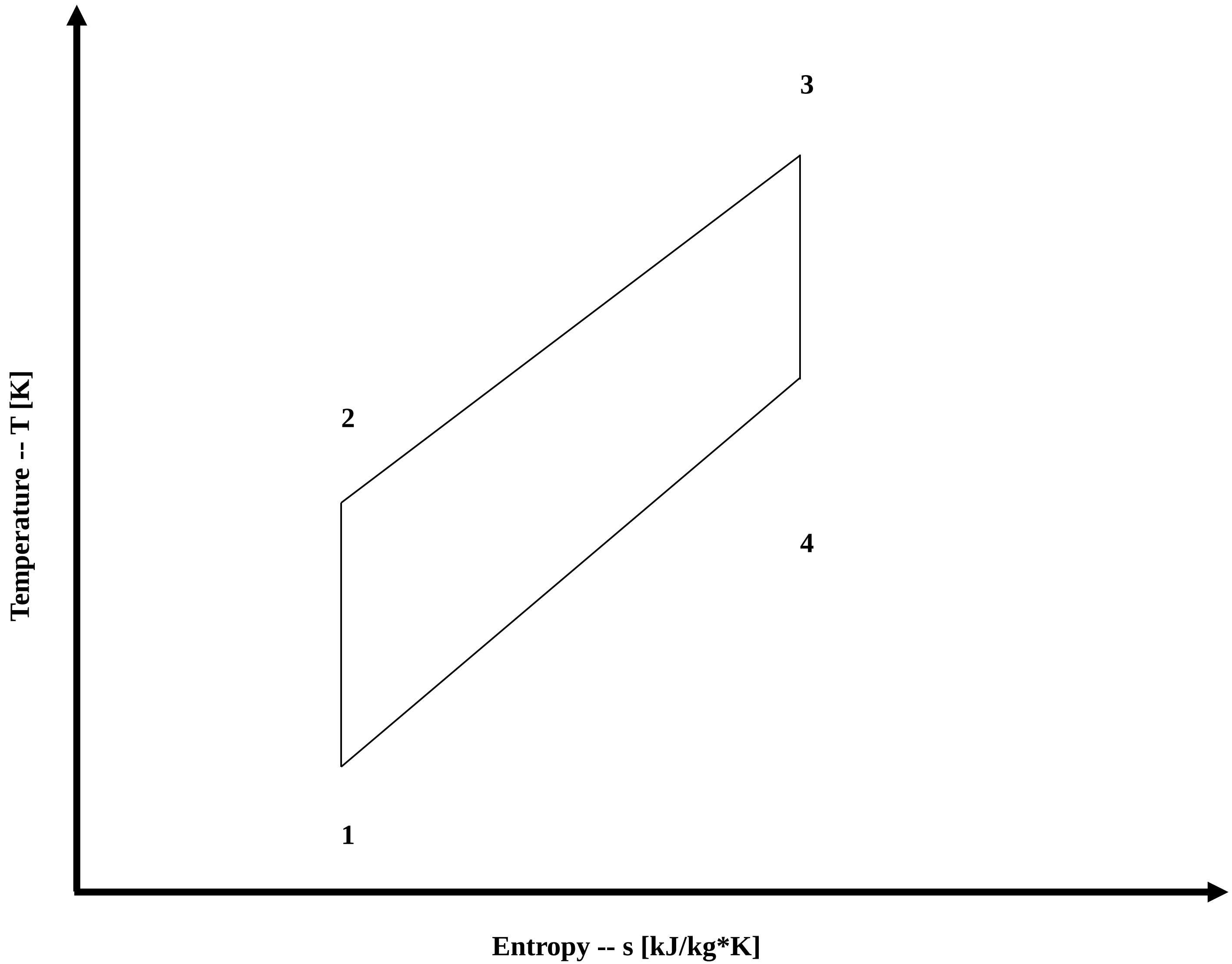
Diesel Cycle Analysis

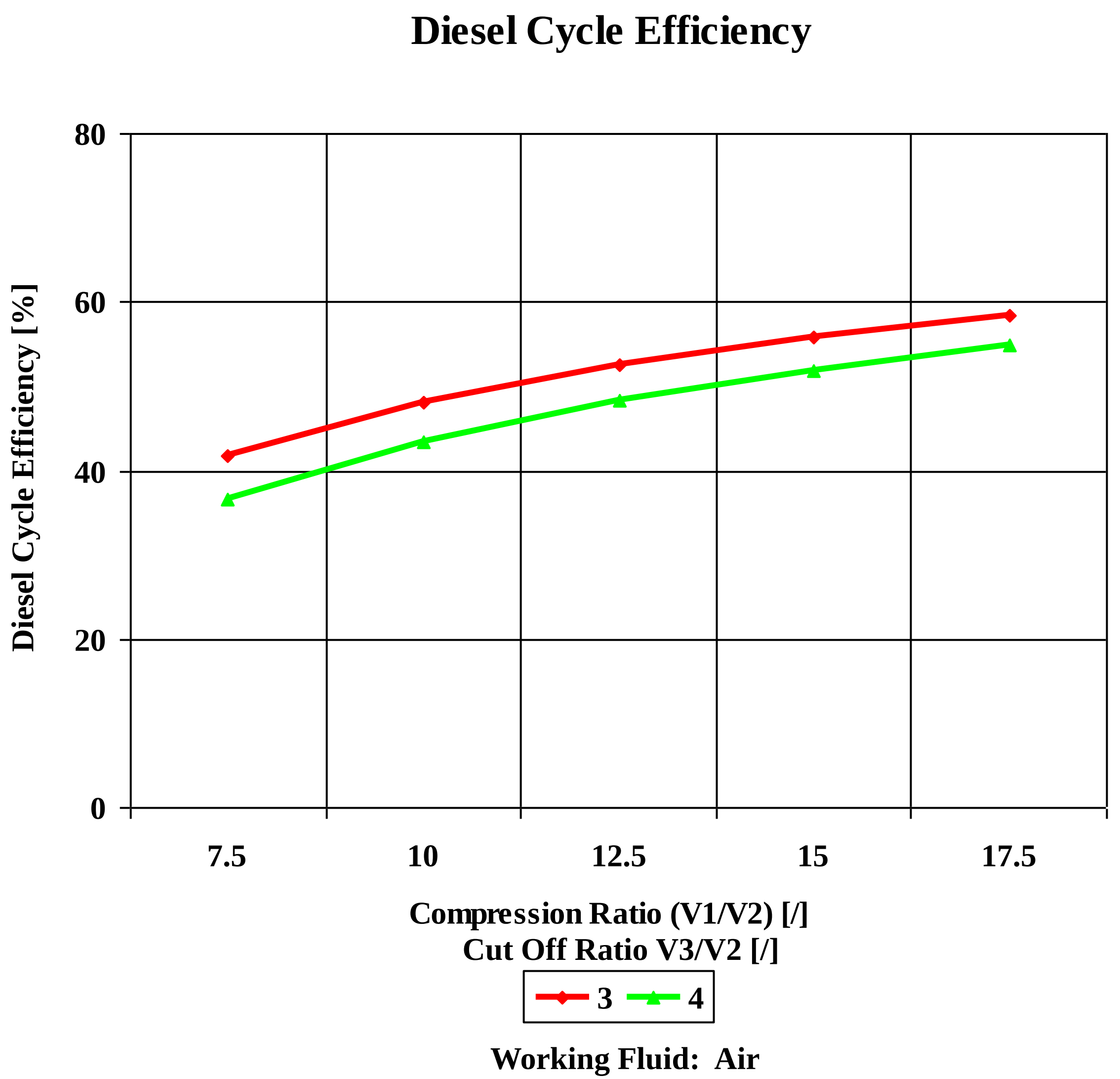
Here are some of the basic Diesel Cycle plots.



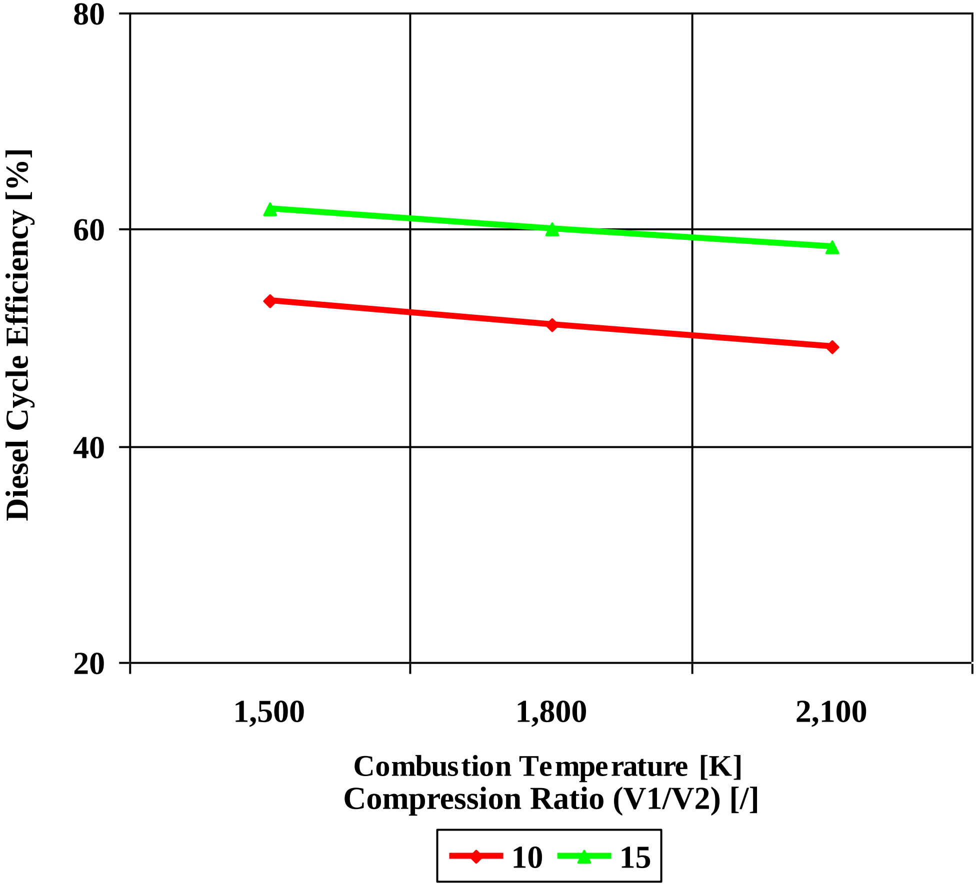
Diesel Cycle p - V Diagram



Diesel Cycle T - s Diagram

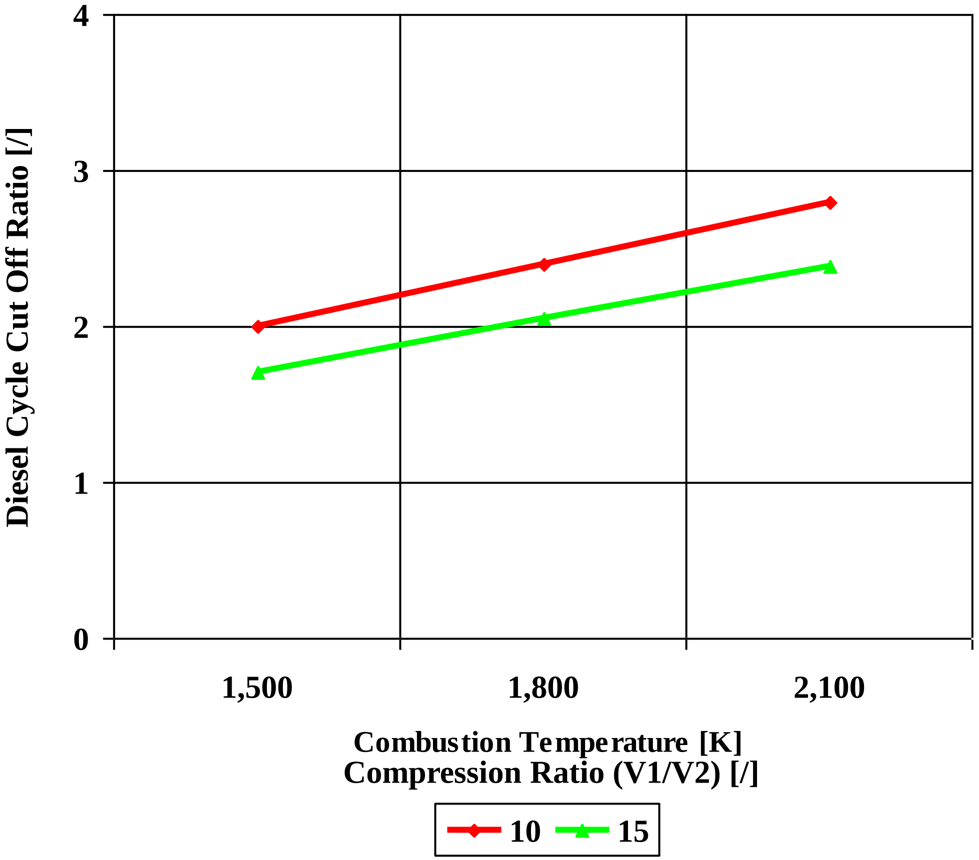

Diesel Cycle Efficiency
80
60
40
20
0
Diesel Cycle Efficiency [%]
7.5
10
12.5
15
17.5
Compression Ratio (V1/V2) [/]
Cut Off Ratio V3/V2 [/]
3
4
Working Fluid: Air

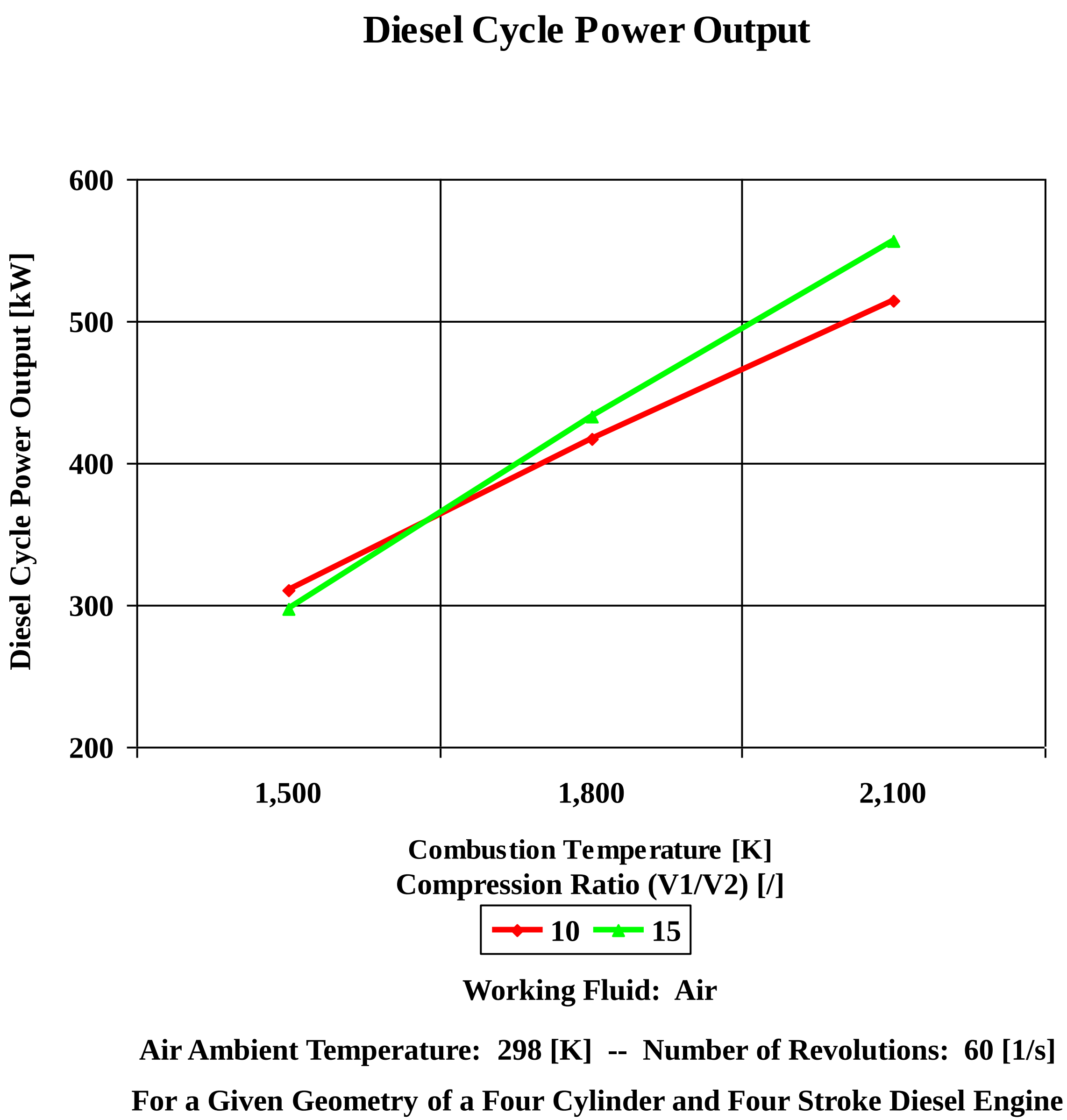
Diesel Cycle Efficiency



Ambient Temperature: 298 [K]

Diesel Cycle Cut Off Ratio




Diesel Cycle Power Output
Diesel Cycle Power Output [kW]
600
500
400
300
200
1,500
1,800
2,100
Combustion Temperature [K]
Compression Ratio (V1/V2) [/]
10
15
Working Fluid: Air
Air Ambient Temperature: 298 [K] -- Number of Revolutions: 60 [1/s]
For a Given Geometry of a Four Cylinder and Four Stroke Diesel Engine

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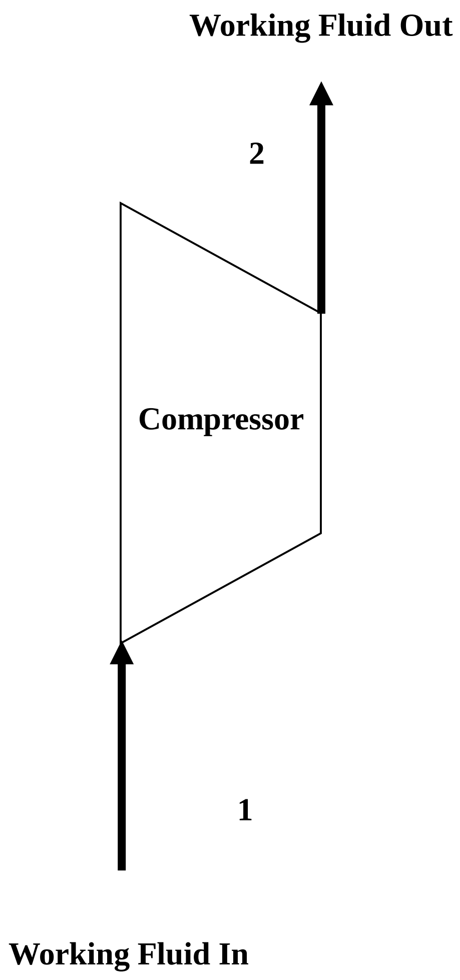
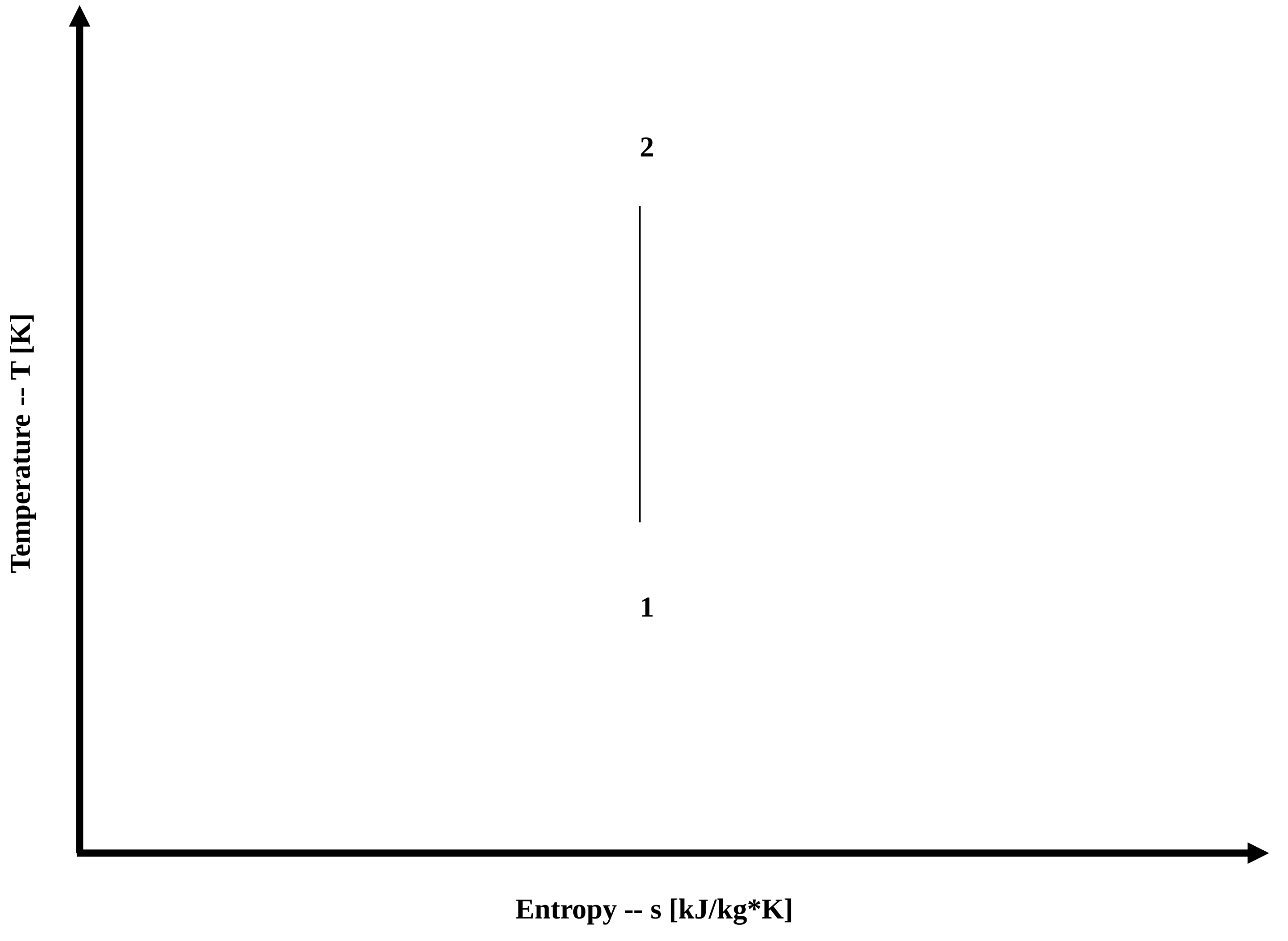
Compression

Here are some of the basic isentropic compression plots.

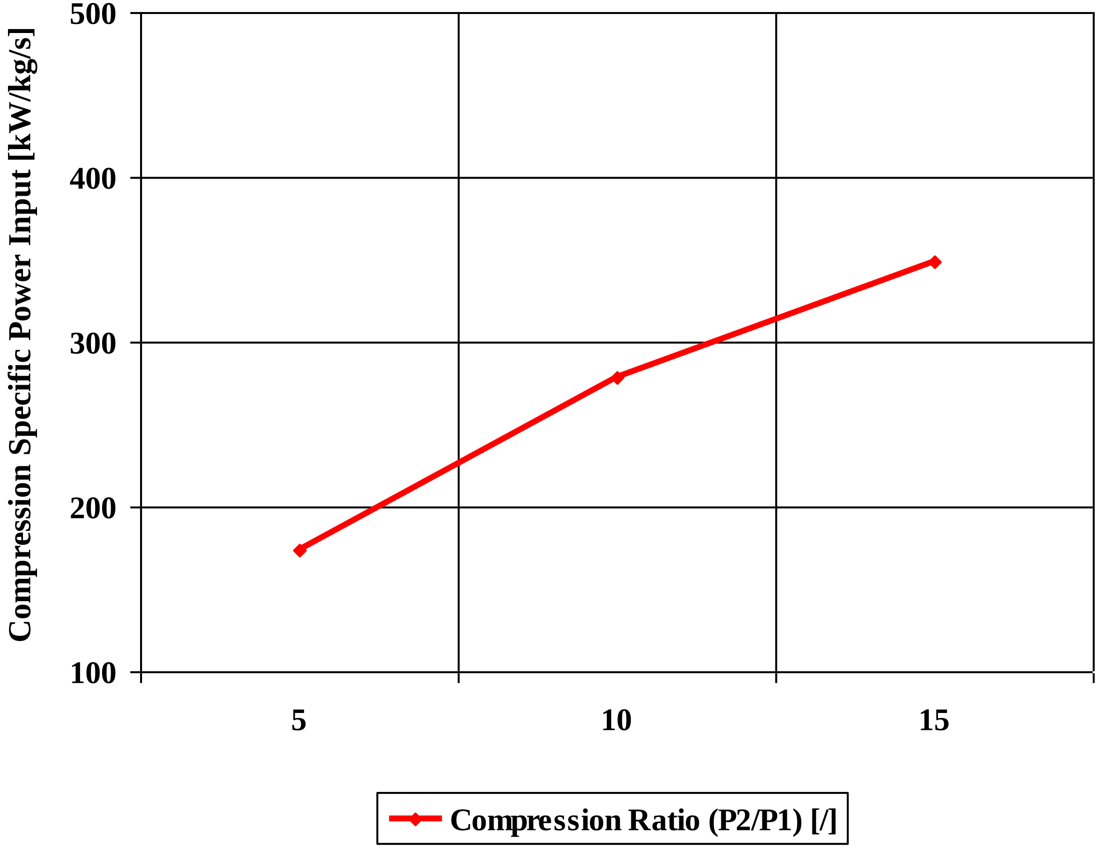


Compression Schematic Layout



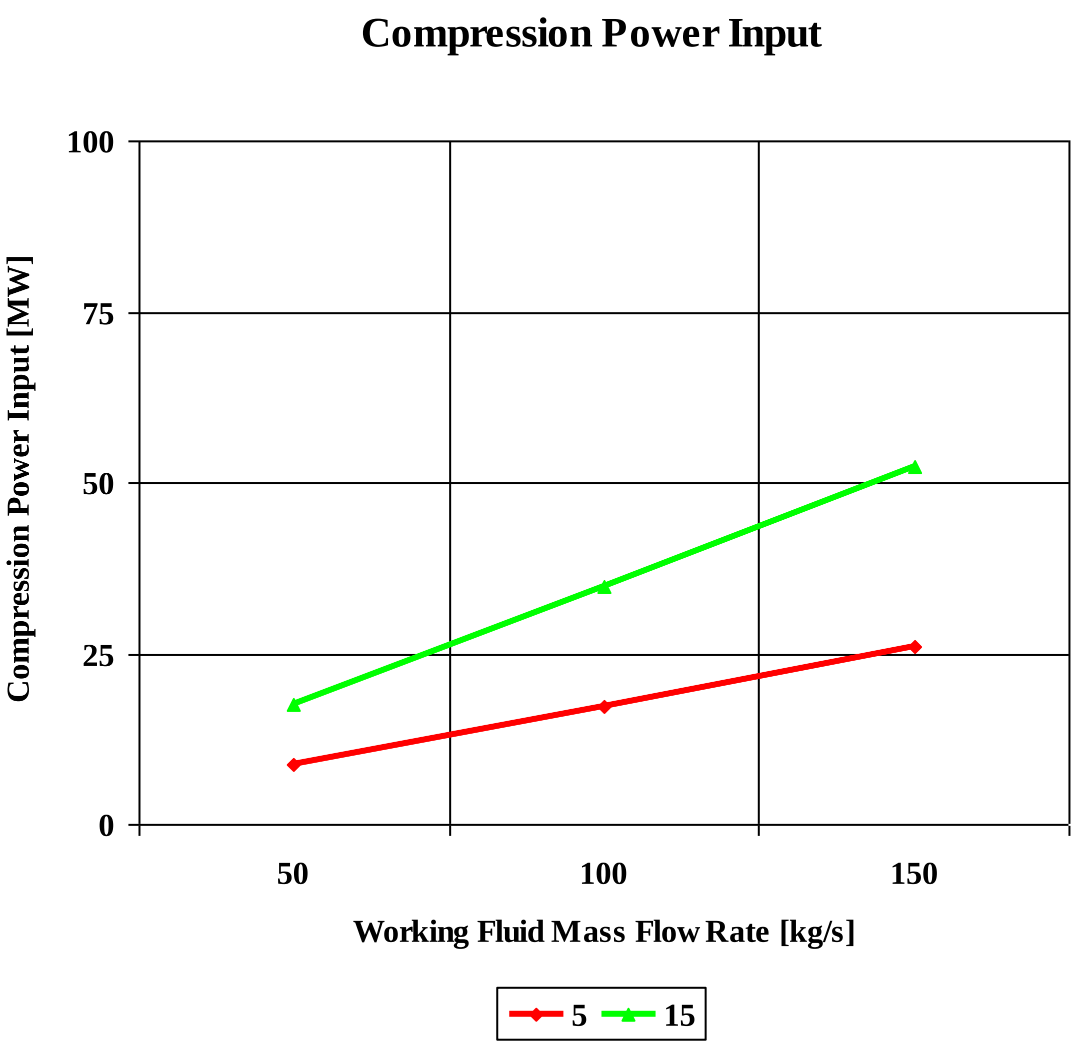
Compression T - s Diagram

Compression Specific Power Input



Working Fluid: Air

Compressor Inlet Temperature: 298 [K]



Compression Ratio (P2/P1) [/]
Working Fluid: Air
Compressor Inlet Temperature: 298 [K]

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Combustion

Here are some of the basic combustion information and plots when considering carbon, hydrogen and sulfur as the fuel and air as the oxidant.

Combustion Assumptions

- Fuel Temperature 298 [K]

- Oxidant Temperature 298 [K]

- Stoichiometric Combustion

- No Heat Losses

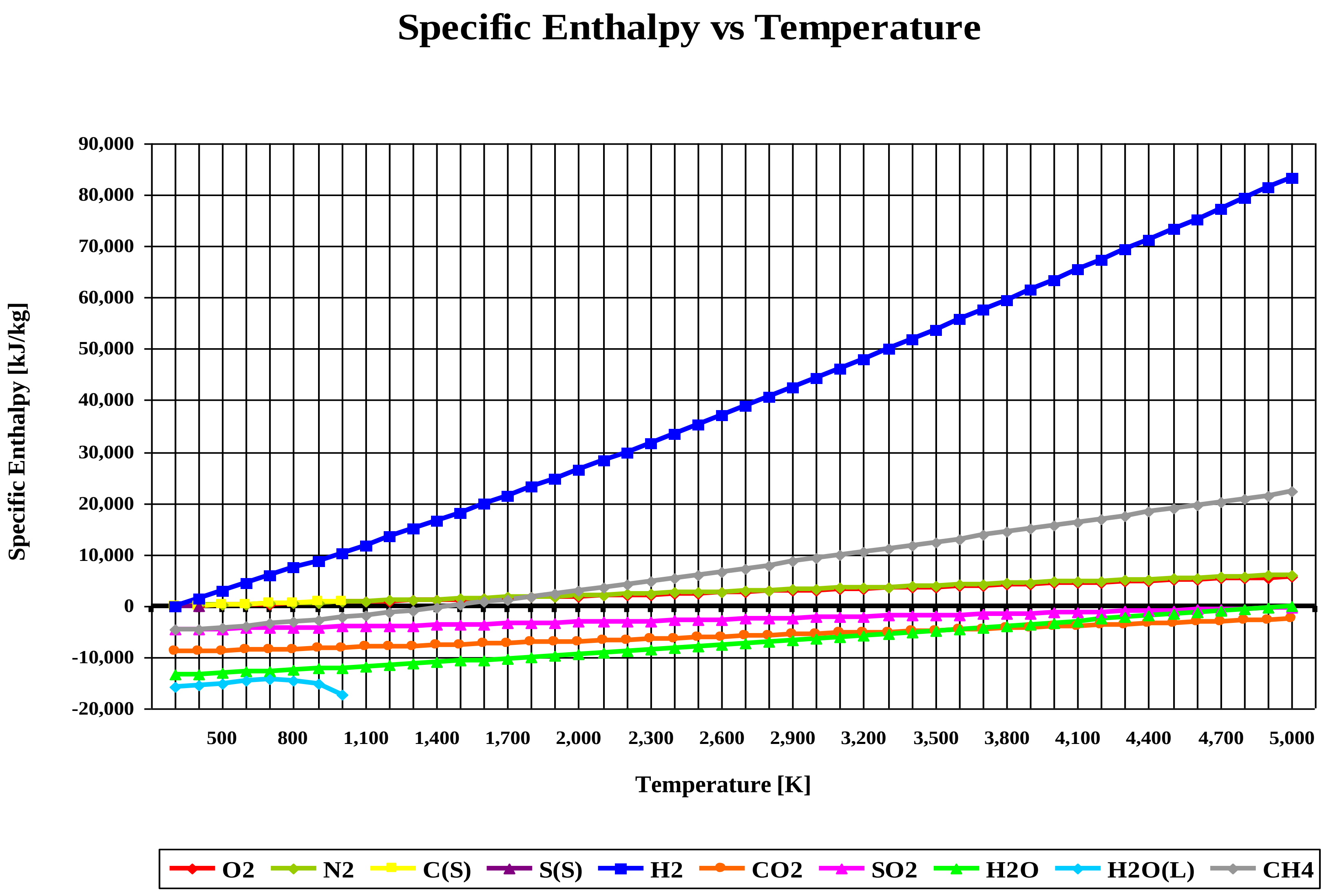
Fuel Composition -- Carbon

Element	Weight [kg/kg]
C	1.00
H	0.00
S	0.00
N	0.00
O	0.00
W	0.00

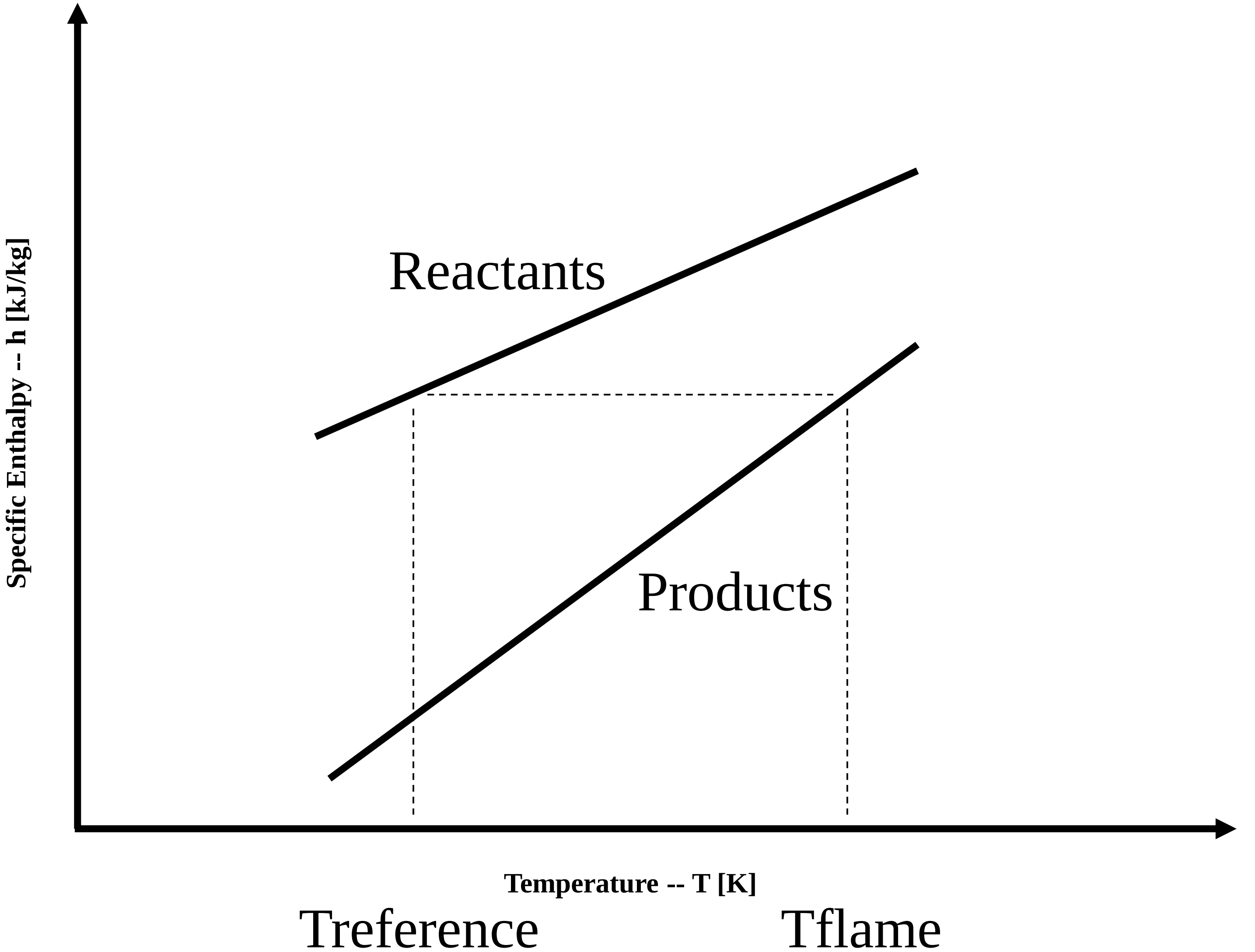
Oxidant (Air) Composition

Element	Weight [kg/kg]	Mole [kmol/kmol]
N	0.767	0.790
O	0.233	0.210

Combustion Schematic Layout



Specific Enthalpy vs Temperature
Specific Enthalpy [kJ/kg]
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
-10,000
-20,000
500
800
1,100
1,400
1,700
2,000
2,300
2,600
2,900
3,200
3,500
3,800
4,100
4,400
4,700
5,000
Temperature [K]
O2
N2
C(S)
S(S)
H2
CO2
SO2
H2O
H2O(L)
CH4



Combustion h - T Diagram

Combustion Products Composition

Element	Weight [kg/kg]	Mole [kmol/kmol]
CO_2	0.295	0.210
H_2O	0.000	0.000
SO_2	0.000	0.000
N_2	0.705	0.790
O_2	0.000	0.000

Combustion Values

Flame Temperature

2,460 [K]

Oxidant To Fuel Ratio

11.444 [/]

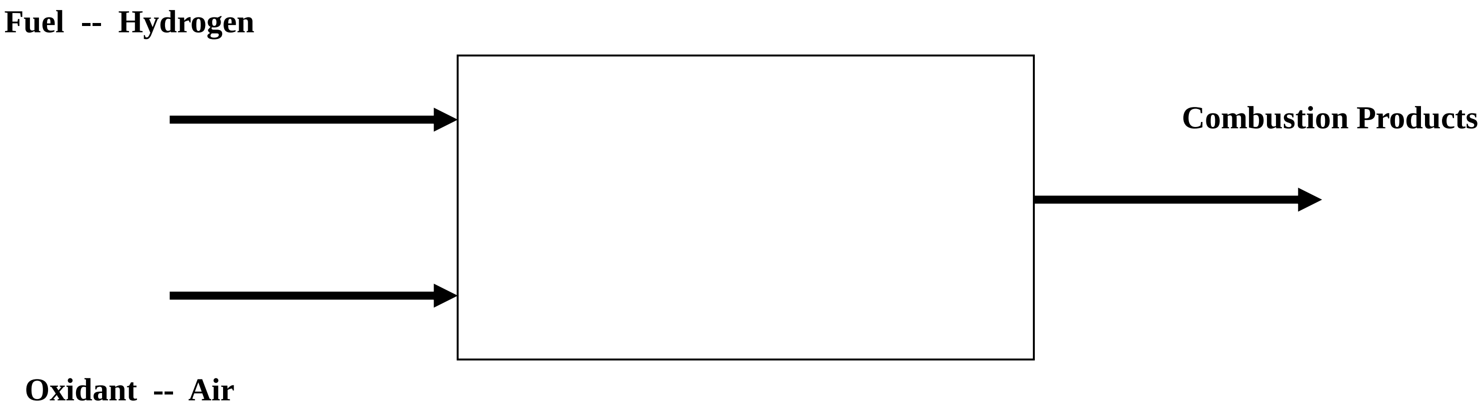
Fuel Composition -- Hydrogen

Element	Weight [kg/kg]
C	0.00
H	1.00
S	0.00
N	0.00
O	0.00
W	0.00

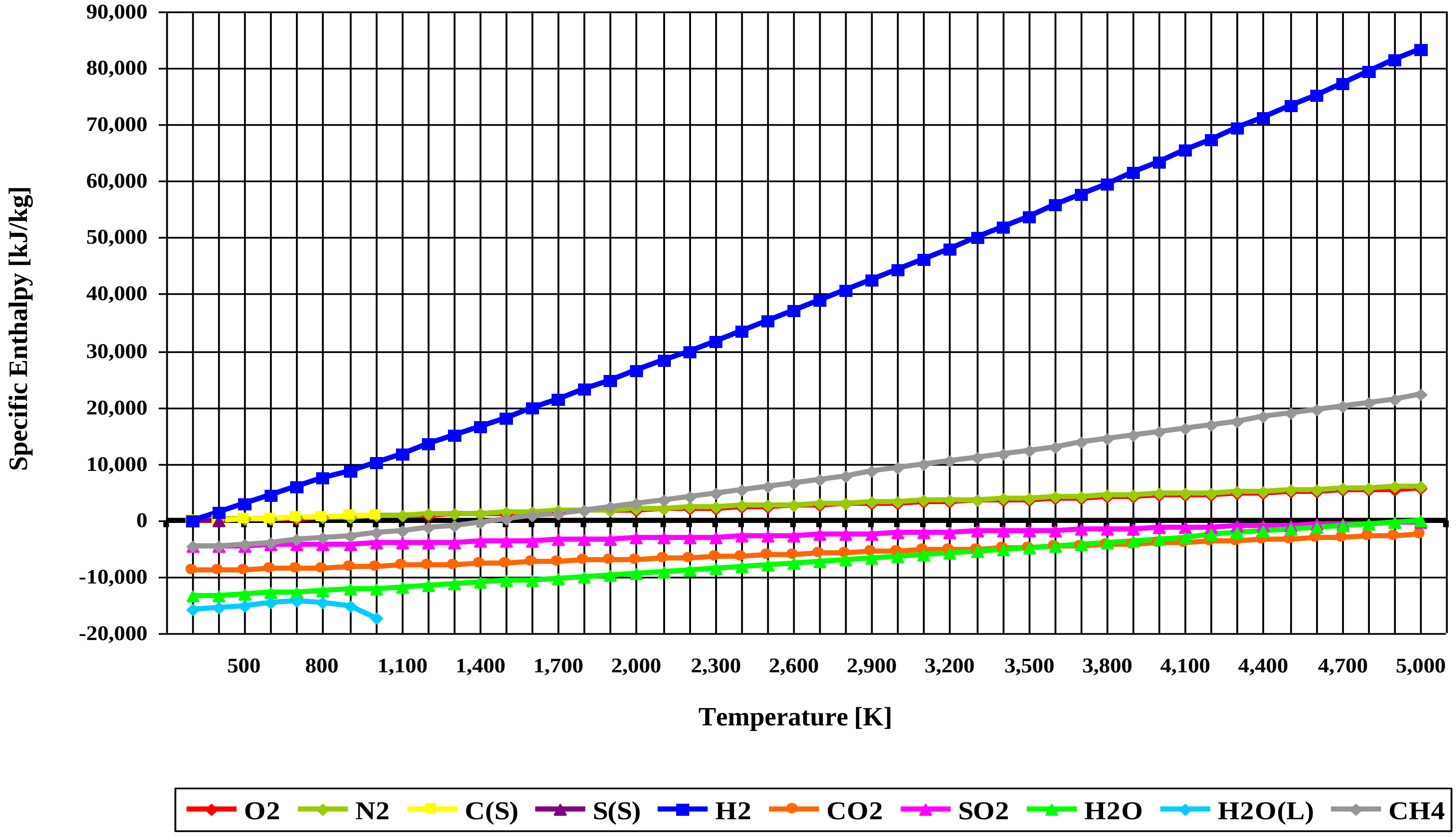
Oxidant (Air) Composition

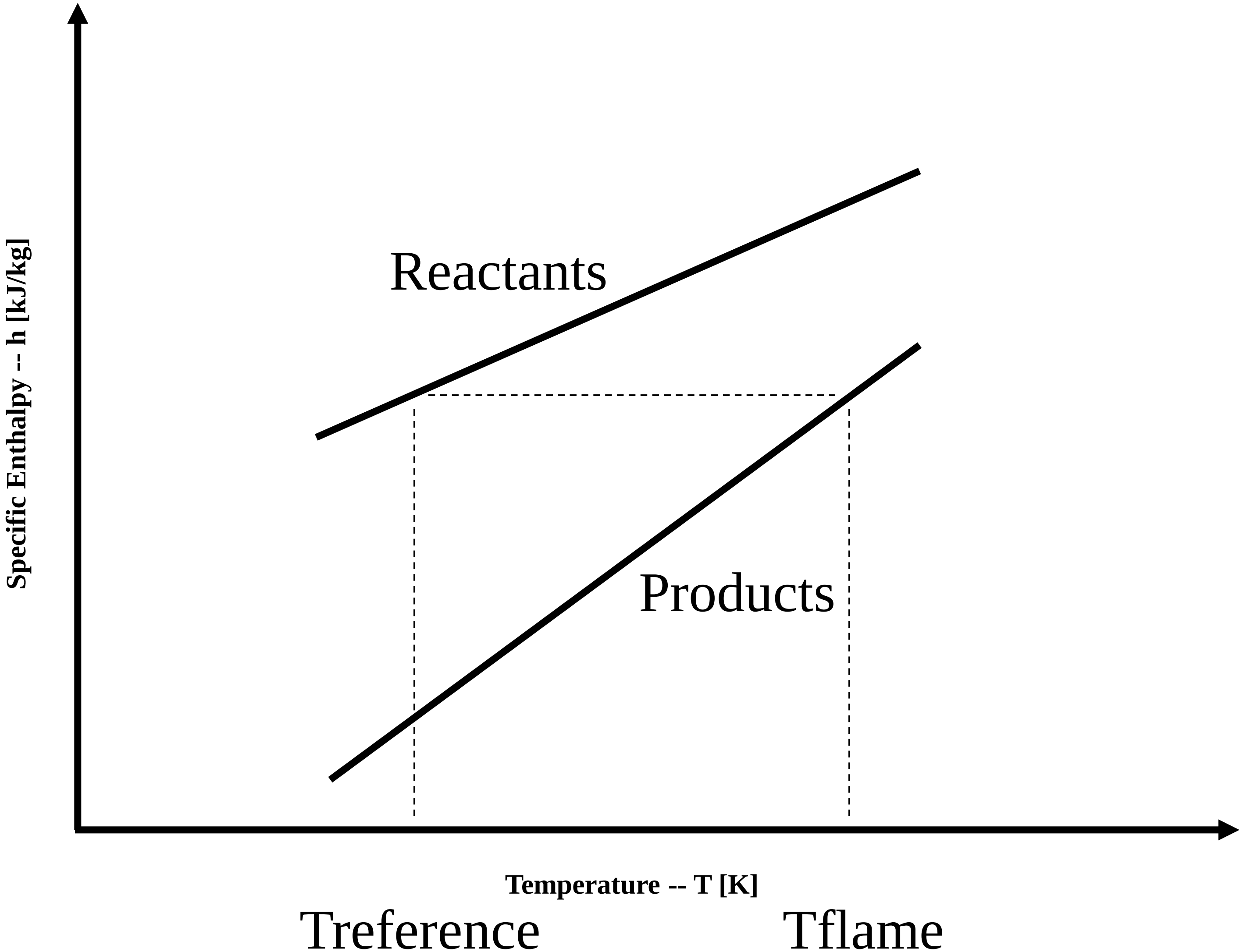
Element	Weight [kg/kg]	Mole [kmol/kmol]
N	0.767	0.790
O	0.233	0.210

Combustion Schematic Layout



Specific Enthalpy vs Temperature





Combustion h - T Diagram

Combustion Products Composition

Element	Weight [kg/kg]	Mole [kmol/kmol]
CO_2	0.000	0.000
H_2O	0.255	0.347
SO_2	0.000	0.000
N_2	0.745	0.653
O_2	0.000	0.000

Combustion Values

Flame Temperature

2,525 [K]

Oxidant To Fuel Ratio

34.333 [/]

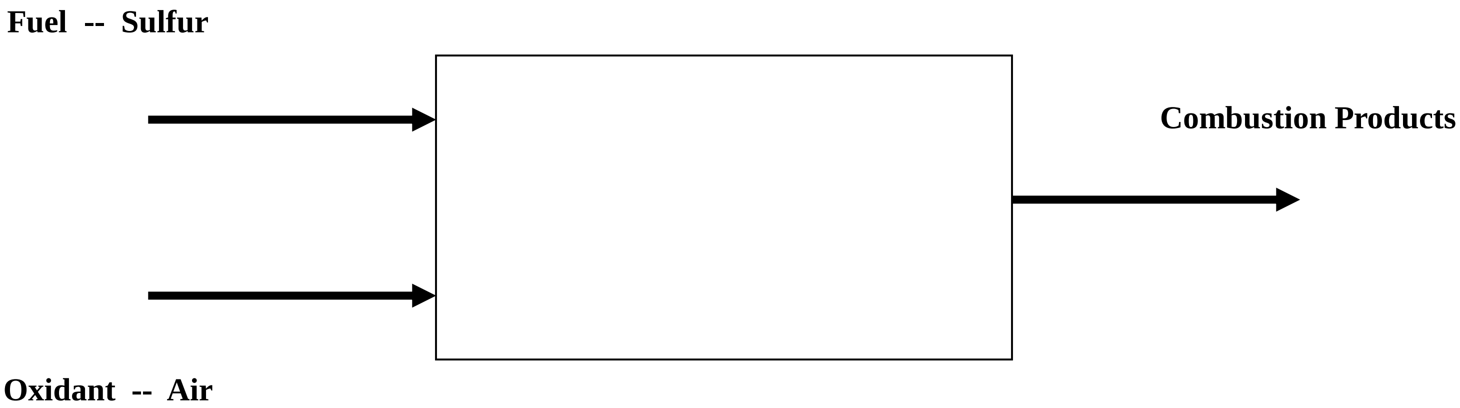
Fuel Composition -- Sulfur

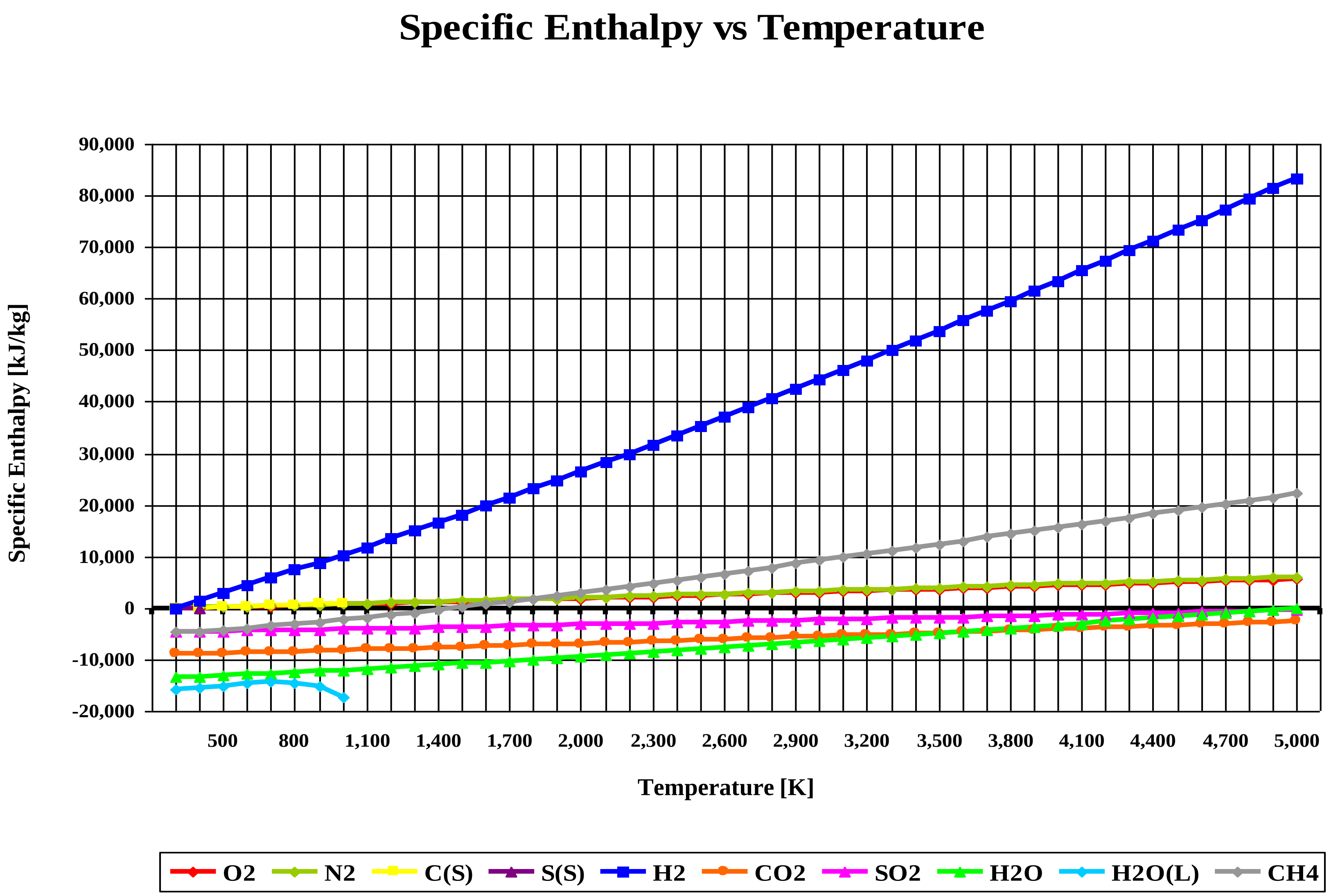
Element	Weight [kg/kg]
C	0.00
H	0.00
S	1.00
N	0.00
O	0.00
W	0.00

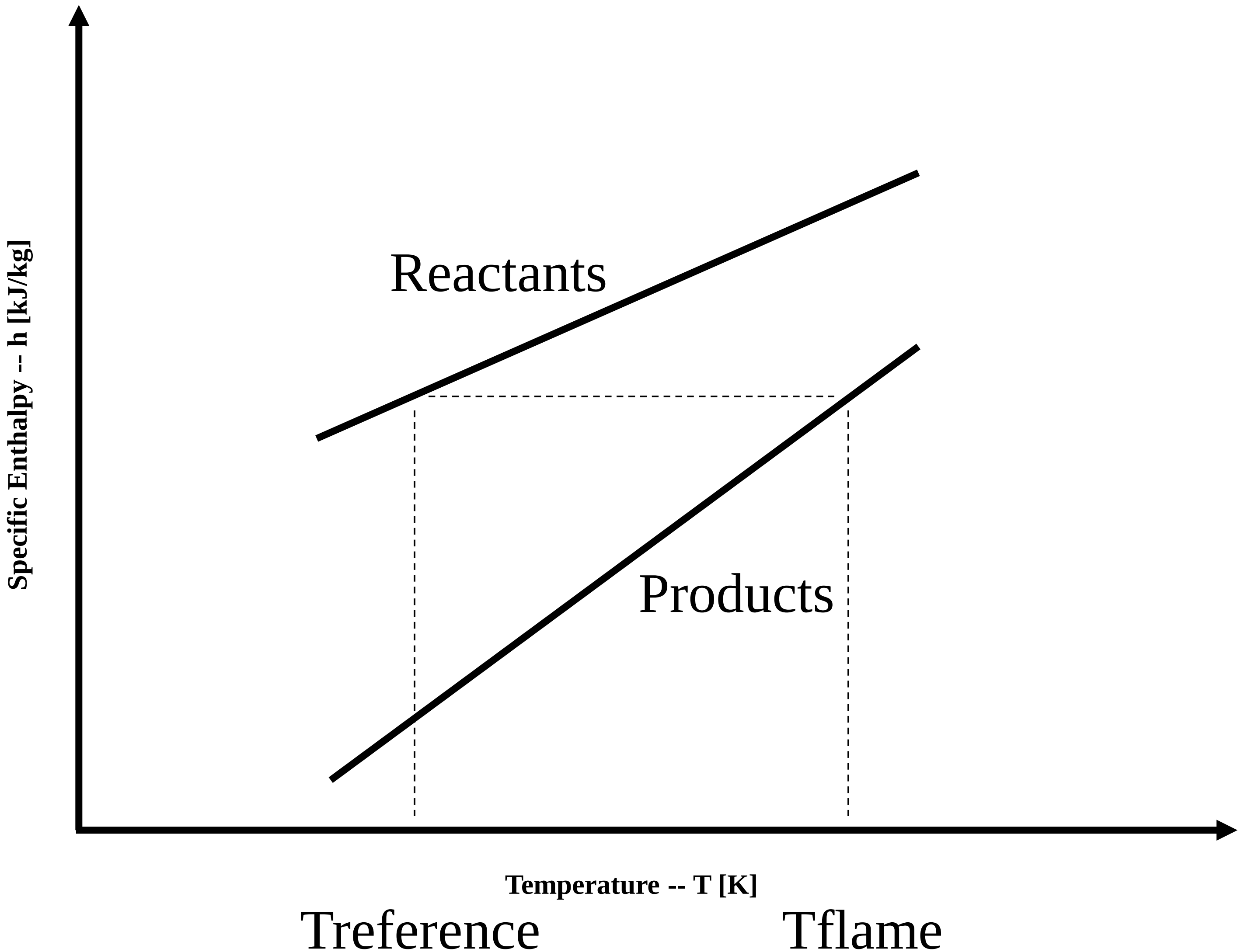
Oxidant (Air) Composition

Element	Weight [kg/kg]	Mole [kmol/kmol]
N	0.767	0.790
O	0.233	0.210

Combustion Schematic Layout




Specific Enthalpy vs Temperature
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
-10,000
-20,000
Specific Enthalpy [kJ/kg]
500
800
1,100
1,400
1,700
2,000
2,300
2,600
2,900
3,200
3,500
3,800
4,100
4,400
4,700
5,000
Temperature [K]
O2
N2
C(S)
S(S)
H2
CO2
SO2
H2O
H2O(L)
CH4



Combustion h - T Diagram

Combustion Products Composition

Element	Weight [kg/kg]	Mole [kmol/kmol]
CO_2	0.000	0.000
H_2O	0.000	0.000
SO_2	0.378	0.210
N_2	0.622	0.790
O_2	0.000	0.000

Combustion Values

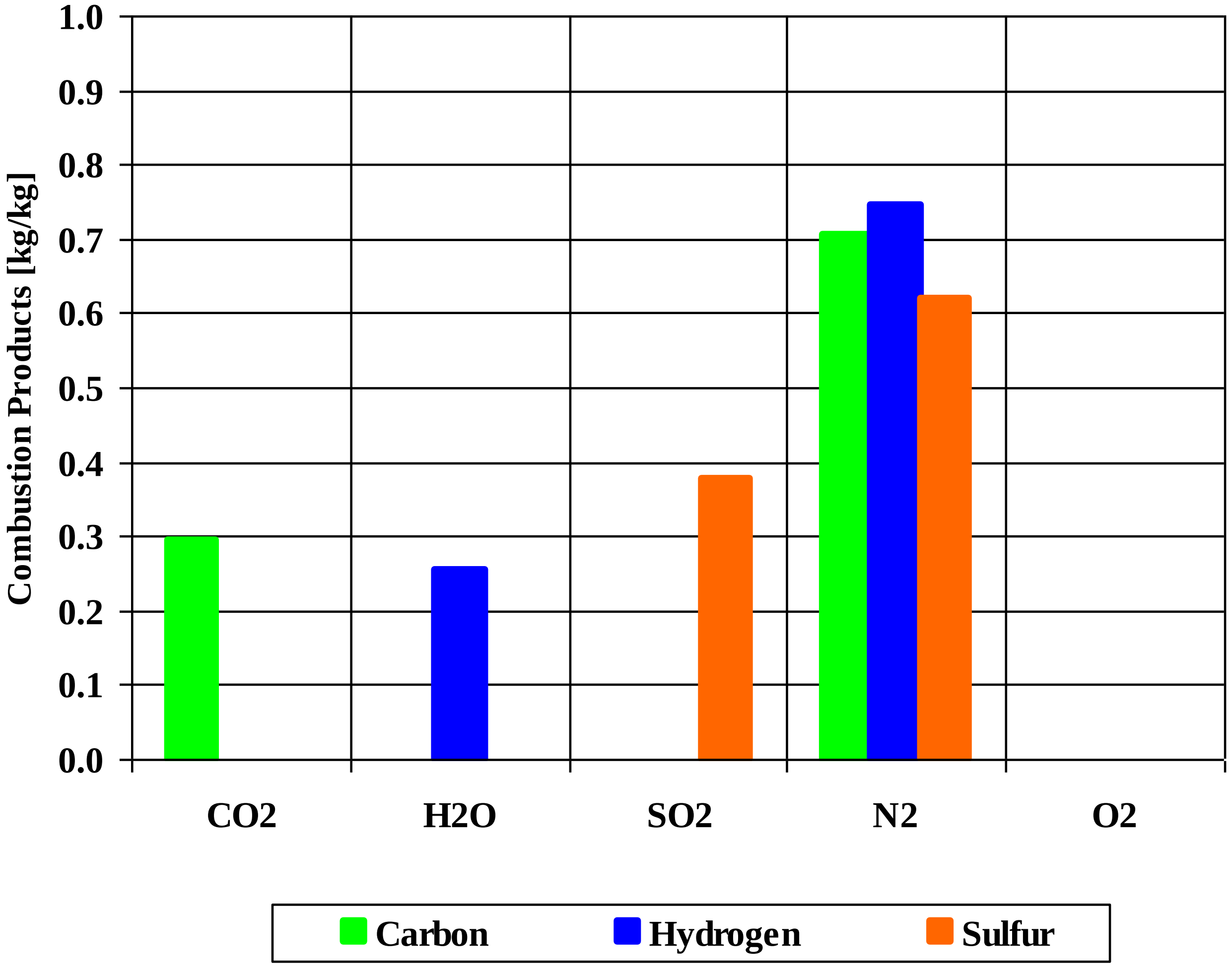
Flame Temperature

1,972 [K]

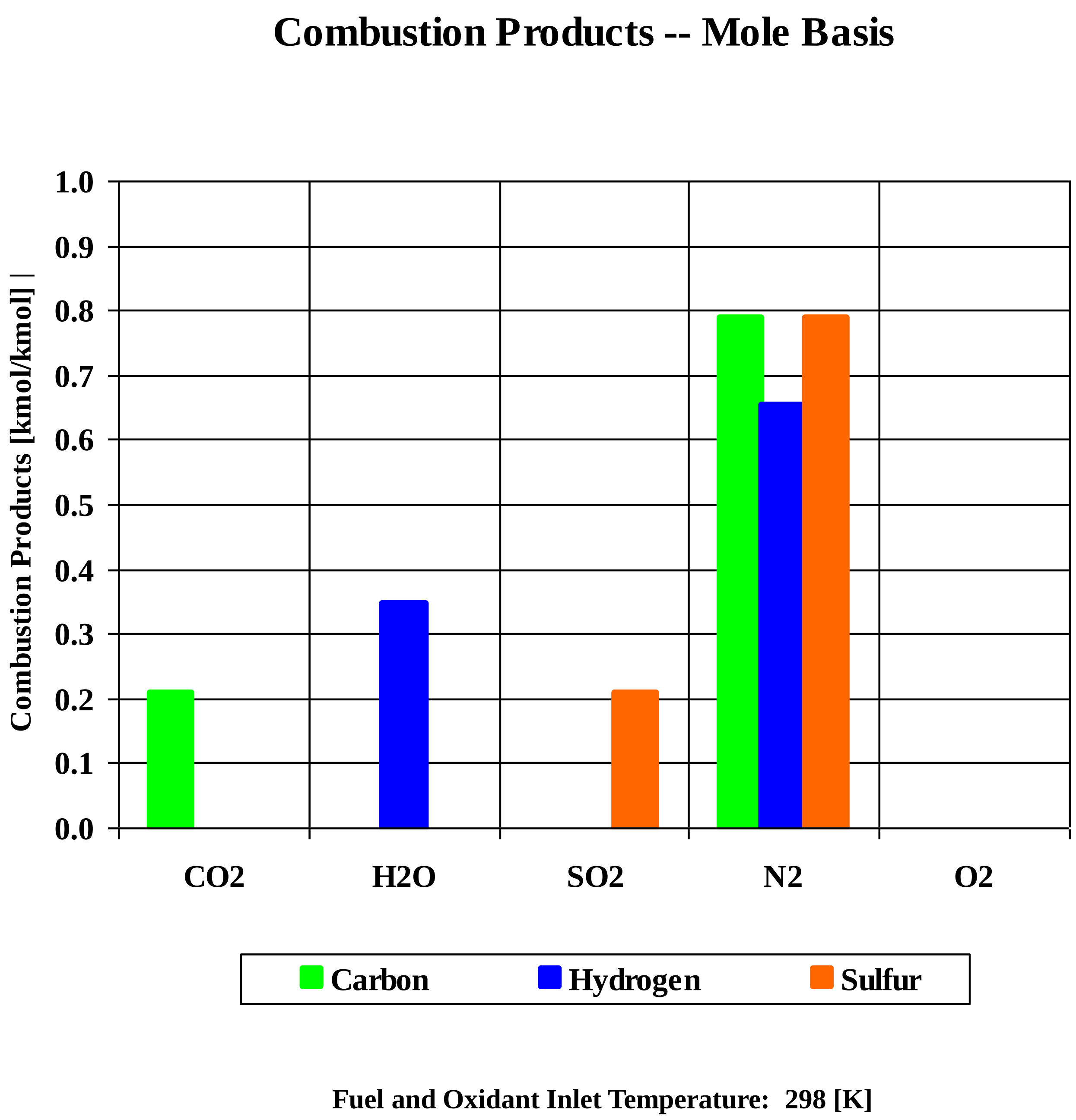
Oxidant To Fuel Ratio

4.292 [/]

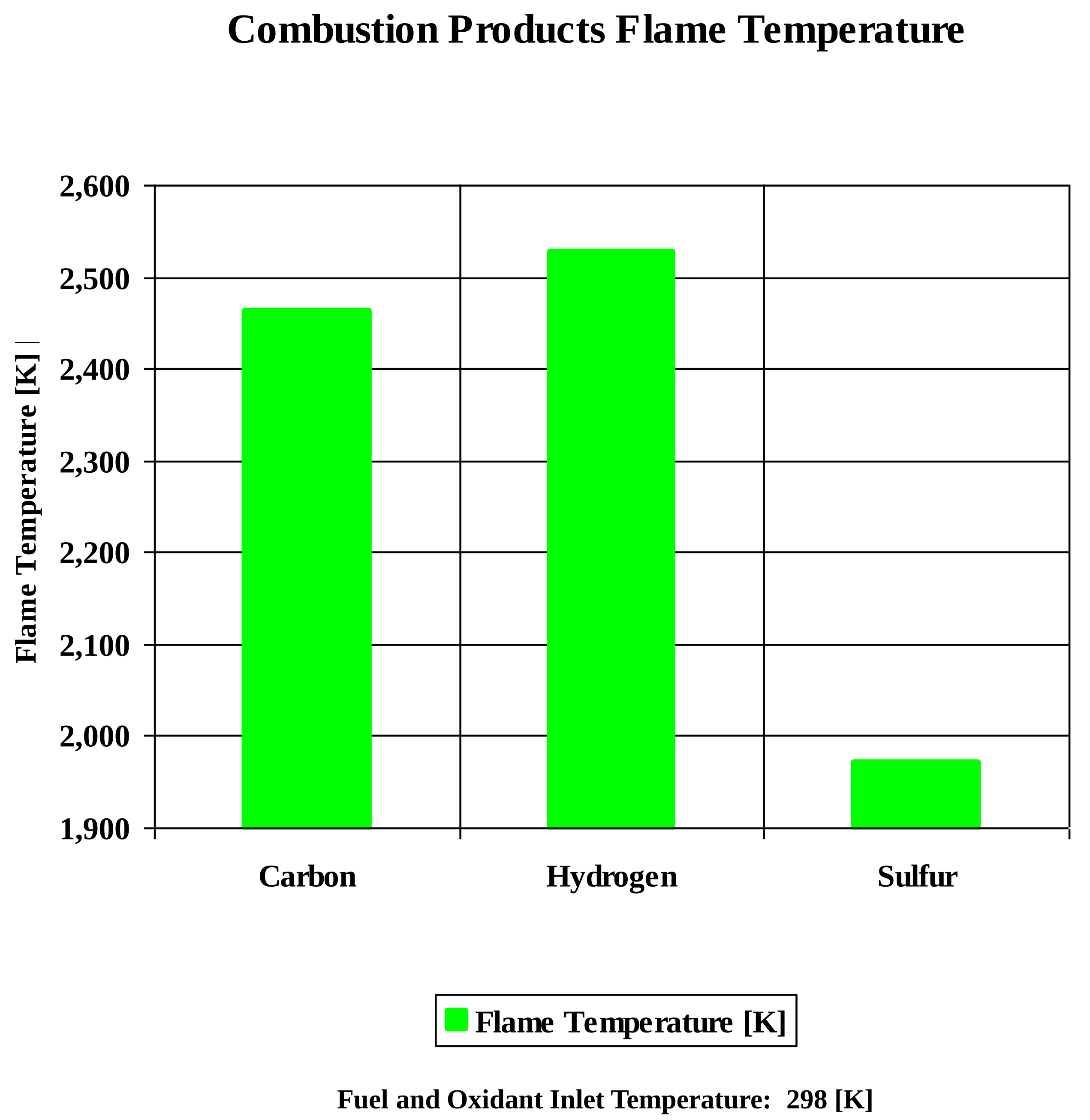
Combustion Products -- Weight Basis



Fuel and Oxidant Inlet Temperature: 298 [K]

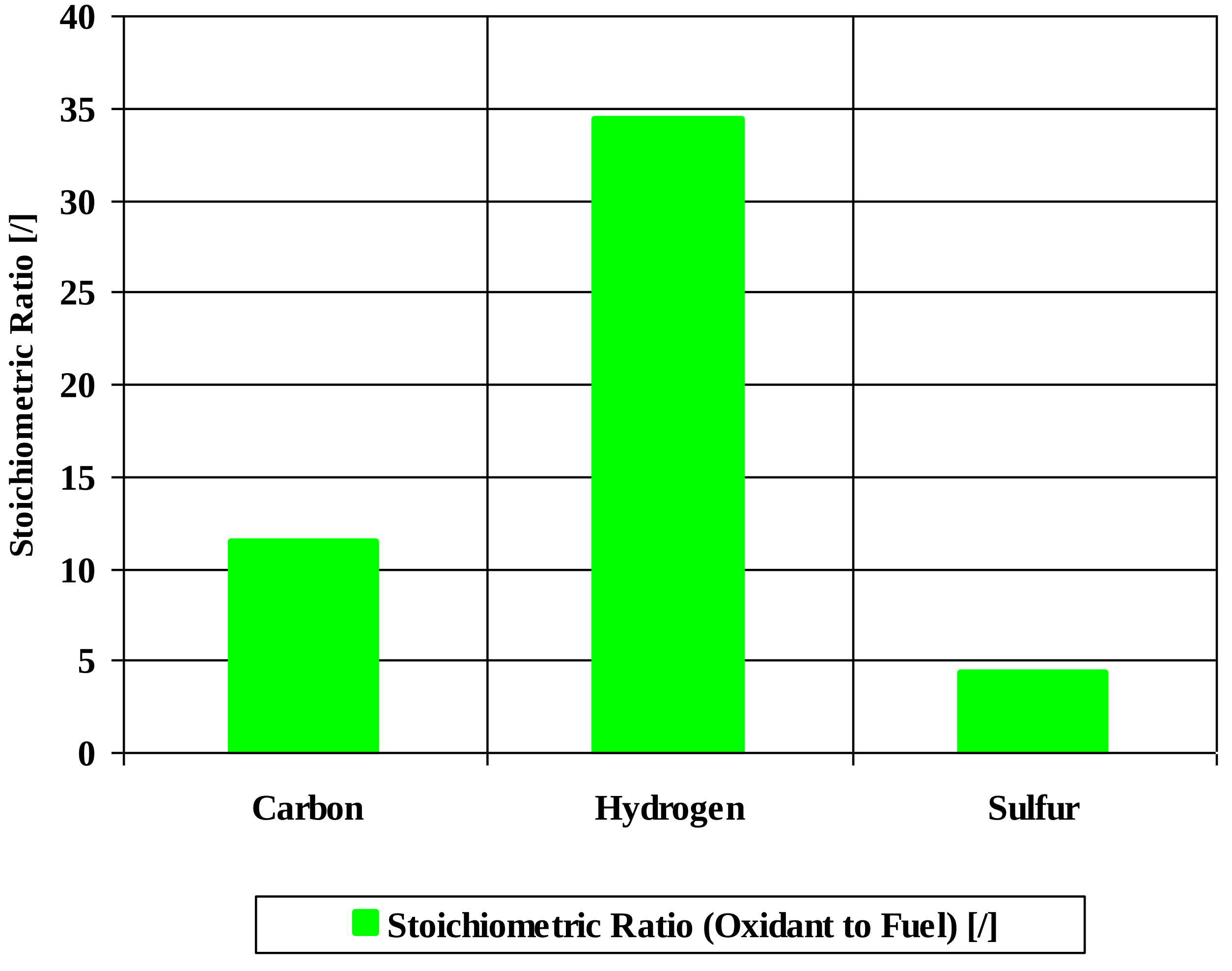


Combustion Products -- Mole Basis
Combustion Products [kmol/kmol]
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
CO2
H2O
SO2
N2
O2
Carbon
Hydrogen
Sulfur
Fuel and Oxidant Inlet Temperature: 298 [K]



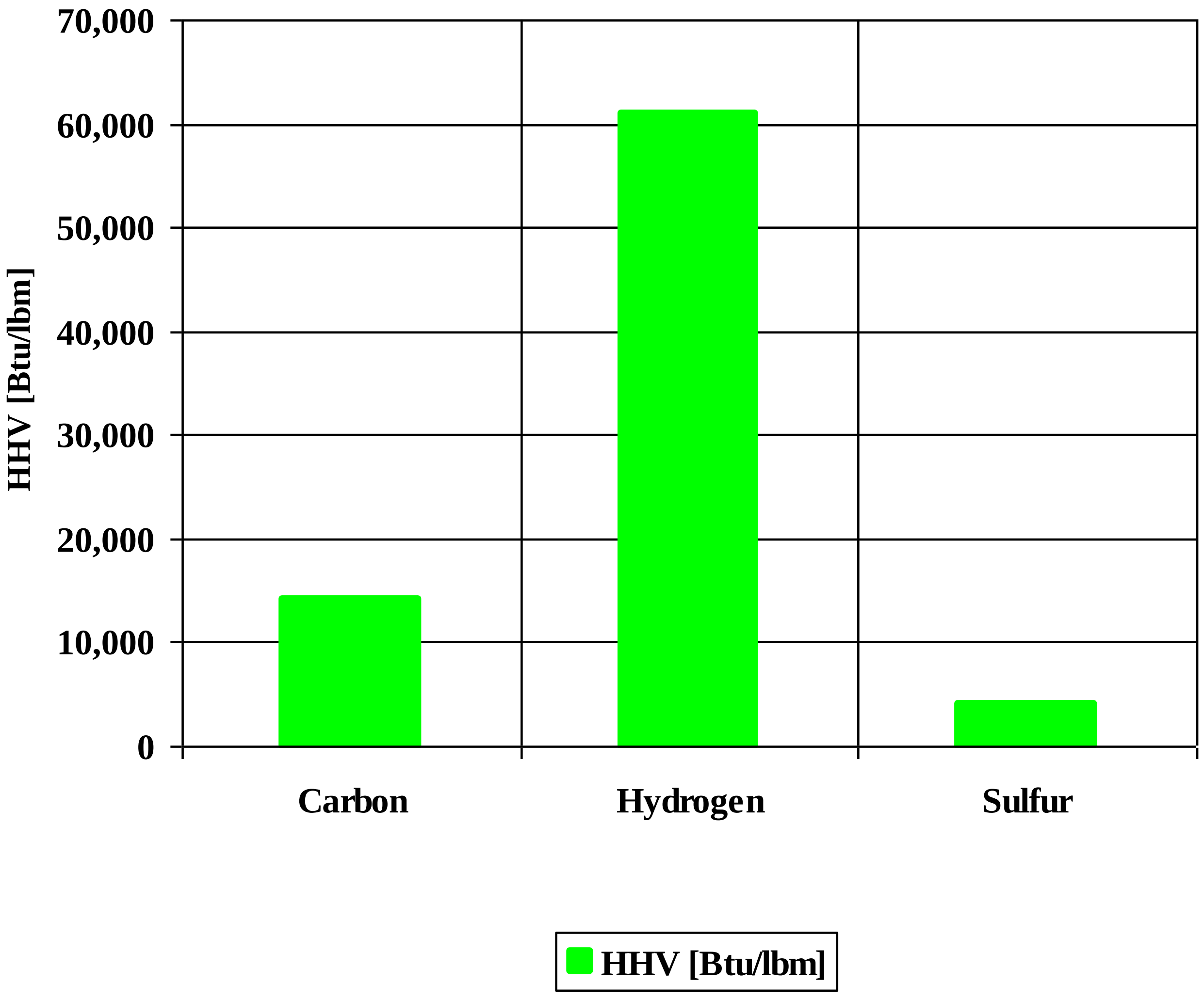
Combustion Products Flame Temperature
Flame Temperature [K]
2,600
2,500
2,400
2,300
2,200
2,100
2,000
1,900
Carbon
Hydrogen
Sulfur
Flame Temperature [K]
Fuel and Oxidant Inlet Temperature: 298 [K]

Combustion Stoichiometric Ratio



Fuel and Oxidant Inlet Temperature: 298 [K]

Higher Heating Value (HHV)



Fuel and Oxidant Inlet Temperature: 298 [K]

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Combustion Analysis

Here are some of the basic combustion information and plots when considering coal and oil as the fuel and air as the oxidant.

Combustion Assumptions

- Fuel Temperature 298 [K]

- Oxidant Temperature 298 [K]

- Stoichiometric Combustion

- No Heat Losses

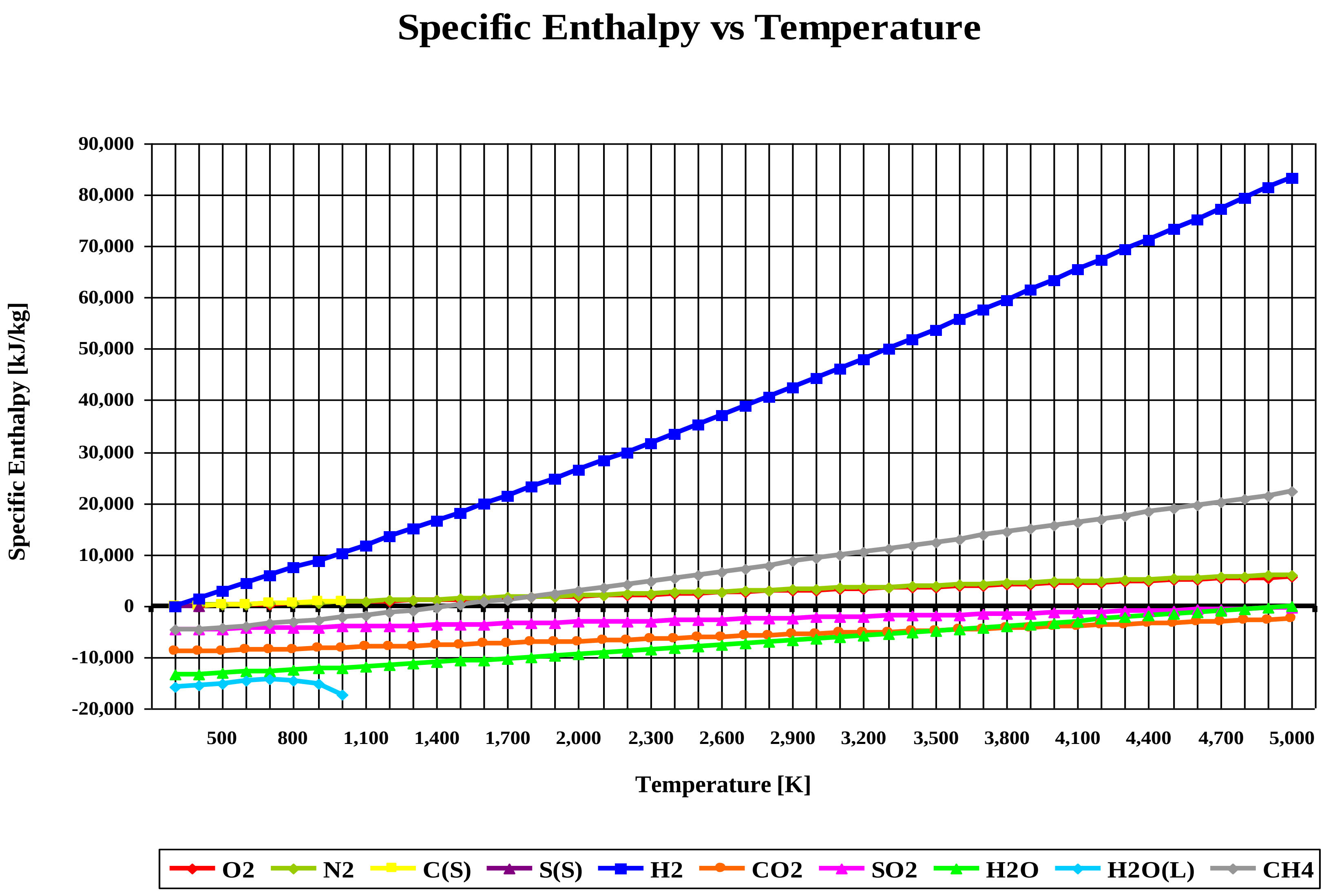
Fuel (Coal) Composition

Element	Weight [kg/kg]
C	0.78
H	0.05
S	0.03
N	0.04
O	0.08
W	0.02

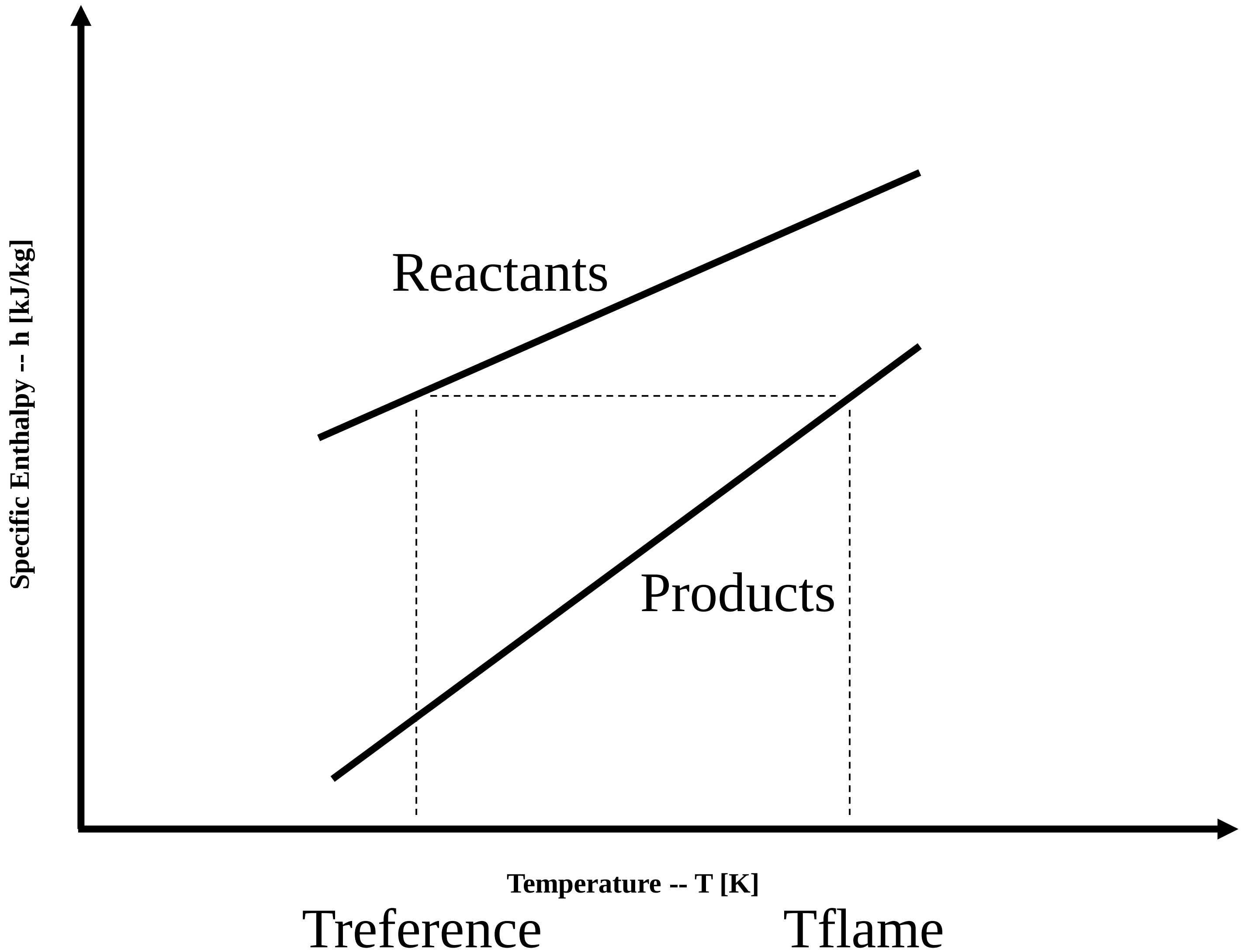
Oxidant (Air) Composition

Element	Weight [kg/kg]	Mole [kmol/kmol]
N	0.767	0.790
O	0.233	0.210

Combustion Schematic Layout



Specific Enthalpy vs Temperature
Specific Enthalpy [kJ/kg]
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
-10,000
-20,000
500
800
1,100
1,400
1,700
2,000
2,300
2,600
2,900
3,200
3,500
3,800
4,100
4,400
4,700
5,000
Temperature [K]
O2
N2
C(S)
S(S)
H2
CO2
SO2
H2O
H2O(L)
CH4



Combustion h - T Diagram

Combustion Products Composition

Element	Weight [kg/kg]	Mole [kmol/kmol]
CO_2	0.249	0.170
H_2O	0.041	0.068
SO_2	0.005	0.002
N_2	0.705	0.759
O_2	0.000	0.000

Combustion Values

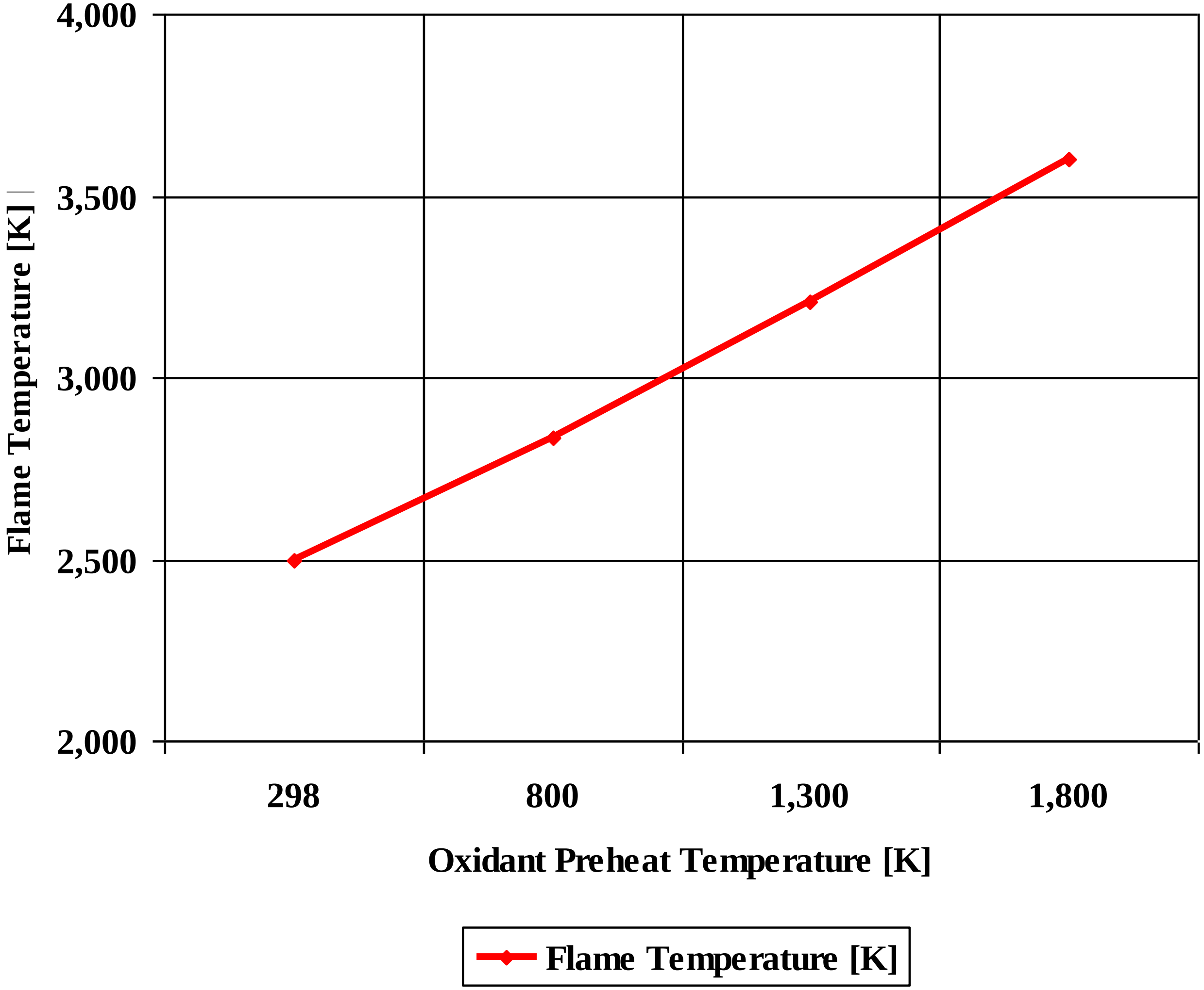
Flame Temperature

2,484 [K]

Oxidant To Fuel Ratio

10.487 [/]

Combustion Products Flame Temperature (Coal as Fuel)



Fuel Inlet Temperature: 298 [K]

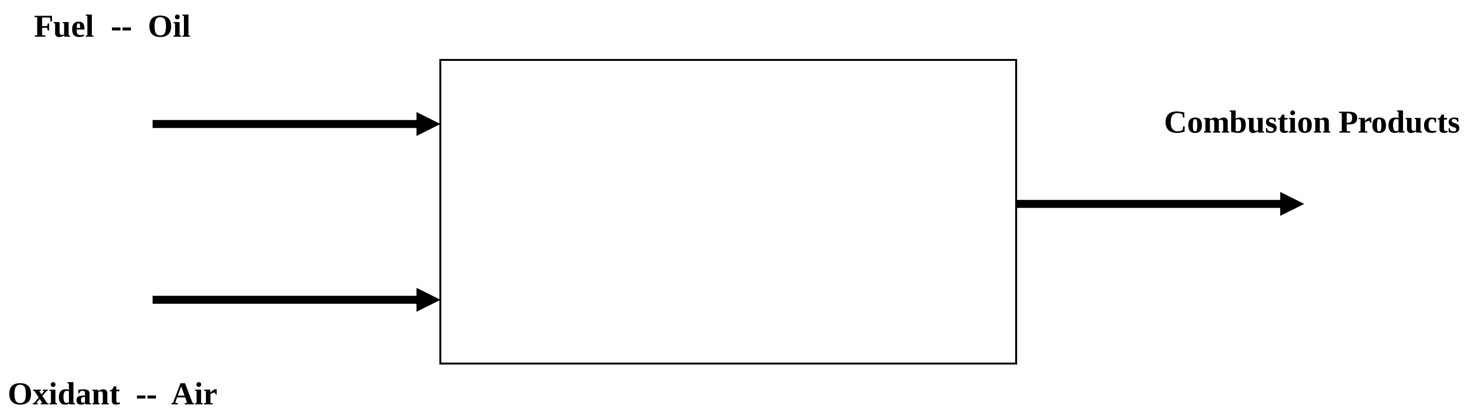
Fuel (Oil) Composition

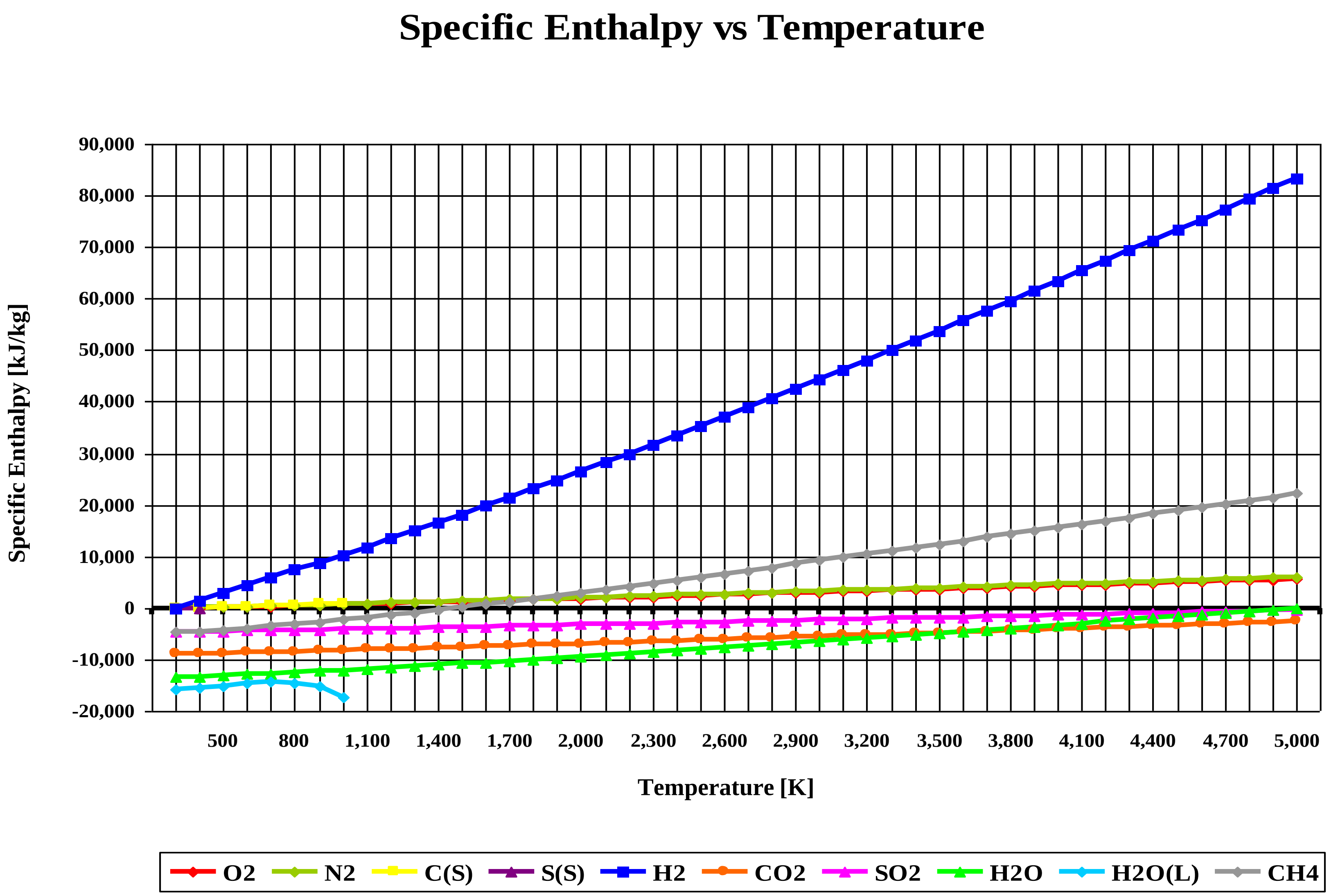
Element	Weight [kg/kg]
C	0.86
H	0.14
S	0.00
N	0.00
O	0.00
W	0.00

Oxidant (Air) Composition

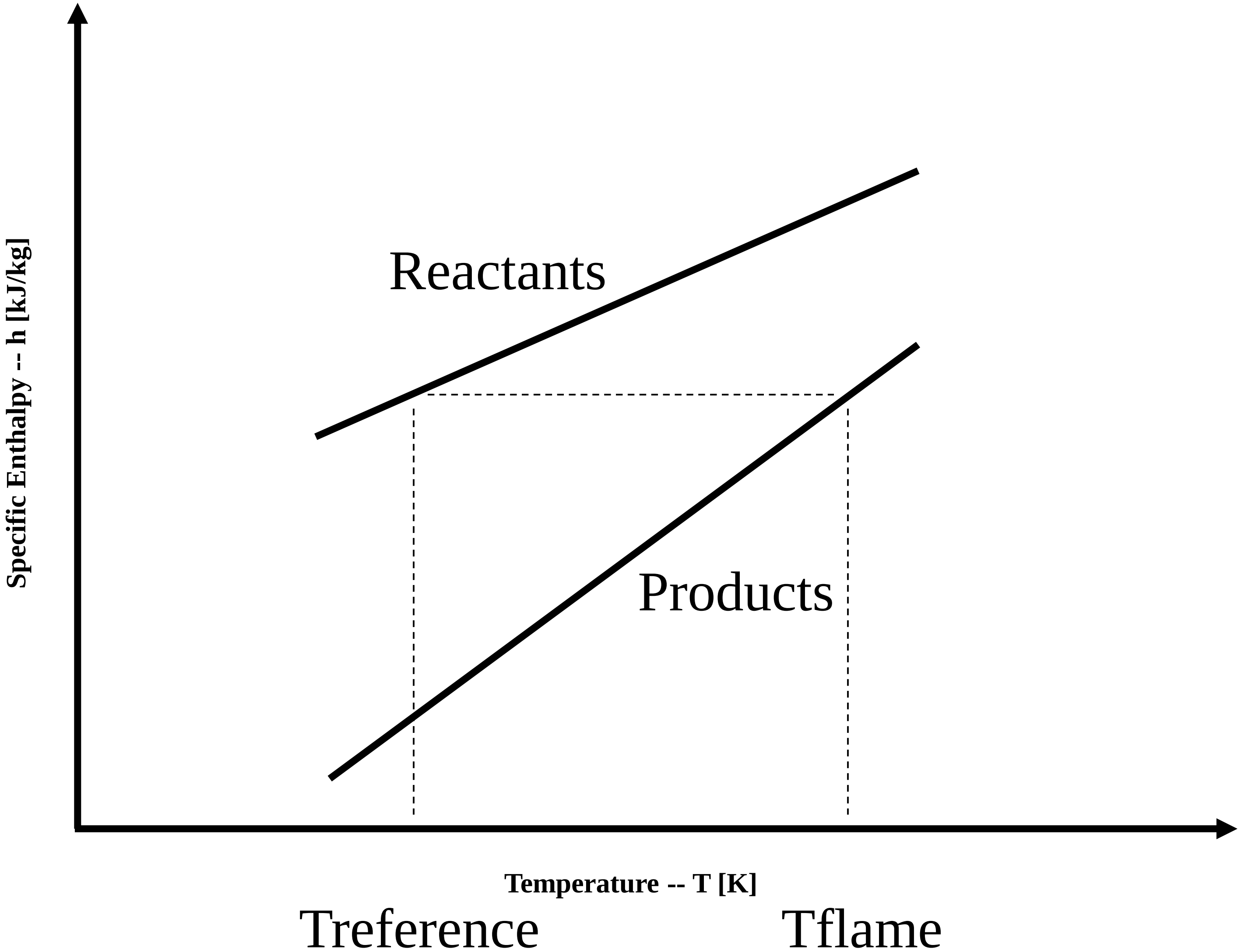
Element	Weight [kg/kg]	Mole [kmol/kmol]
N	0.767	0.790
O	0.233	0.210

Combustion Schematic Layout





Specific Enthalpy vs Temperature
Specific Enthalpy [kJ/kg]
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
-10,000
-20,000
500
800
1,100
1,400
1,700
2,000
2,300
2,600
2,900
3,200
3,500
3,800
4,100
4,400
4,700
5,000
Temperature [K]
O2
N2
C(S)
S(S)
H2
CO2
SO2
H2O
H2O(L)
CH4



Combustion h - T Diagram

Combustion Products Composition

Element	Weight [kg/kg]	Mole [kmol/kmol]
CO_2	0.202	0.132
H_2O	0.080	0.129
SO_2	0.000	0.000
N_2	0.718	0.739
O_2	0.000	0.000

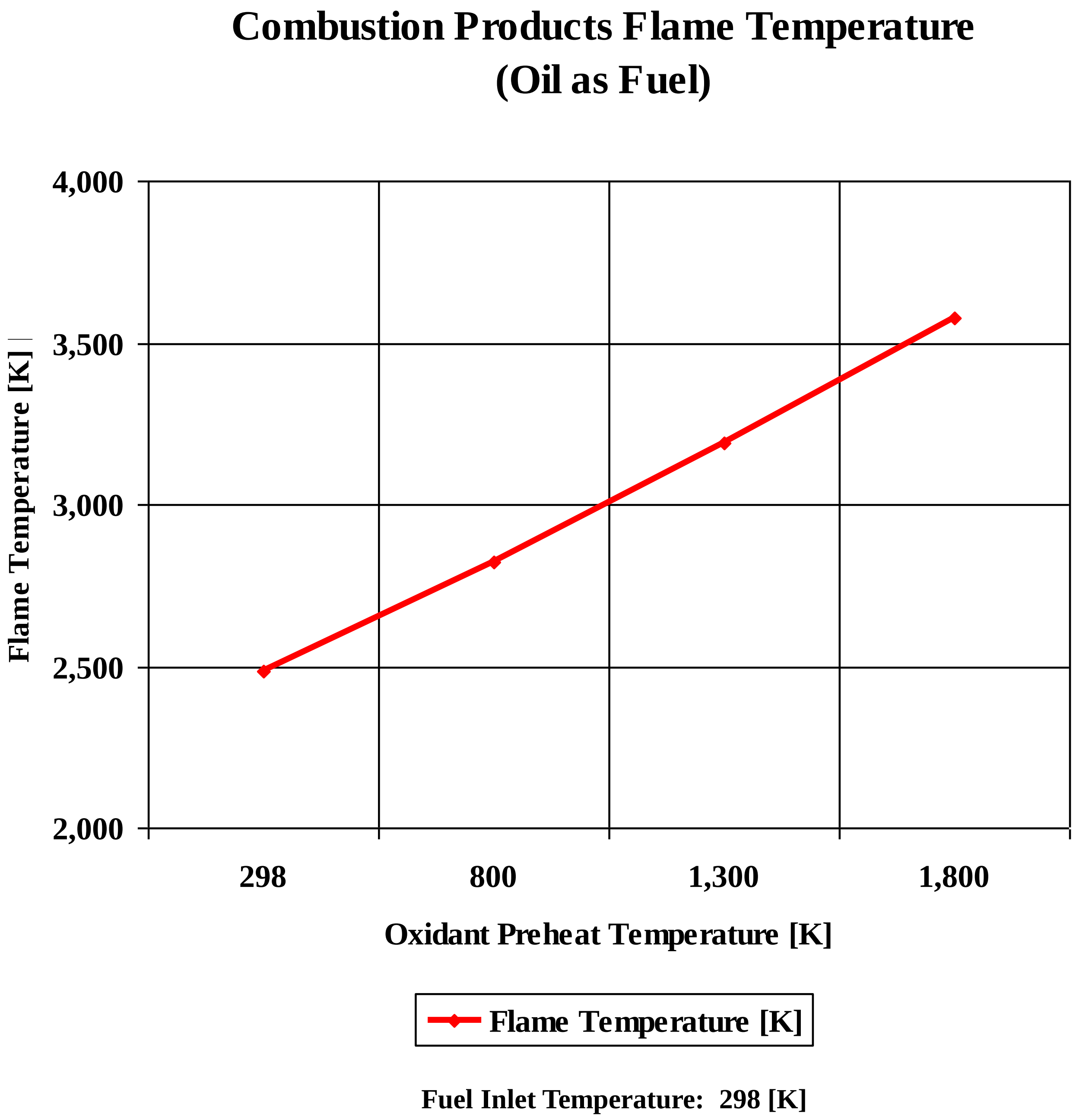
Combustion Values

Flame Temperature

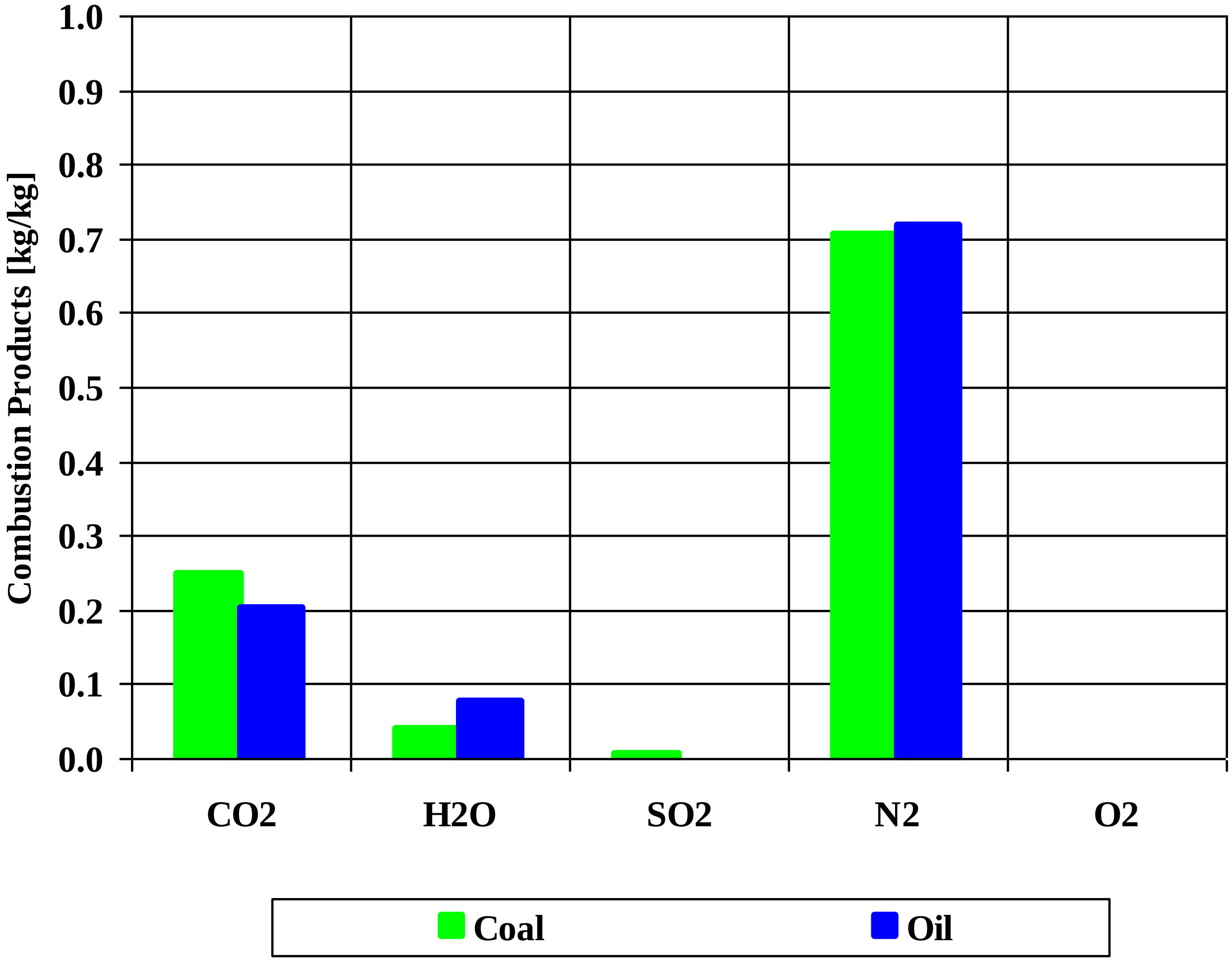
2,484 [K]

Oxidant To Fuel Ratio

14.649 [/]

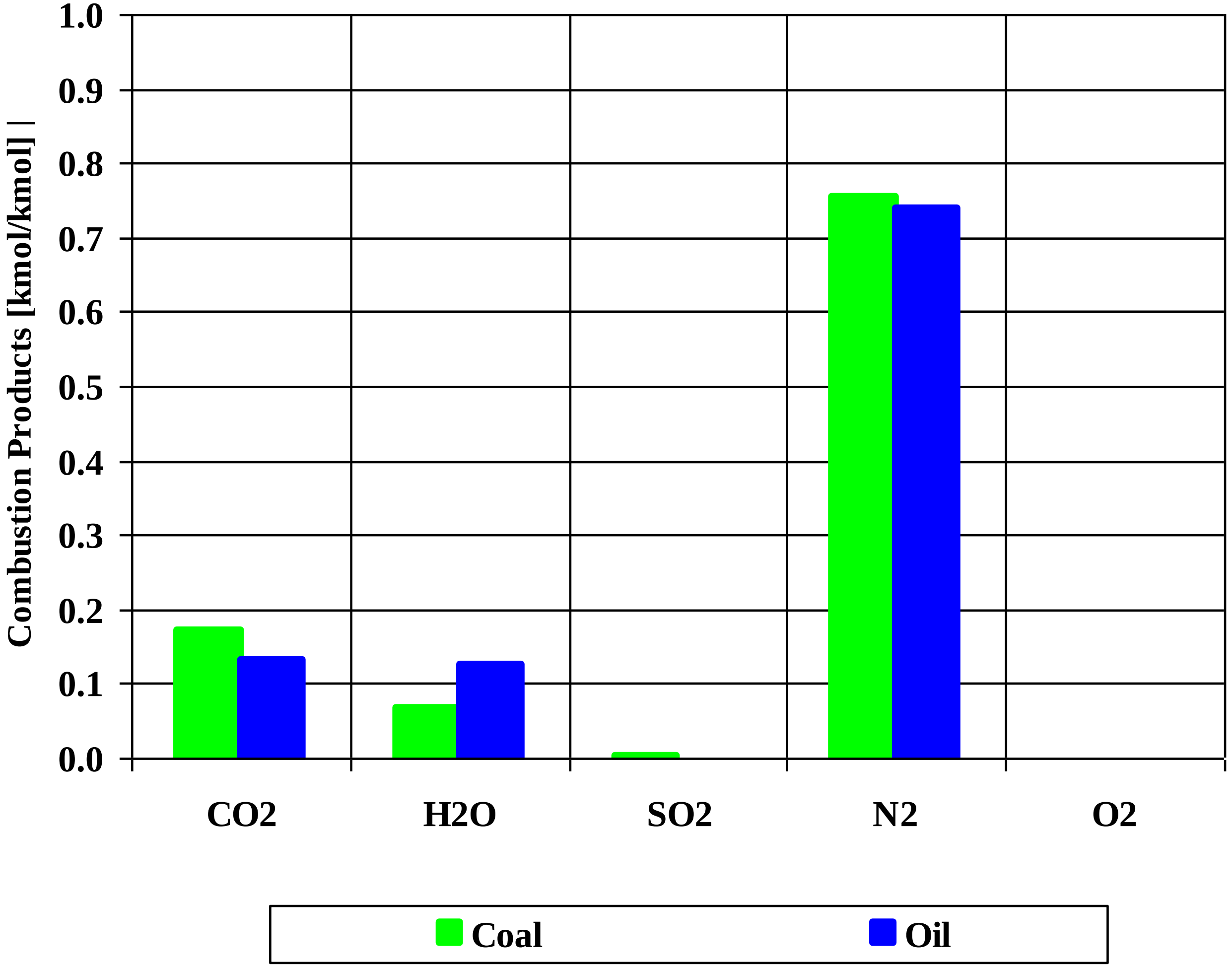

Combustion Products Flame Temperature
(Oil as Fuel)
4,000
3,500
3,000
2,500
2,000
Flame Temperature [K]
298
800
1,300
1,800
Oxidant Preheat Temperature [K]
Flame Temperature [K]
Fuel Inlet Temperature: 298 [K]

Combustion Products -- Weight Basis



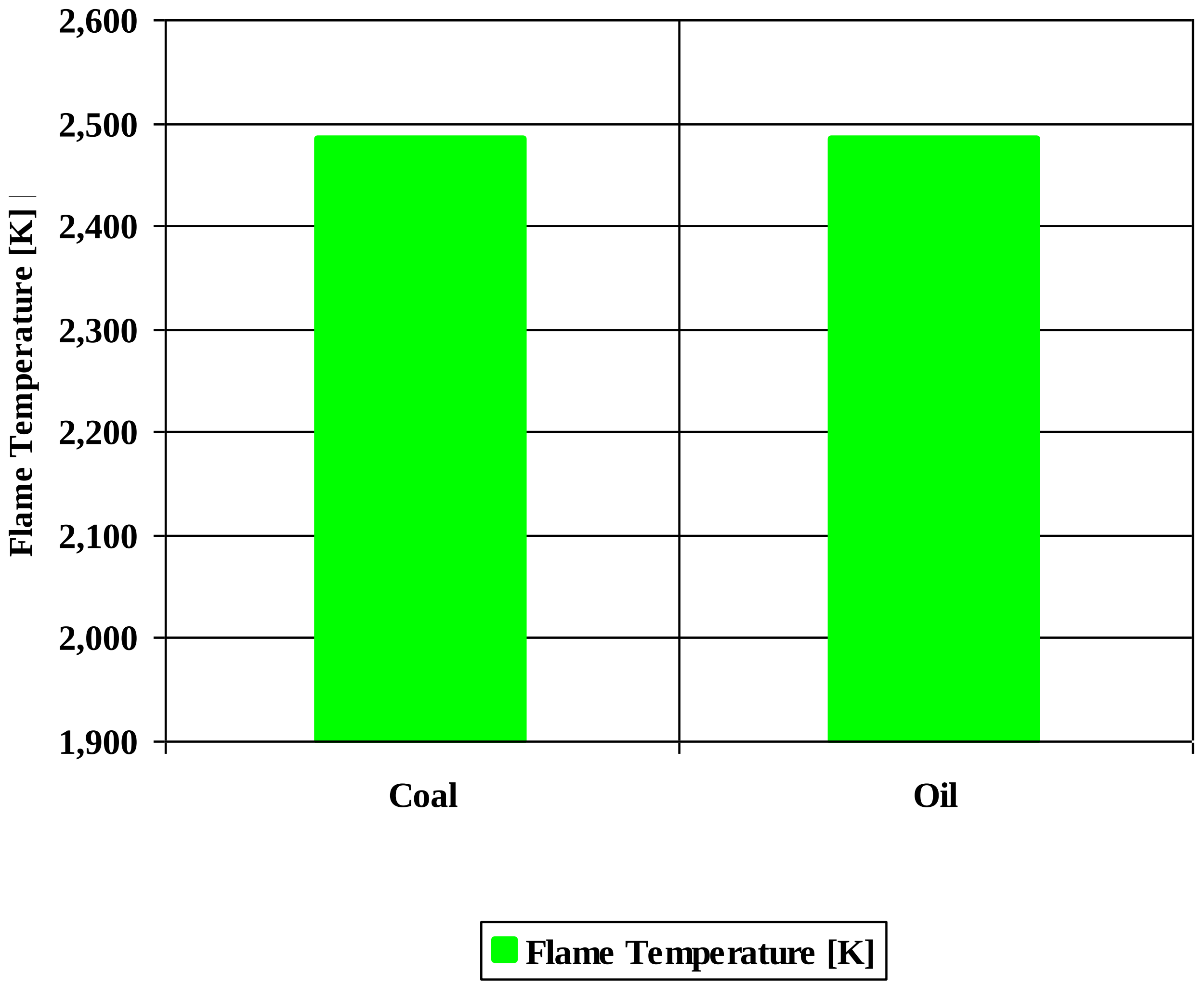
Fuel and Oxidant Inlet Temperature: 298 [K]

Combustion Products -- Mole Basis

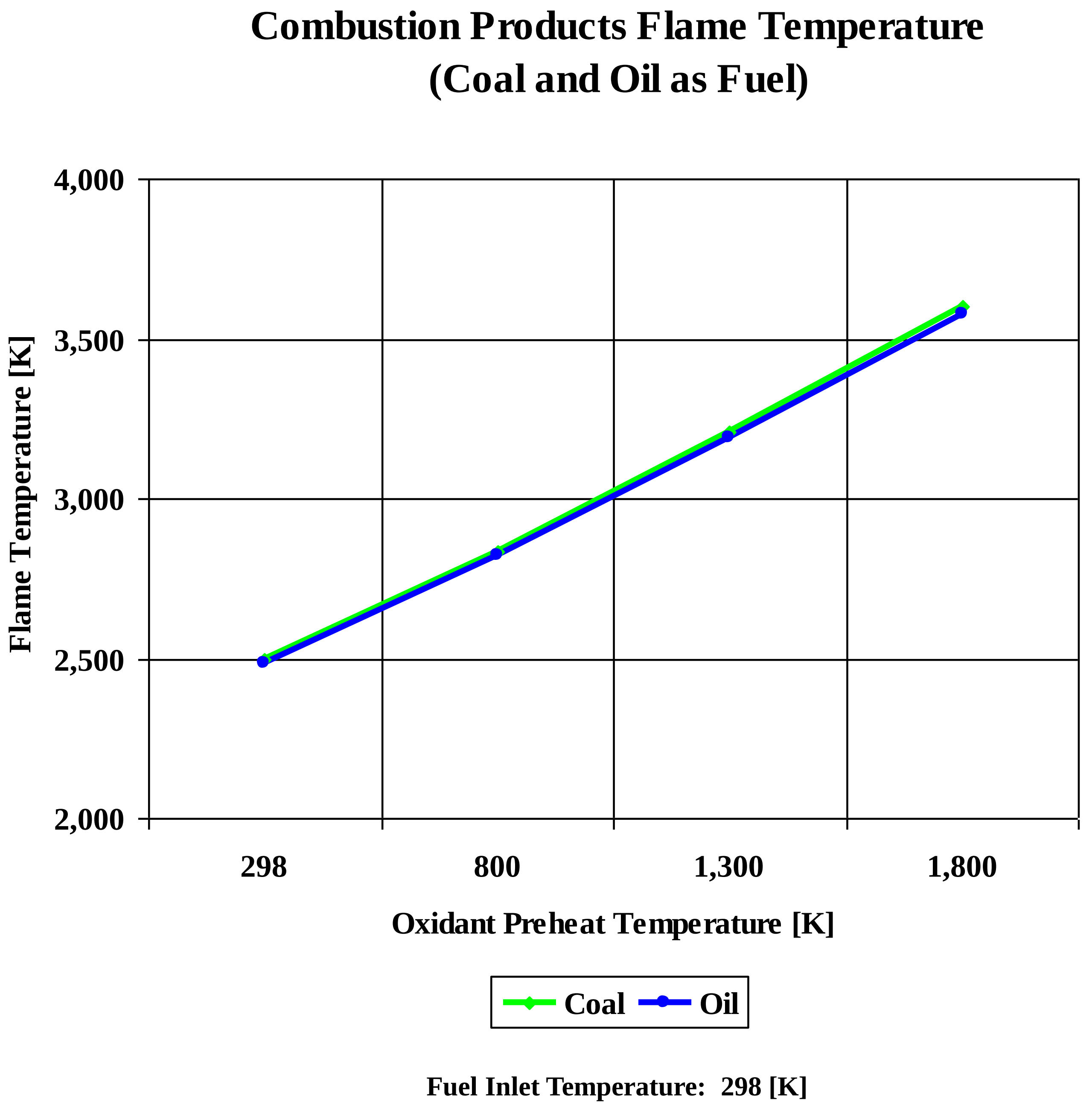


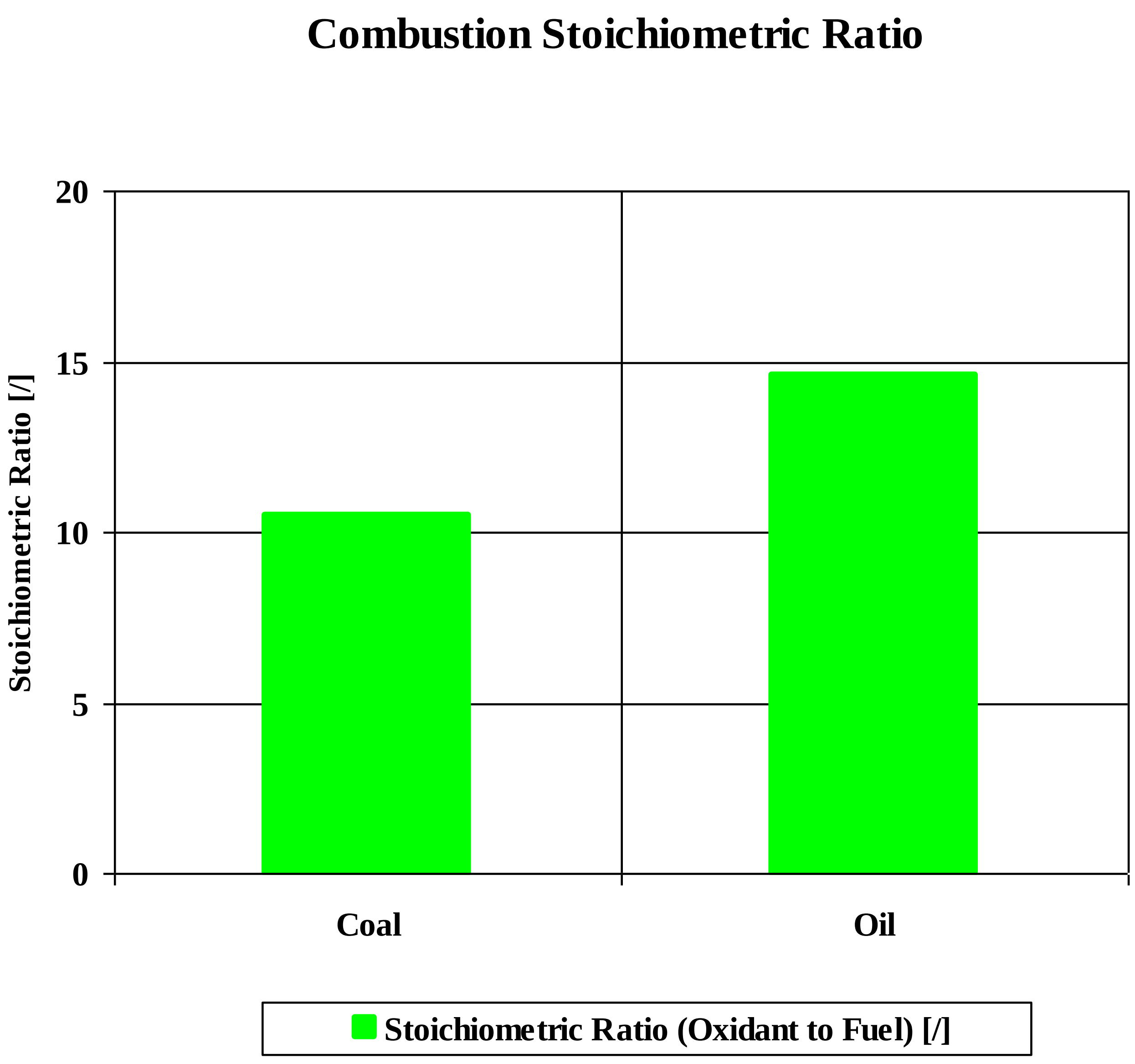
Fuel and Oxidant Inlet Temperature: 298 [K]

Combustion Products Flame Temperature

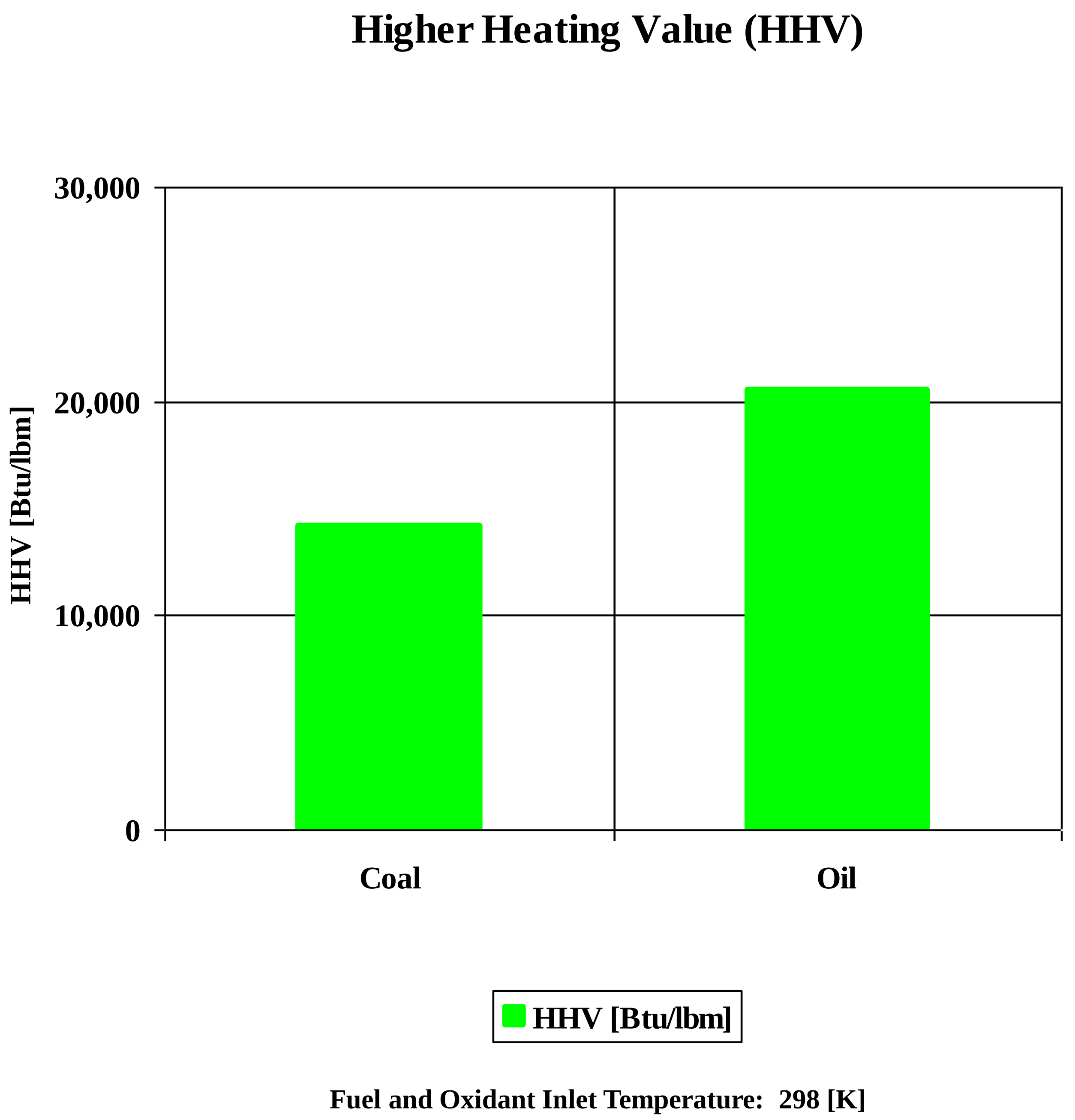


Fuel and Oxidant Inlet Temperature: 298 [K]


Combustion Products Flame Temperature
(Coal and Oil as Fuel)
4,000
3,500
3,000
2,500
2,000
Flame Temperature [K]
298
800
1,300
1,800
Oxidant Preheat Temperature [K]
Coal
Oil
Fuel Inlet Temperature: 298 [K]



Fuel and Oxidant Inlet Temperature: 298 [K]


Higher Heating Value (HHV)
HHV [Btu/lbm]
30,000
20,000
10,000
0
Coal
Oil
HHV [Btu/lbm]
Fuel and Oxidant Inlet Temperature: 298 [K]

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Combustion Analysis

Here are some of the basic combustion information and plots when considering gas (methane) as the fuel and air as the oxidant.

Combustion Assumptions

- Fuel Temperature 298 [K]

- Oxidant Temperature 298 [K]

- Stoichiometric Combustion

- No Heat Losses

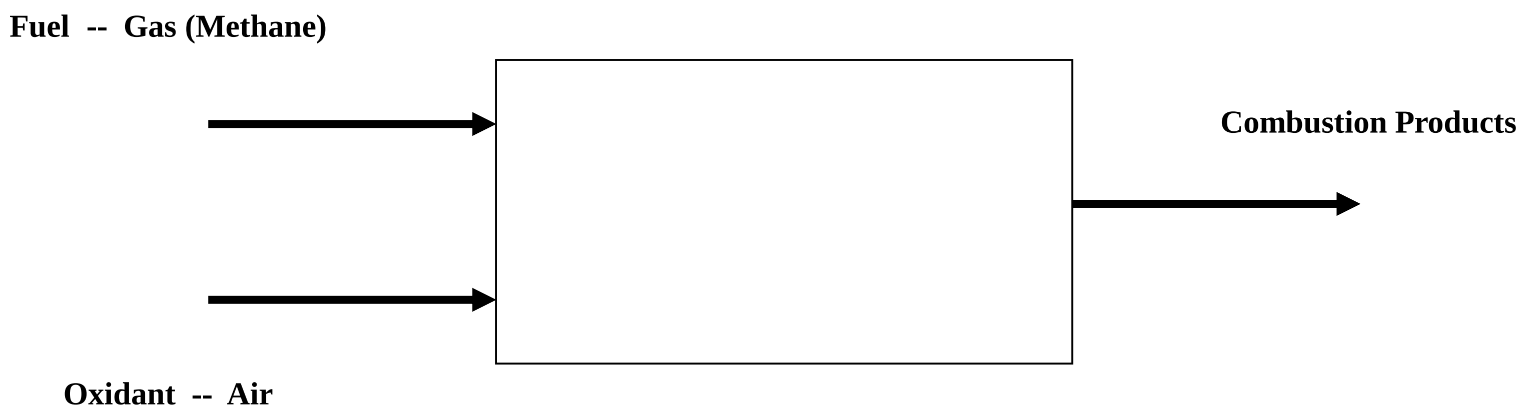
Fuel (Gas -- Methane) Composition

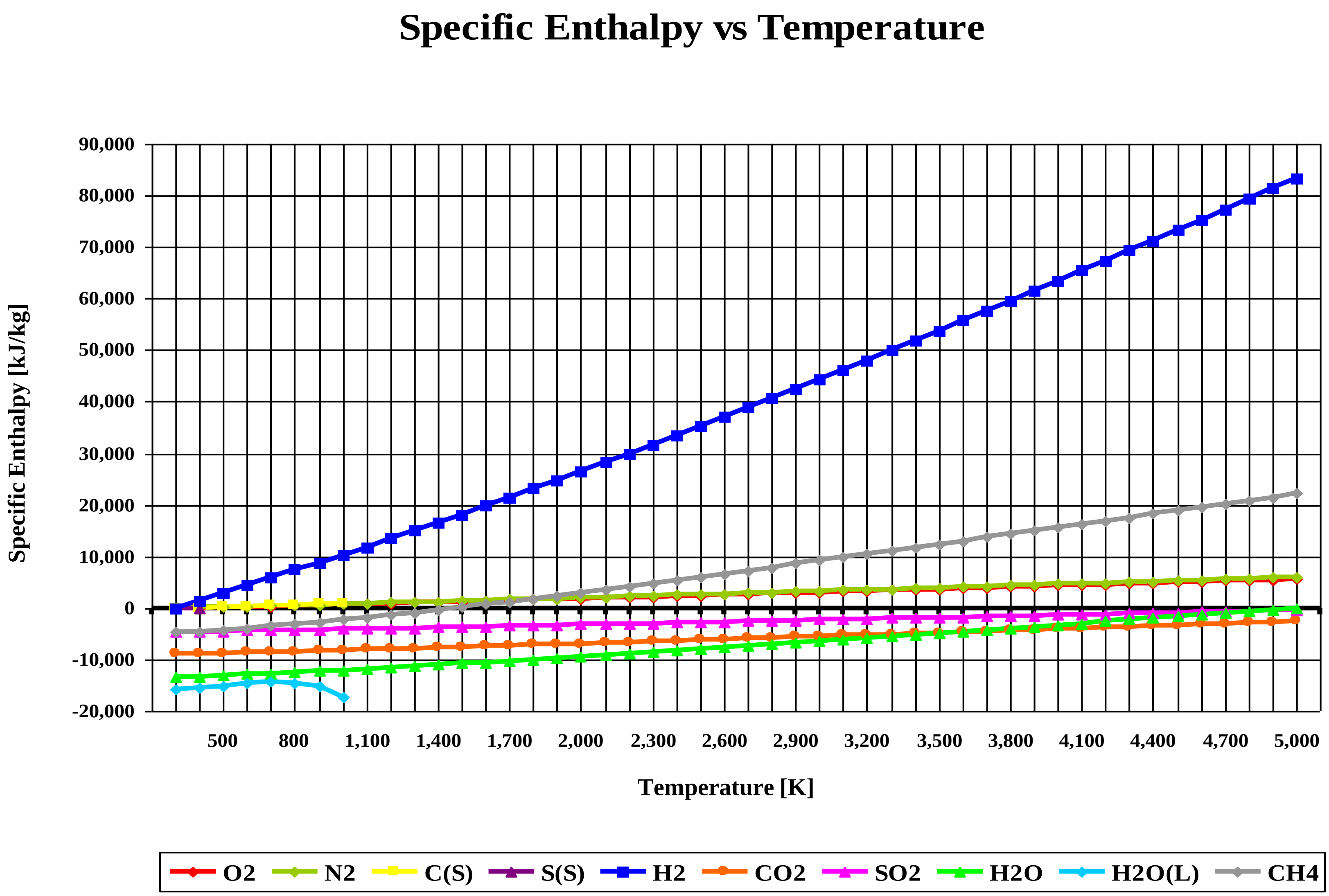
Element	Weight [kg/kg]	Mole [kmol/kmol]
CH_4	1.00	1.00

Oxidant (Air) Composition

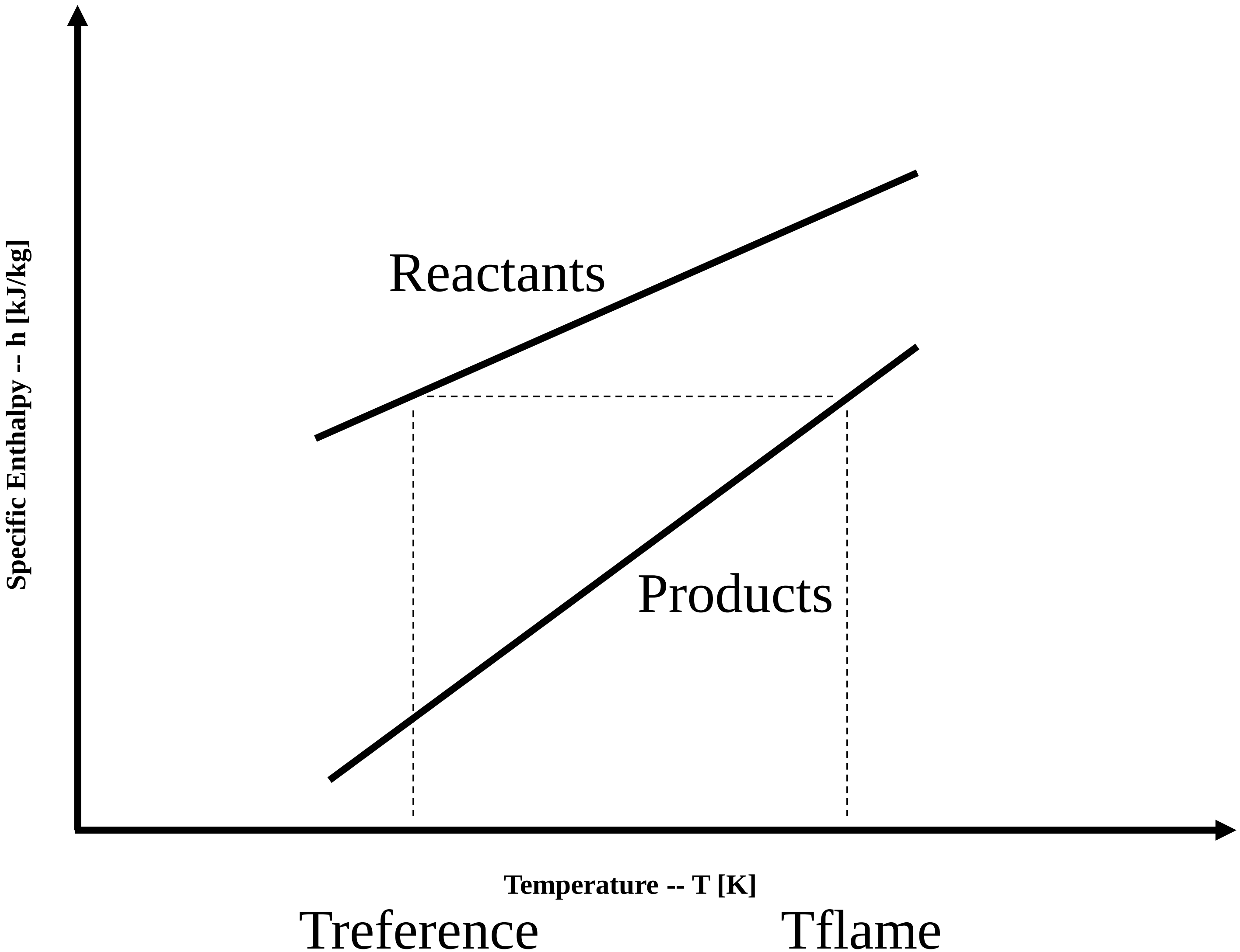
Element	Weight [kg/kg]	Mole [kmol/kmol]
N	0.767	0.790
O	0.233	0.210

Combustion Schematic Layout





Specific Enthalpy vs Temperature
Specific Enthalpy [kJ/kg]
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
-10,000
-20,000
500
800
1,100
1,400
1,700
2,000
2,300
2,600
2,900
3,200
3,500
3,800
4,100
4,400
4,700
5,000
Temperature [K]
O2
N2
C(S)
S(S)
H2
CO2
SO2
H2O
H2O(L)
CH4



Combustion h - T Diagram

Combustion Products Composition

Element	Weight [kg/kg]	Mole [kmol/kmol]
CO_2	0.151	0.095
H_2O	0.124	0.190
SO_2	0.000	0.000
N_2	0.725	0.715
O_2	0.000	0.000

Combustion Values

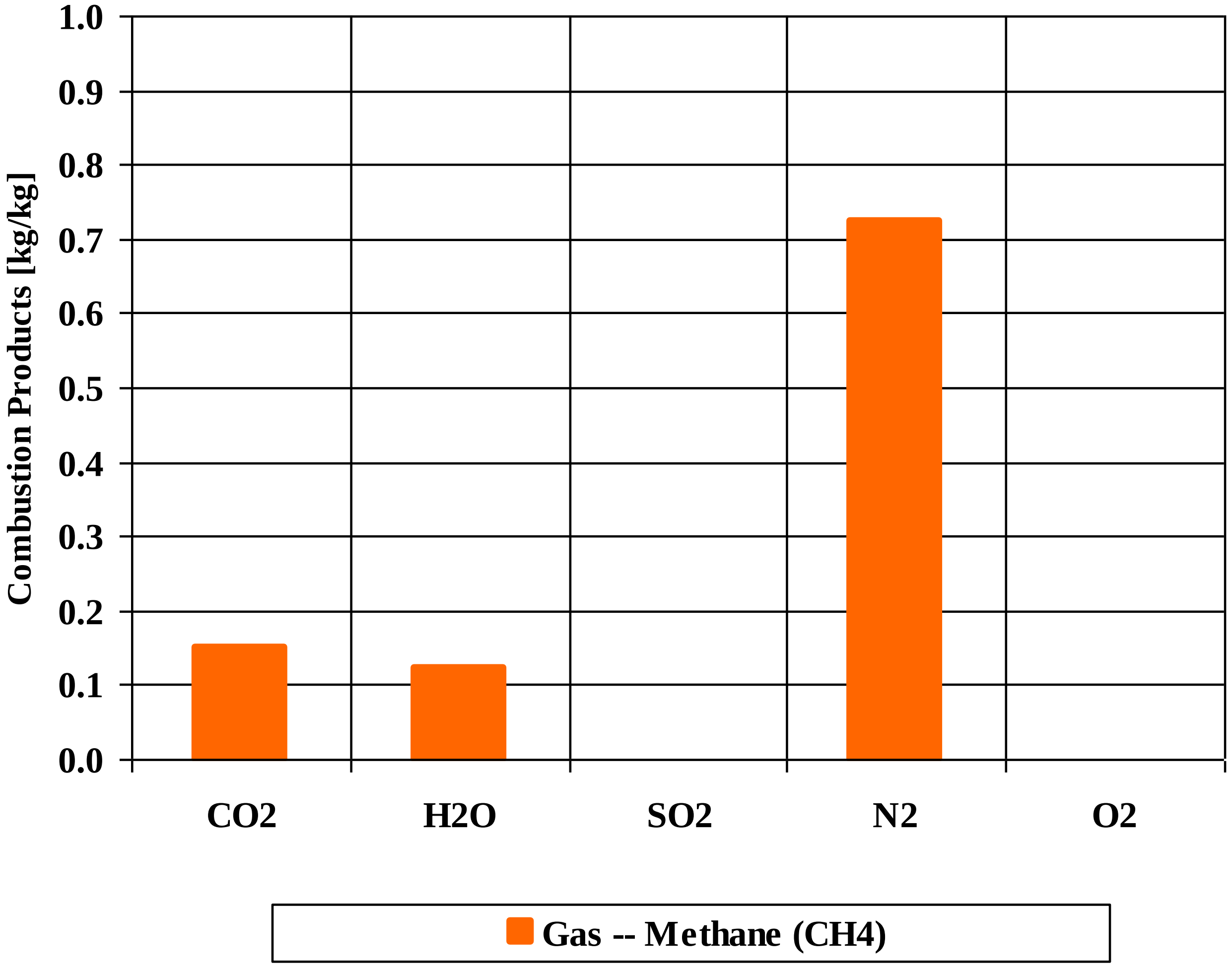
Flame Temperature

2,327 [K]

Oxidant To Fuel Ratio

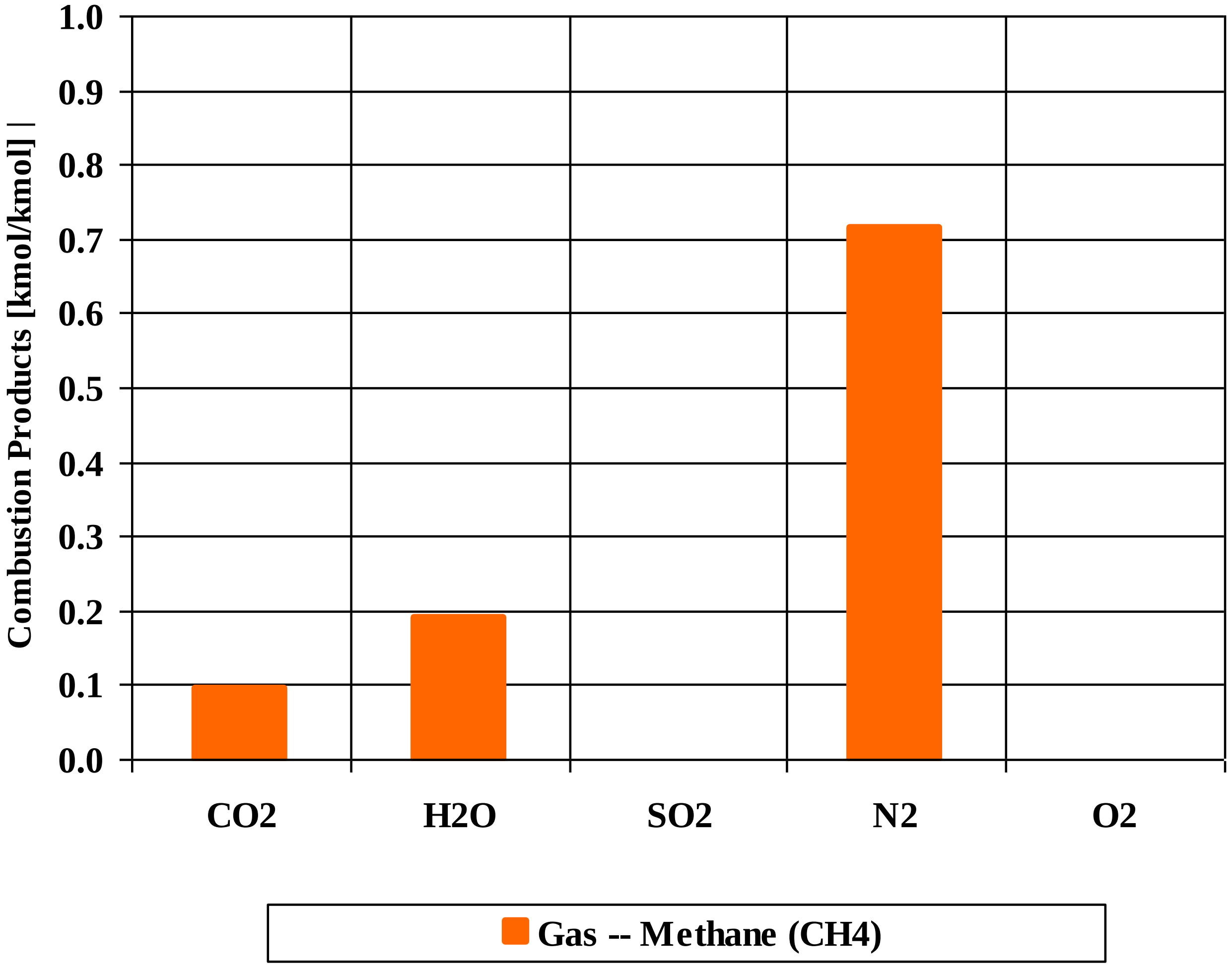
17.167 [/]

Combustion Products -- Weight Basis

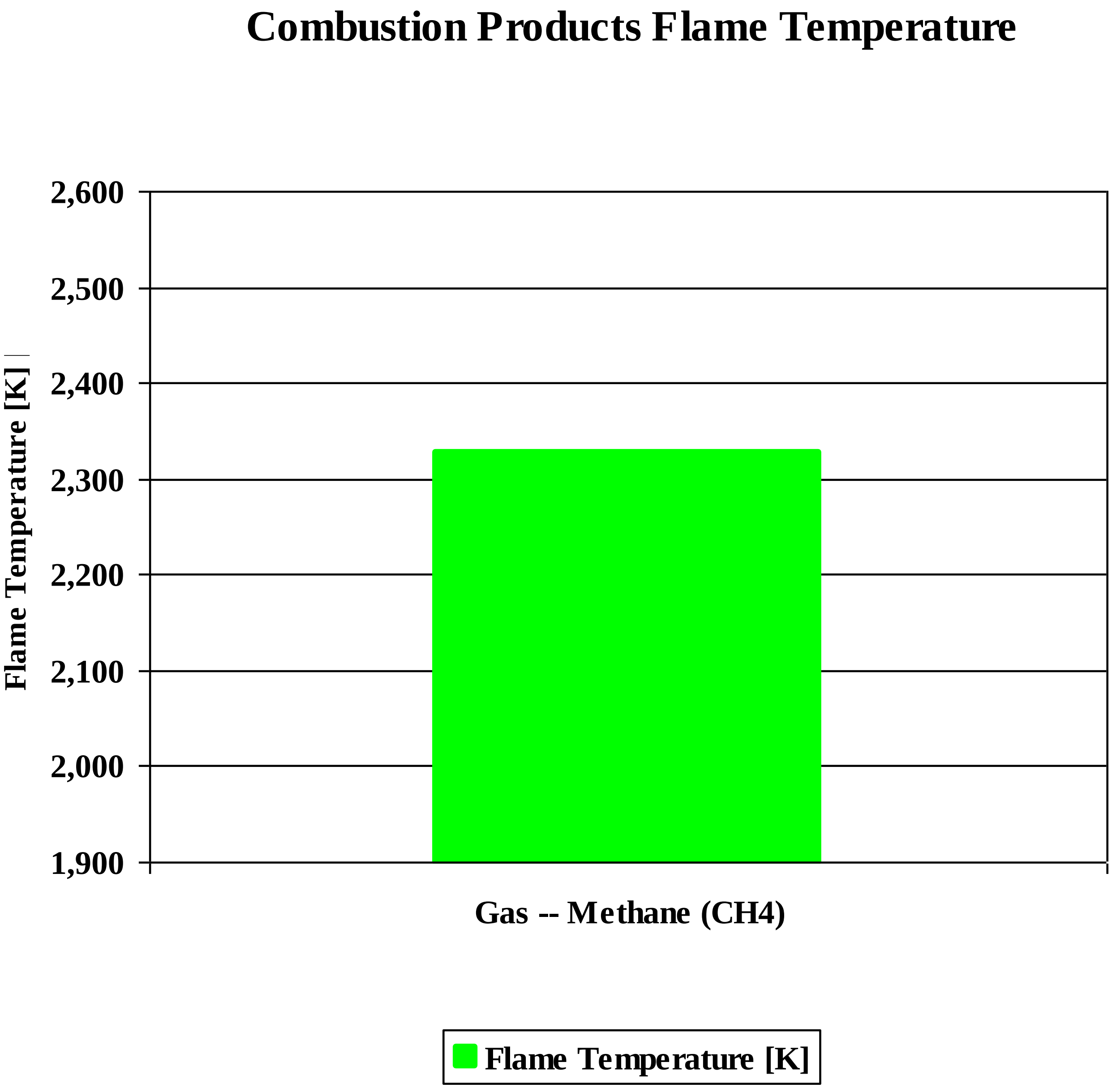


Fuel and Oxidant Inlet Temperature: 298 [K]

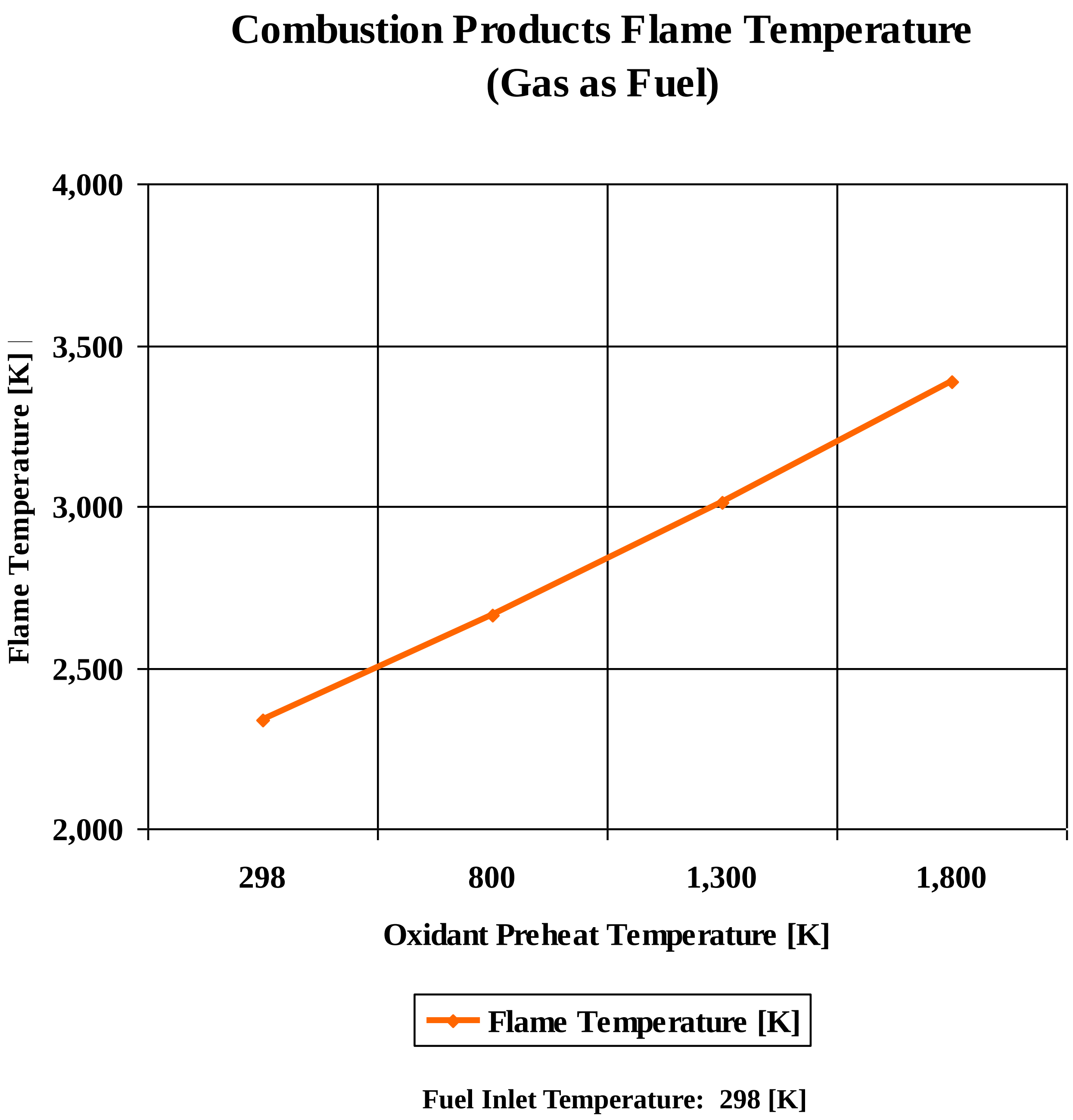
Combustion Products -- Mole Basis



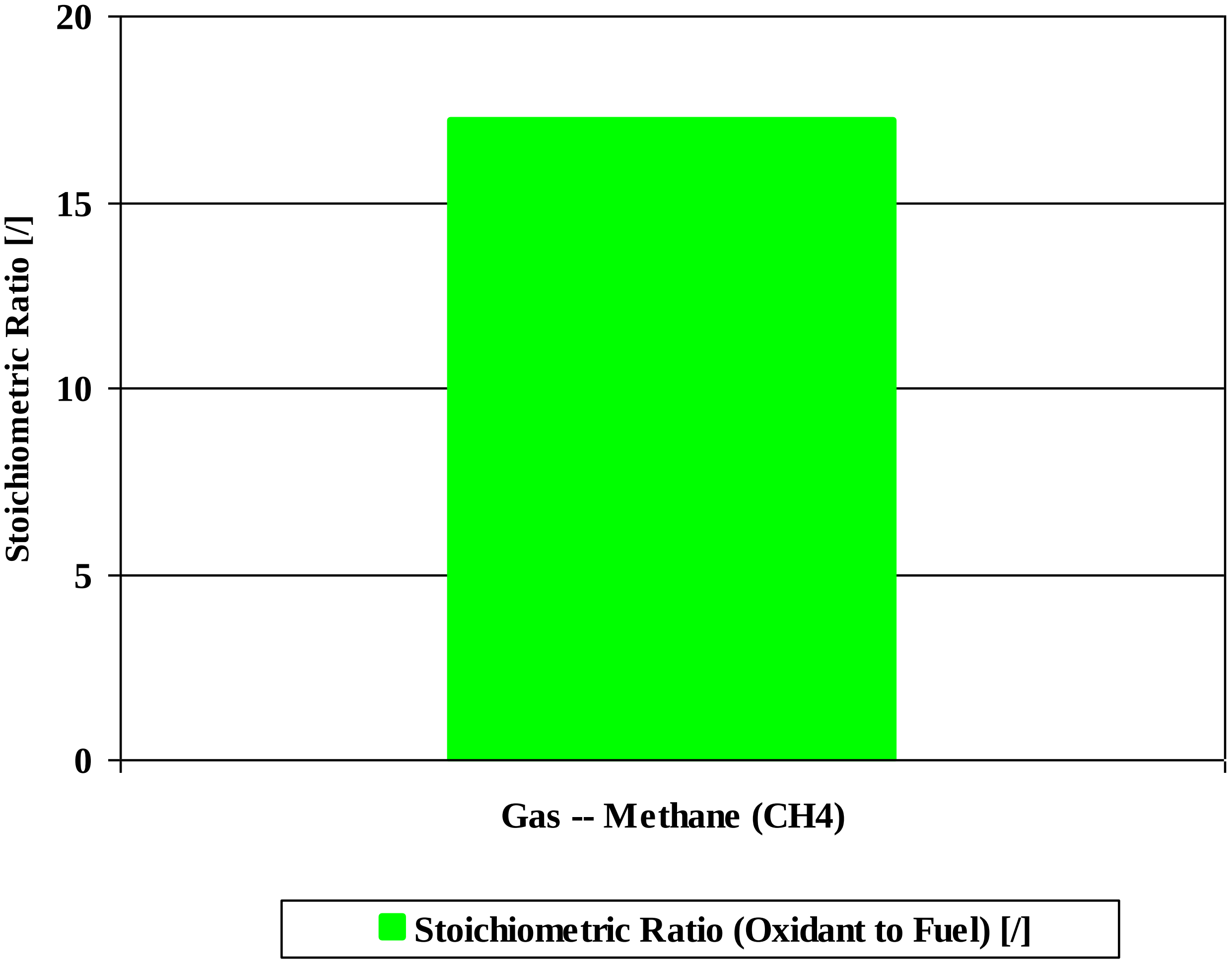
Fuel and Oxidant Inlet Temperature: 298 [K]



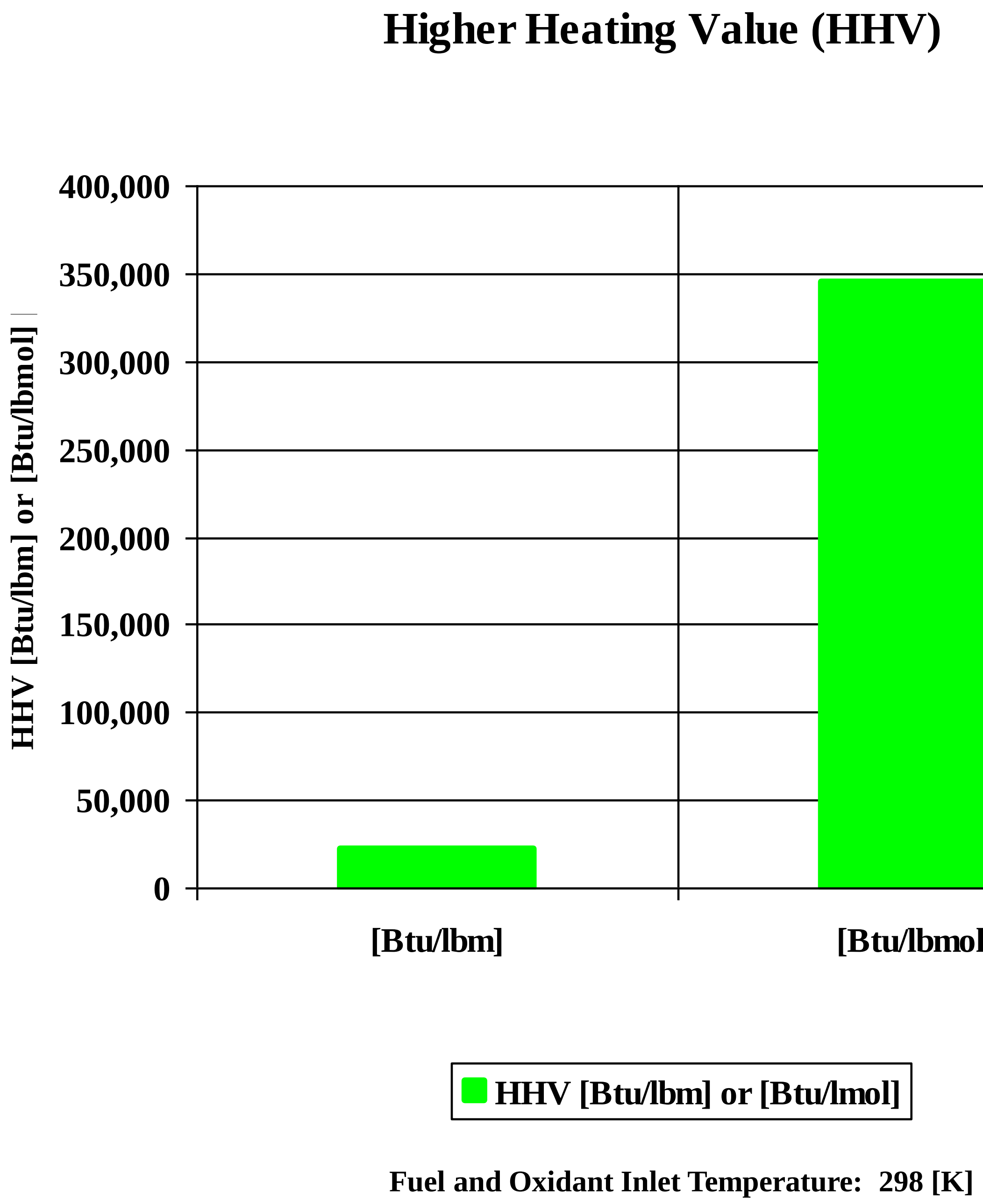
Fuel and Oxidant Inlet Temperature: 298 [K]


Combustion Products Flame Temperature
(Gas as Fuel)
4,000
3,500
3,000
2,500
2,000
Flame Temperature [K]
298
800
1,300
1,800
Oxidant Preheat Temperature [K]
Flame Temperature [K]
Fuel Inlet Temperature: 298 [K]

Combustion Stoichiometric Ratio



Fuel and Oxidant Inlet Temperature: 298 [K]


Higher Heating Value (HHV)
HHV [Btu/lbm] or [Btu/lbmol]
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
[Btu/lbm]
[Btu/lbmol]
HHV [Btu/lbm] or [Btu/lmol]
Fuel and Oxidant Inlet Temperature: 298 [K]

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Combustion Analysis

Here are some of the basic combustion information and plots when considering coal, oil and gas (methane) as the fuel and air as the oxidant.

Combustion Assumptions

- Fuel Temperature 298 [K]

- Oxidant Temperature 298 [K]

- Stoichiometric Combustion

- No Heat Losses

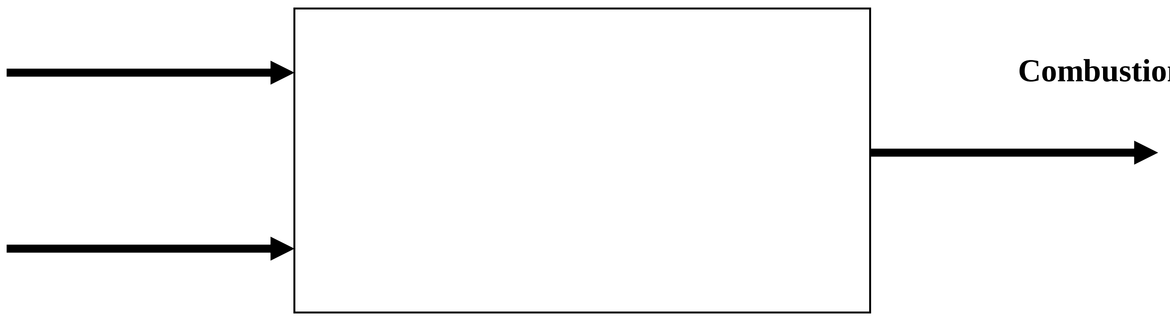
Fuel (Coal) Composition

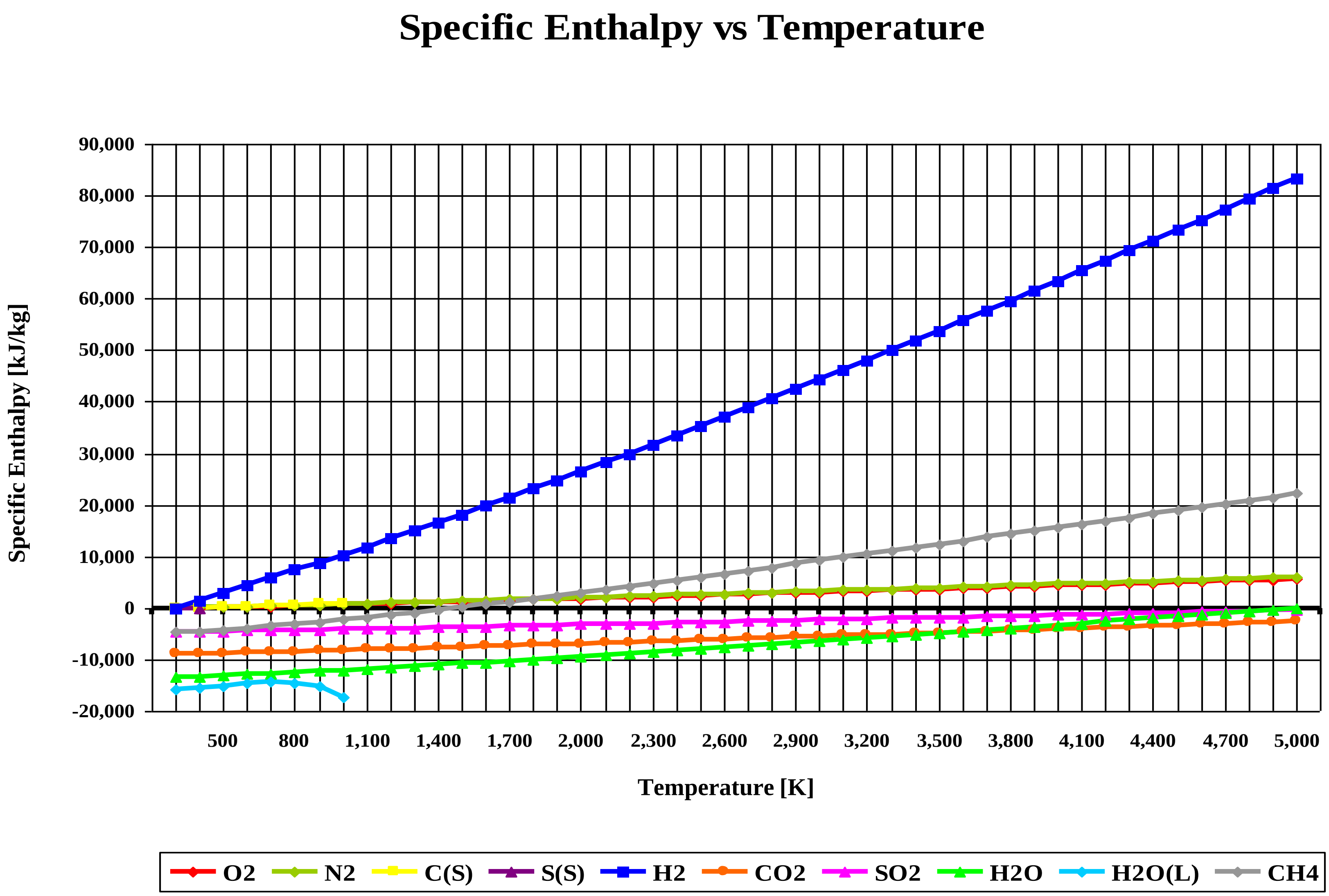
Element	Weight [kg/kg]
C	0.78
H	0.05
S	0.03
N	0.04
O	0.08
W	0.02

Oxidant (Air) Composition

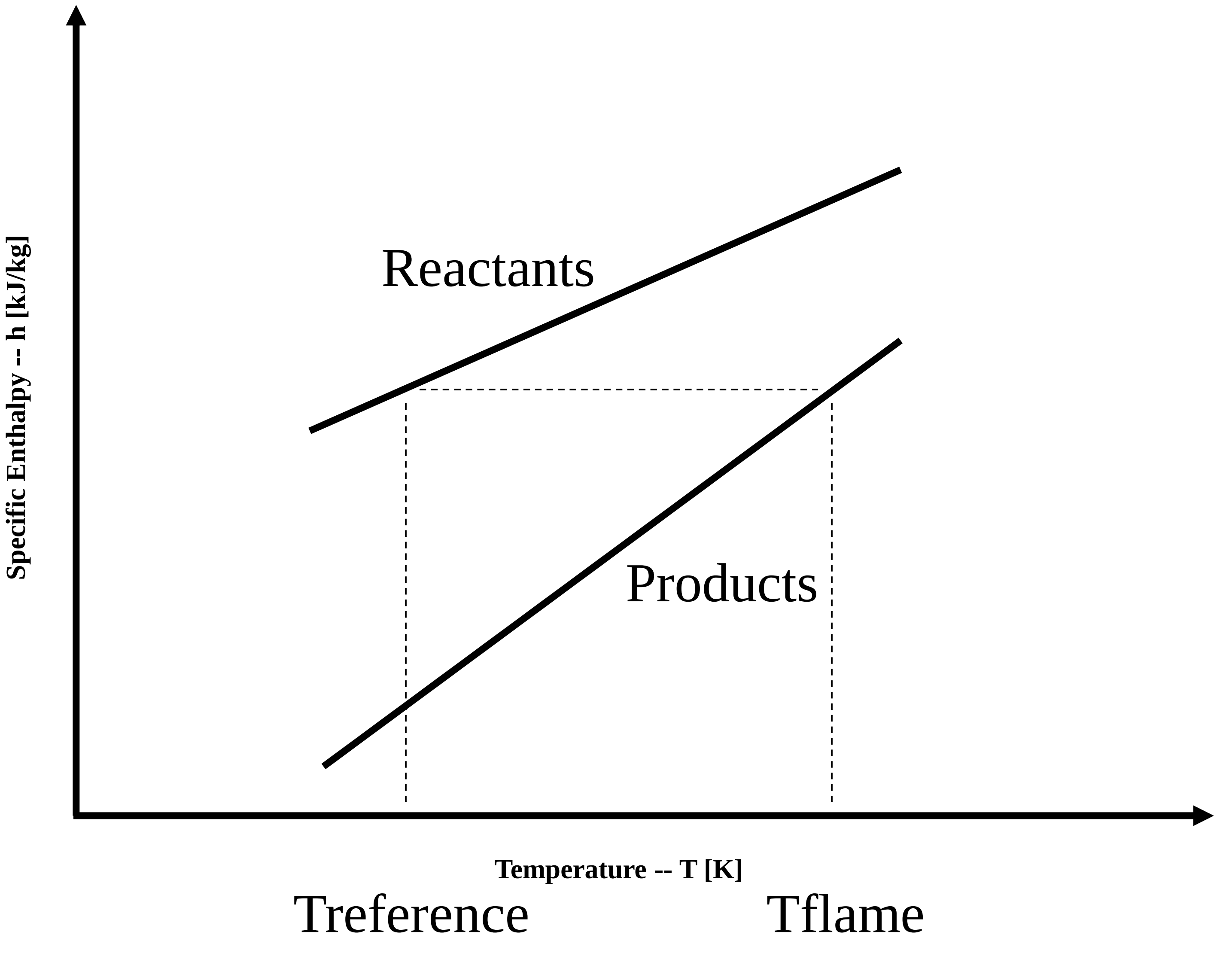
Element	Weight [kg/kg]	Mole [kmol/kmol]
N	0.767	0.790
O	0.233	0.210

Combustion Schematic Layout





Specific Enthalpy vs Temperature
Specific Enthalpy [kJ/kg]
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
-10,000
-20,000
500
800
1,100
1,400
1,700
2,000
2,300
2,600
2,900
3,200
3,500
3,800
4,100
4,400
4,700
5,000
Temperature [K]
O2
N2
C(S)
S(S)
H2
CO2
SO2
H2O
H2O(L)
CH4



Combustion h - T Diagram

Combustion Products Composition

Element	Weight [kg/kg]	Mole [kmol/kmol]
CO_2	0.249	0.170
H_2O	0.041	0.068
SO_2	0.005	0.002
N_2	0.705	0.759
O_2	0.000	0.000

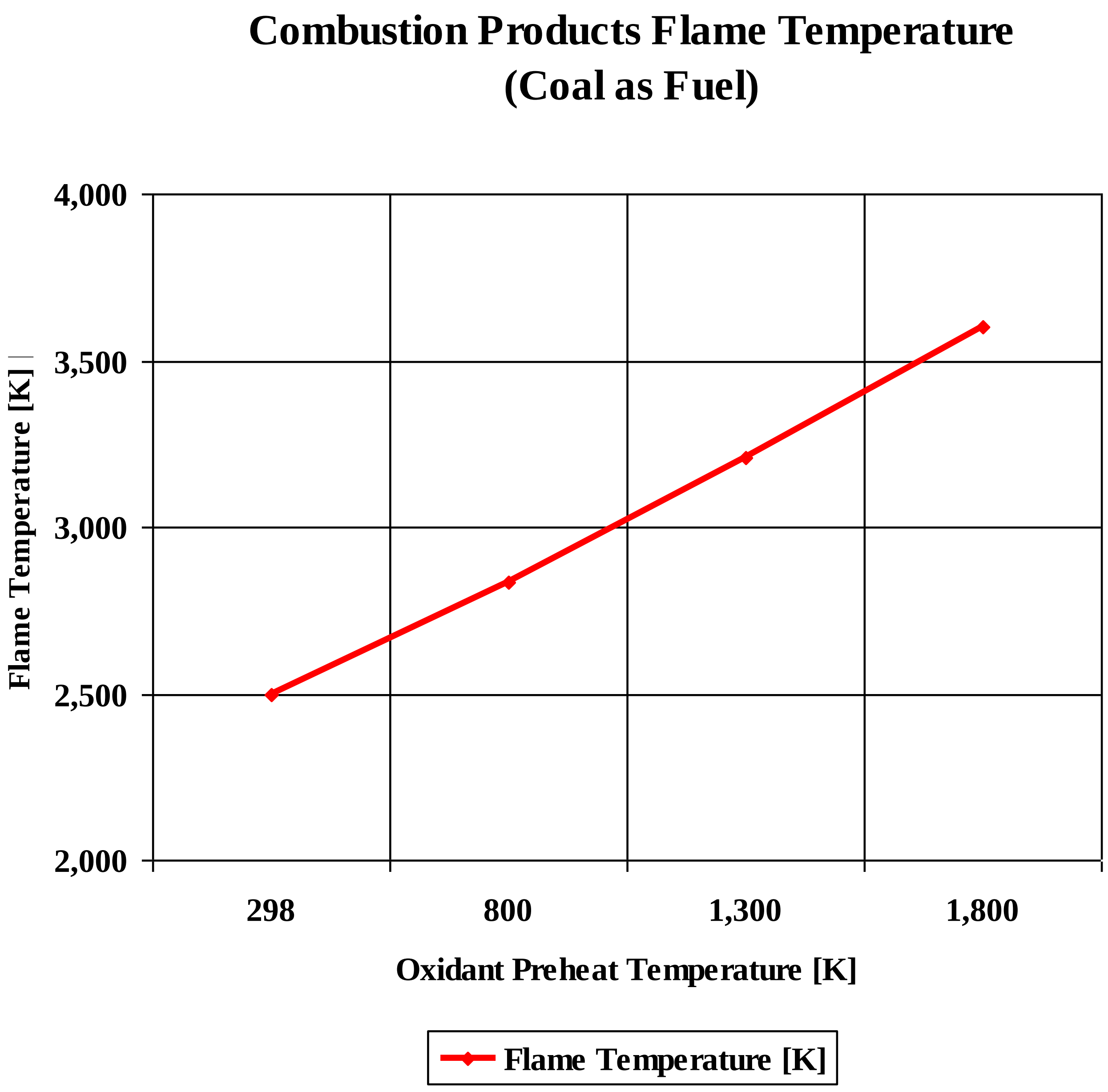
Combustion Values

Flame Temperature

2,484 [K]

Oxidant To Fuel Ratio

10.487 [/]



Fuel Inlet Temperature: 298 [K]

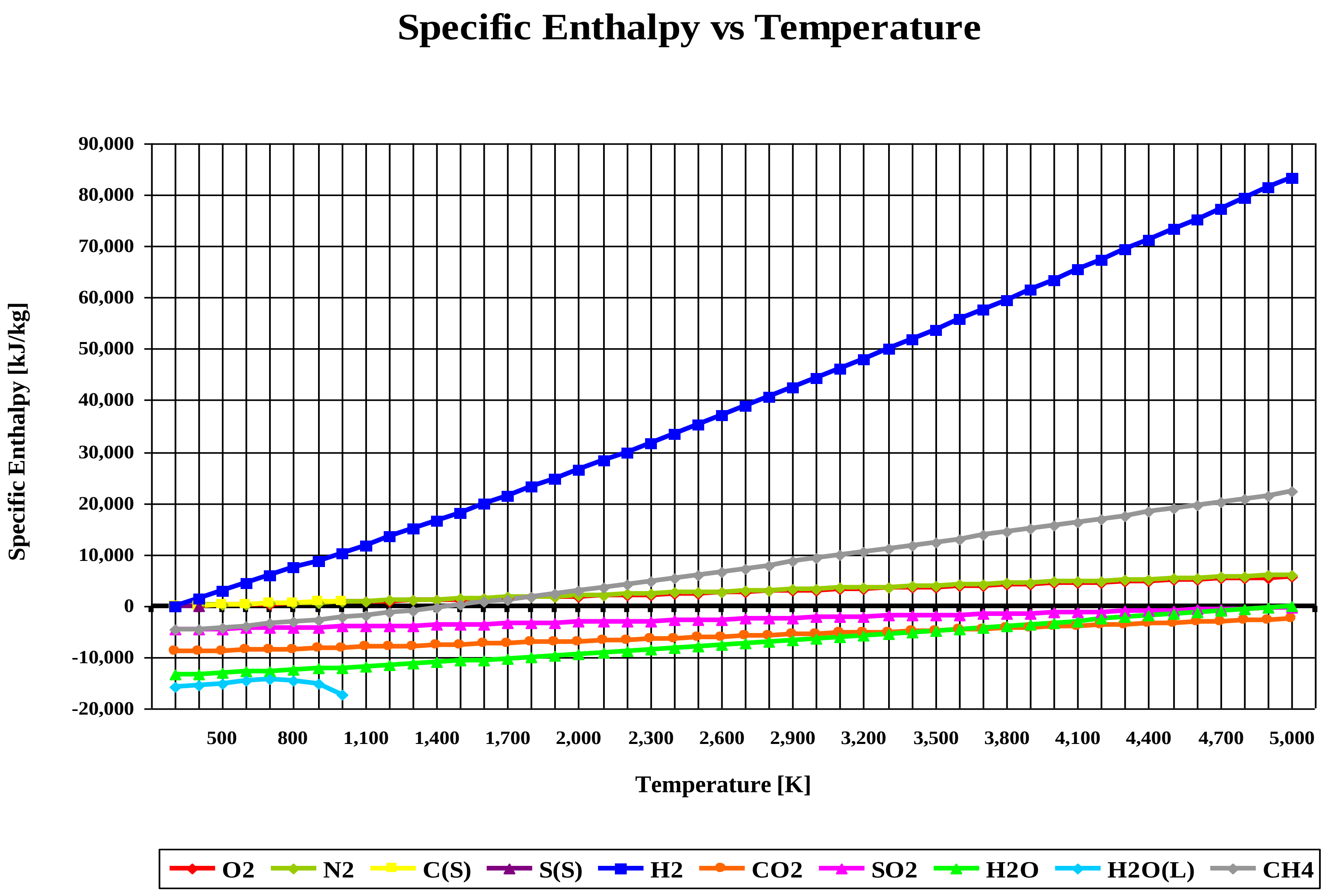
Fuel (Oil) Composition

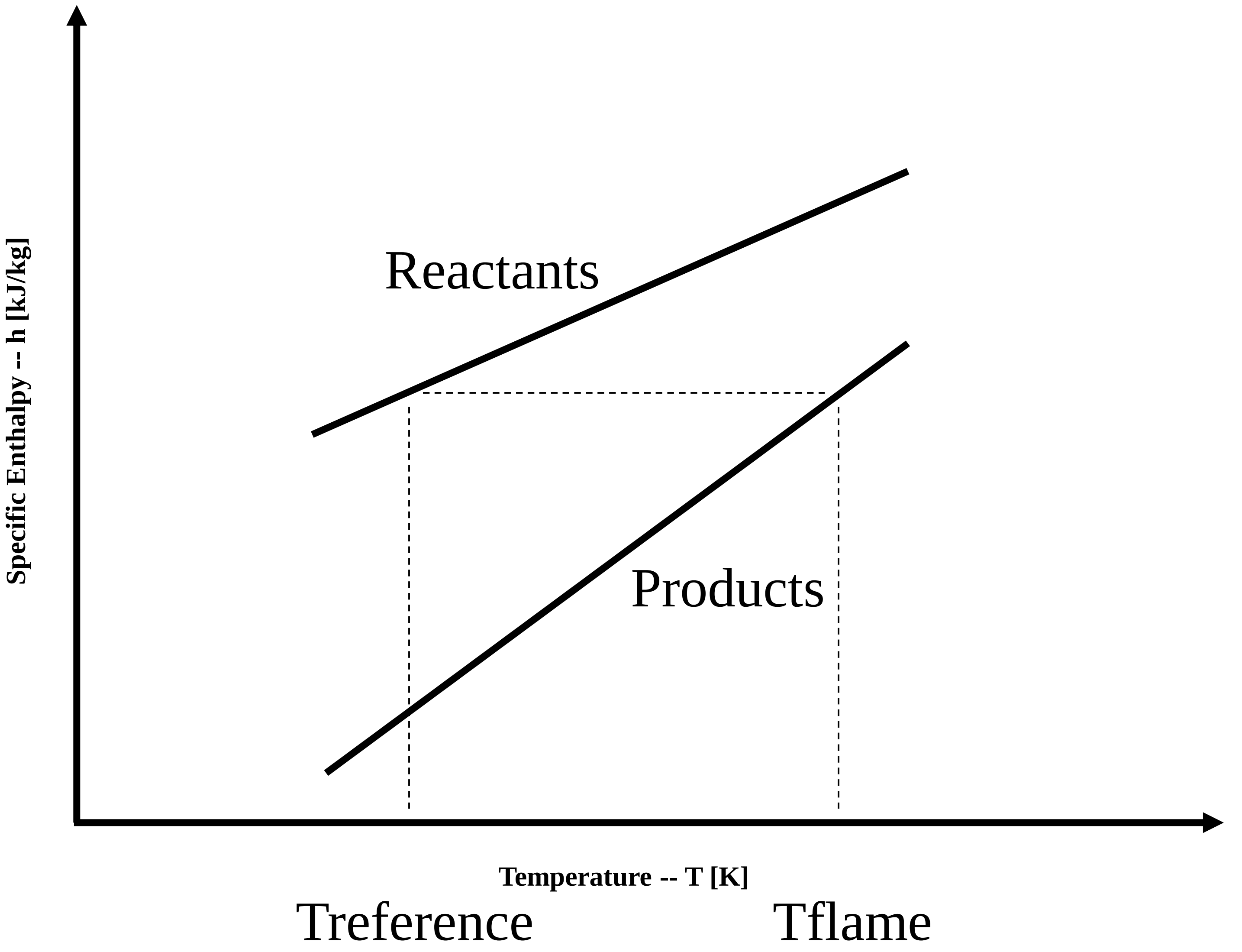
Element	Weight [kg/kg]
C	0.86
H	0.14
S	0.00
N	0.00
O	0.00
W	0.00

Oxidant (Air) Composition

Element	Weight [kg/kg]	Mole [kmol/kmol]
N	0.767	0.790
O	0.233	0.210

Combustion Schematic Layout


Specific Enthalpy vs Temperature
Specific Enthalpy [kJ/kg]
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
-10,000
-20,000
500
800
1,100
1,400
1,700
2,000
2,300
2,600
2,900
3,200
3,500
3,800
4,100
4,400
4,700
5,000
Temperature [K]
O2
N2
C(S)
S(S)
H2
CO2
SO2
H2O
H2O(L)
CH4



Combustion h - T Diagram

Combustion Products Composition

Element	Weight [kg/kg]	Mole [kmol/kmol]
CO_2	0.202	0.132
H_2O	0.080	0.129
SO_2	0.000	0.000
N_2	0.718	0.739
O_2	0.000	0.000

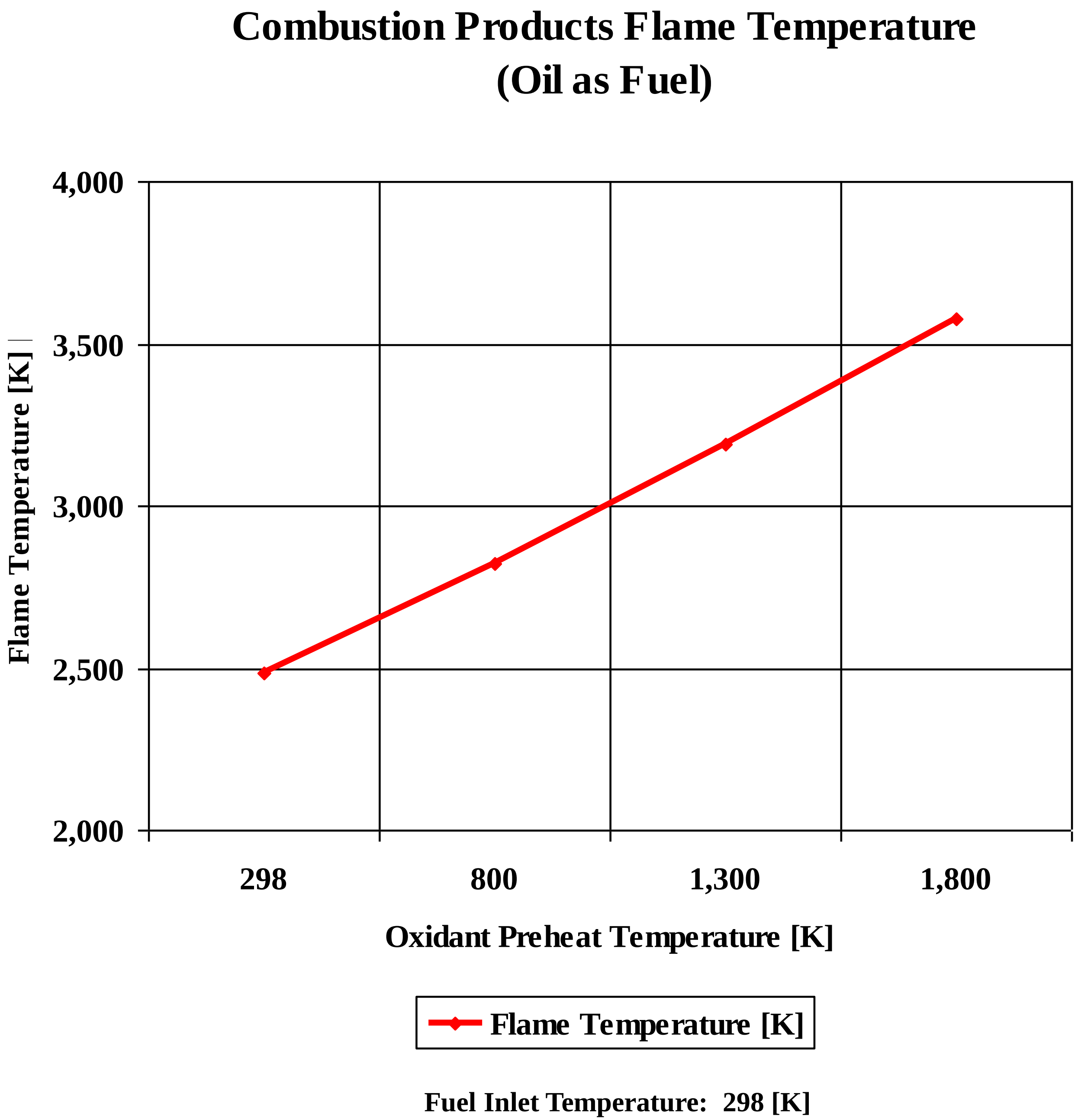
Combustion Values

Flame Temperature

2,484 [K]

Oxidant To Fuel Ratio

14.649 [/]


Combustion Products Flame Temperature
(Oil as Fuel)
4,000
3,500
3,000
2,500
2,000
Flame Temperature [K]
298
800
1,300
1,800
Oxidant Preheat Temperature [K]
Flame Temperature [K]
Fuel Inlet Temperature: 298 [K]

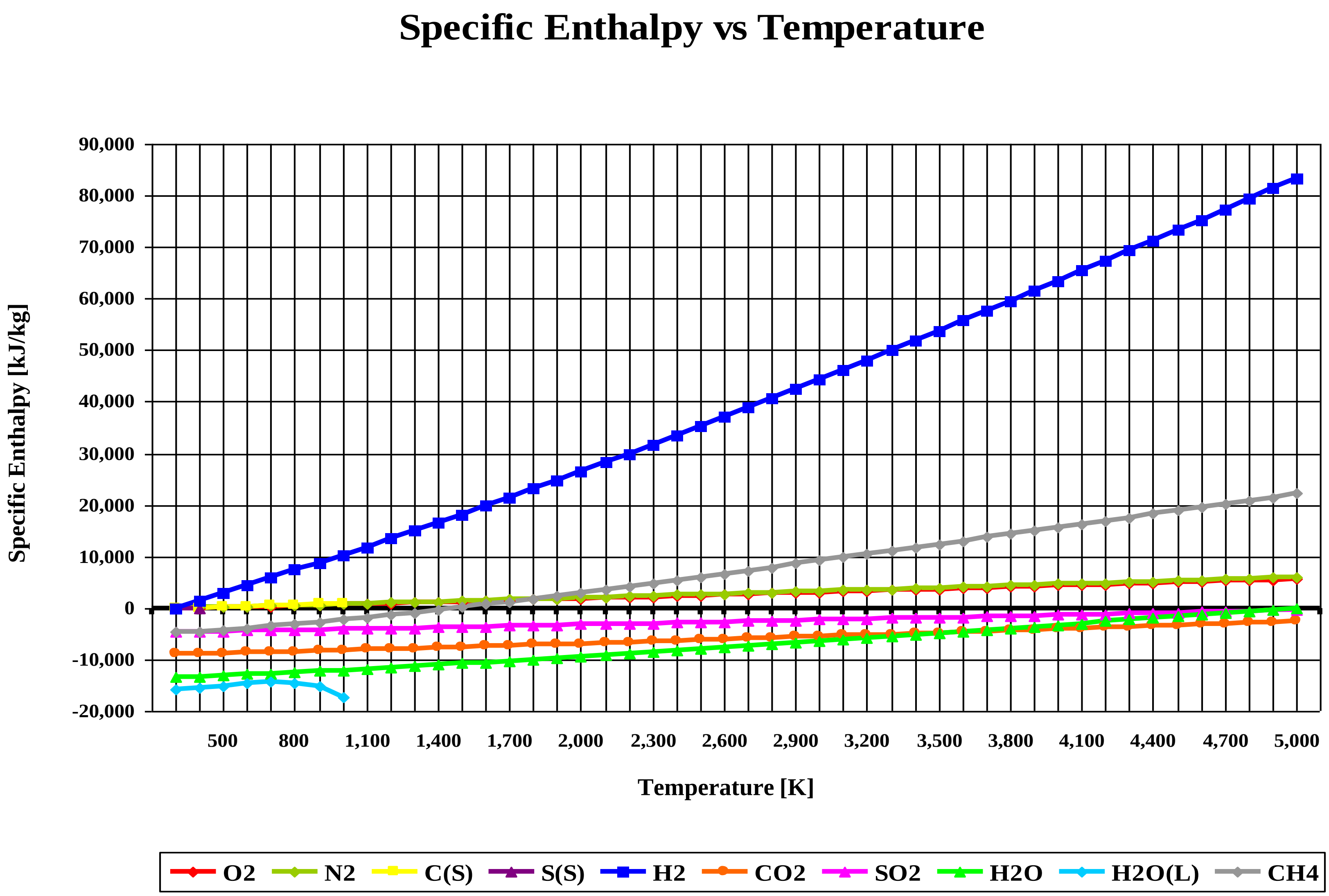
Fuel (Gas -- Methane) Composition

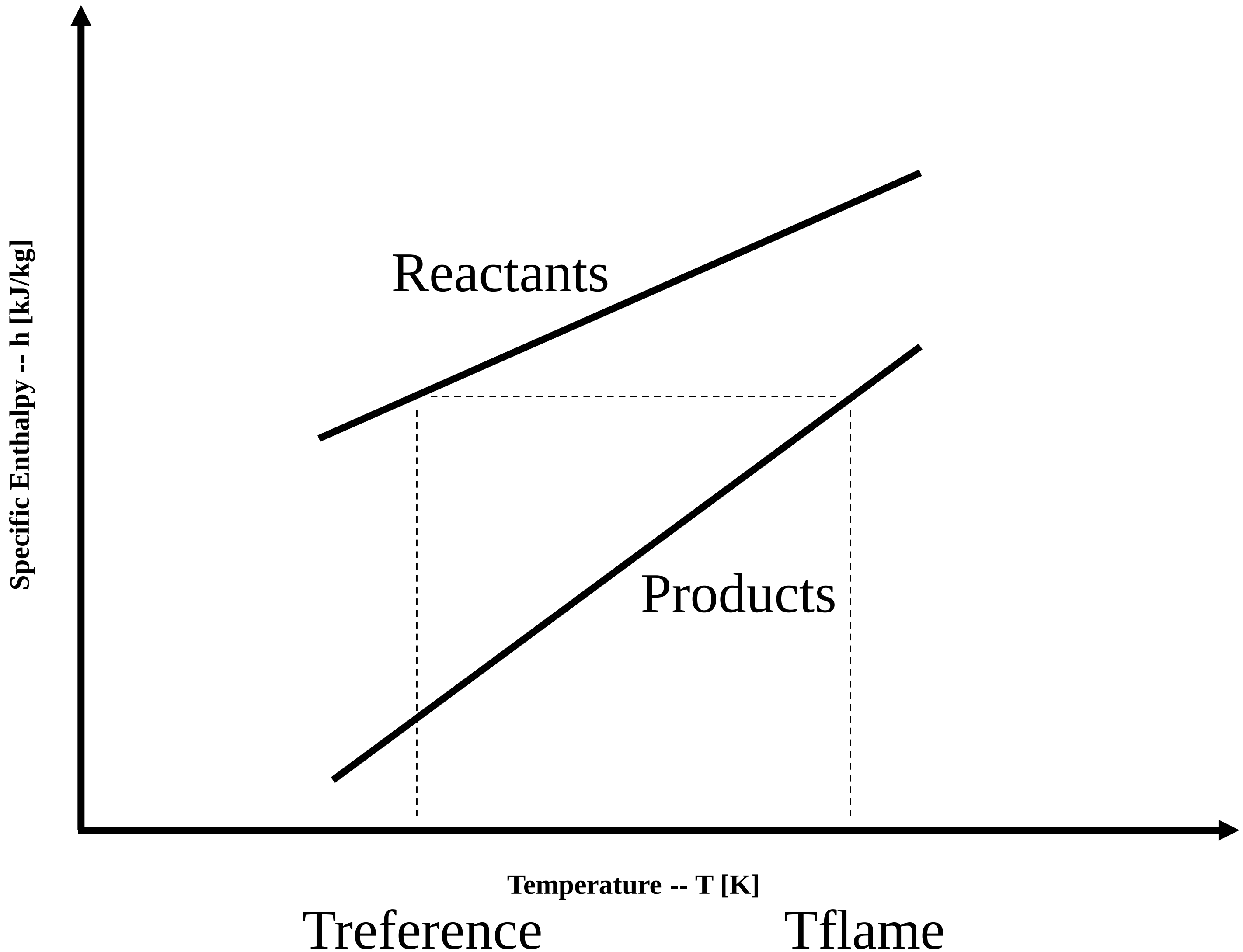
Element	Weight [kg/kg]	Mole [kmol/kmol]
CH_4	1.00	1.00

Oxidant (Air) Composition

Element	Weight [kg/kg]	Mole [kmol/kmol]
N	0.767	0.790
O	0.233	0.210

Combustion Schematic Layout


Specific Enthalpy vs Temperature
Specific Enthalpy [kJ/kg]
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
-10,000
-20,000
500
800
1,100
1,400
1,700
2,000
2,300
2,600
2,900
3,200
3,500
3,800
4,100
4,400
4,700
5,000
Temperature [K]
O2
N2
C(S)
S(S)
H2
CO2
SO2
H2O
H2O(L)
CH4



Combustion h - T Diagram

Combustion Products Composition

Element	Weight [kg/kg]	Mole [kmol/kmol]
CO_2	0.151	0.095
H_2O	0.124	0.190
SO_2	0.000	0.000
N_2	0.725	0.715
O_2	0.000	0.000

Combustion Values

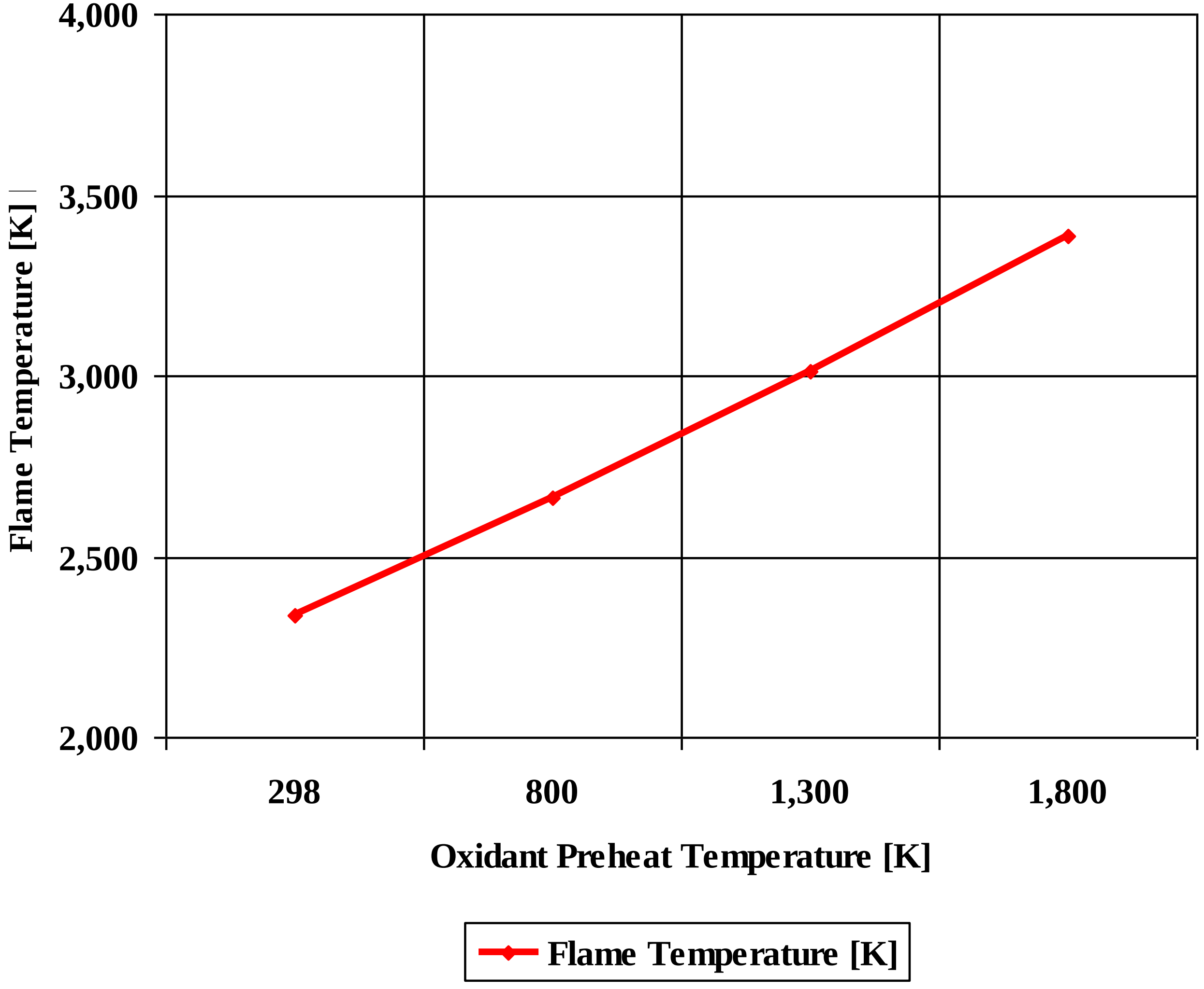
Flame Temperature

2,327 [K]

Oxidant To Fuel Ratio

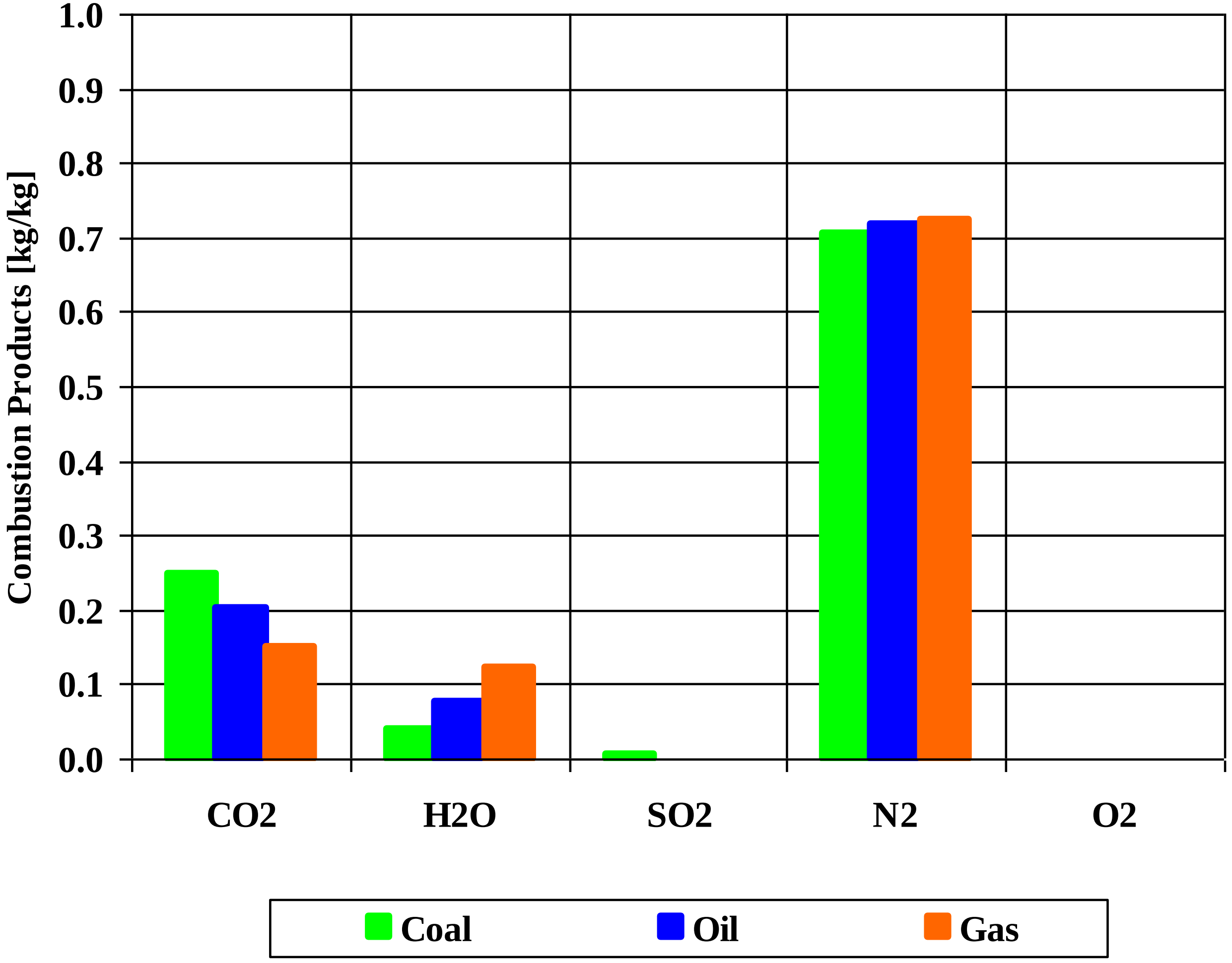
17.167 [/]

Combustion Products Flame Temperature
(Gas as Fuel)



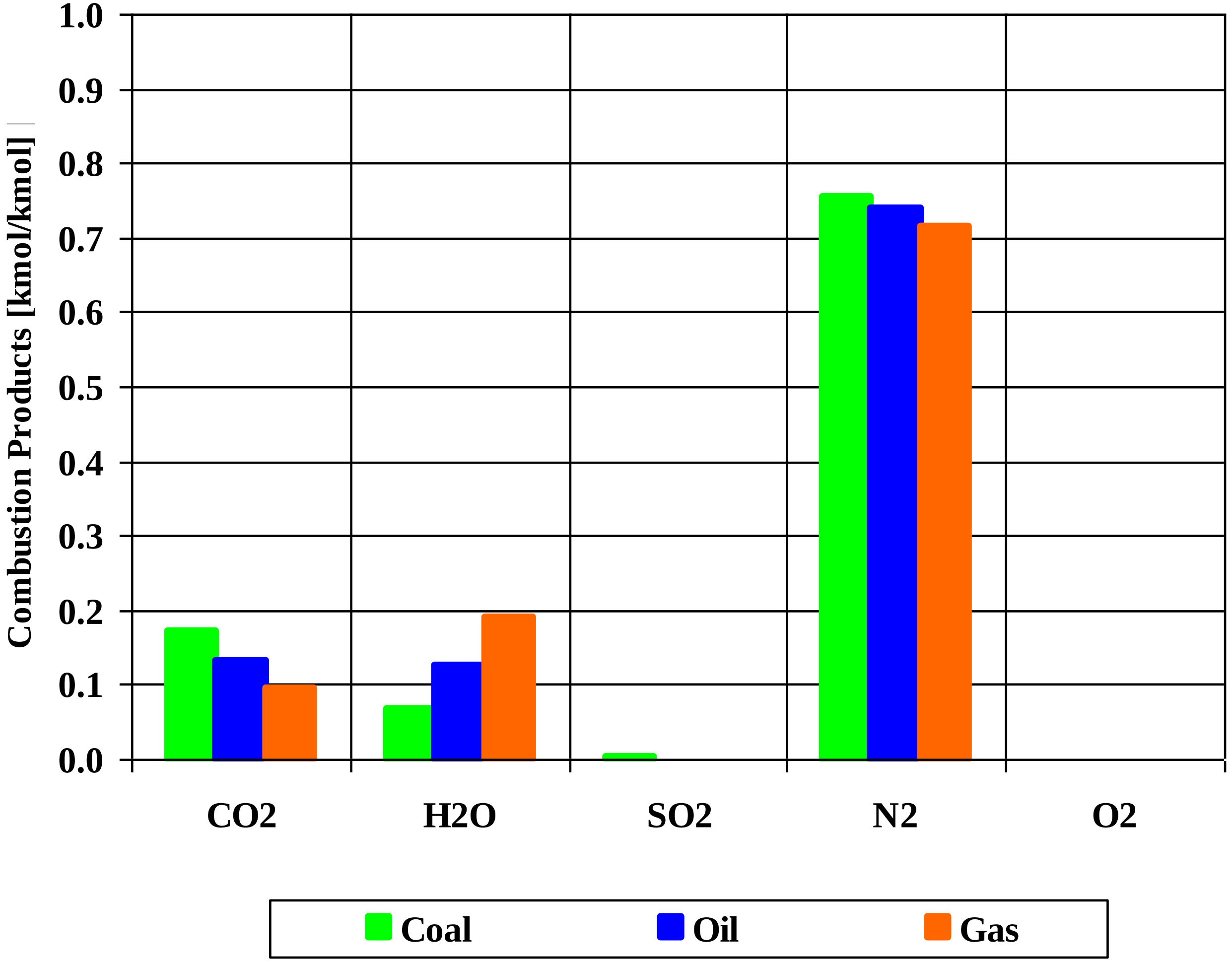
Fuel Inlet Temperature: 298 [K]

Combustion Products -- Weight Basis



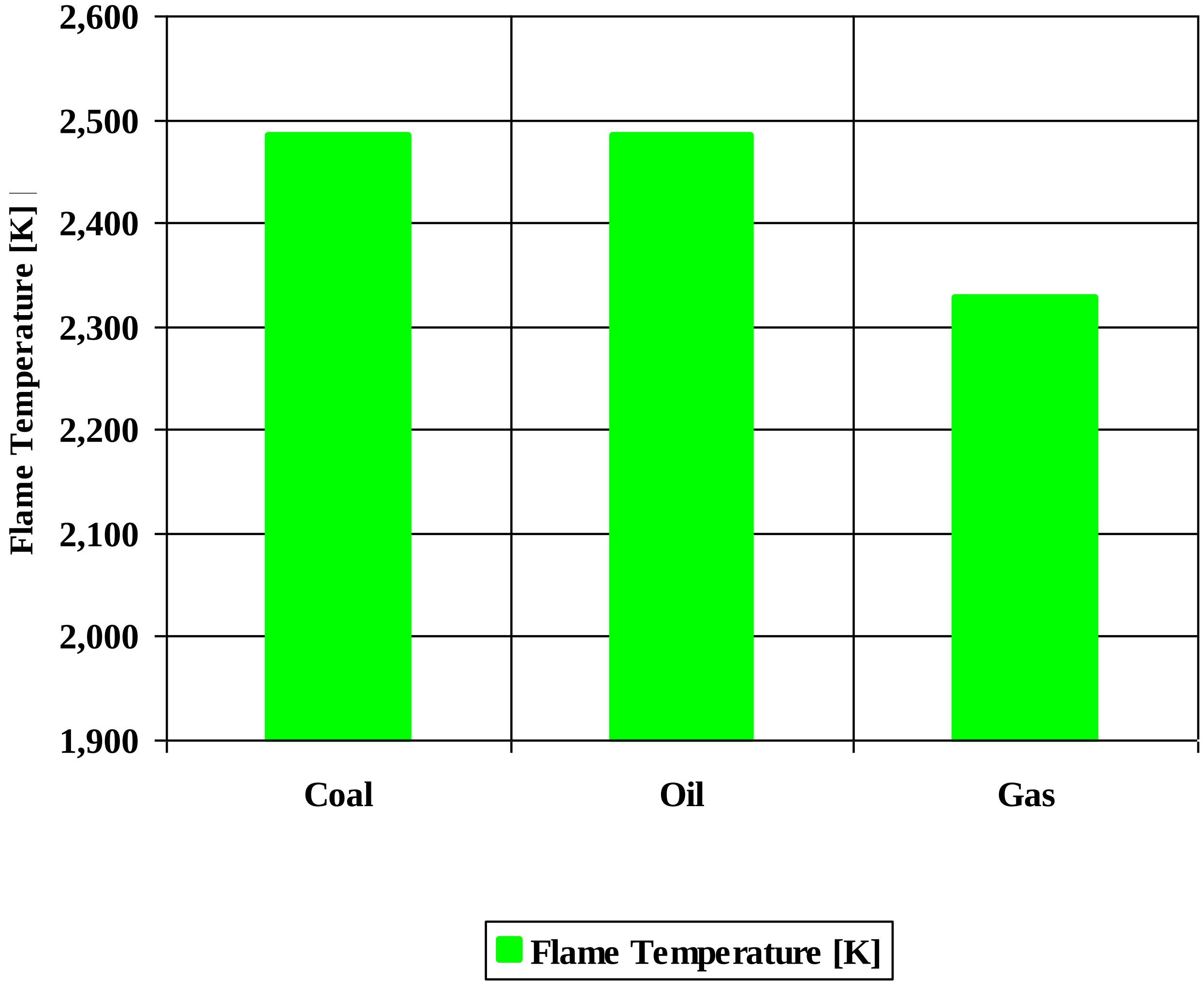
Fuel and Oxidant Inlet Temperature: 298 [K]

Combustion Products -- Mole Basis

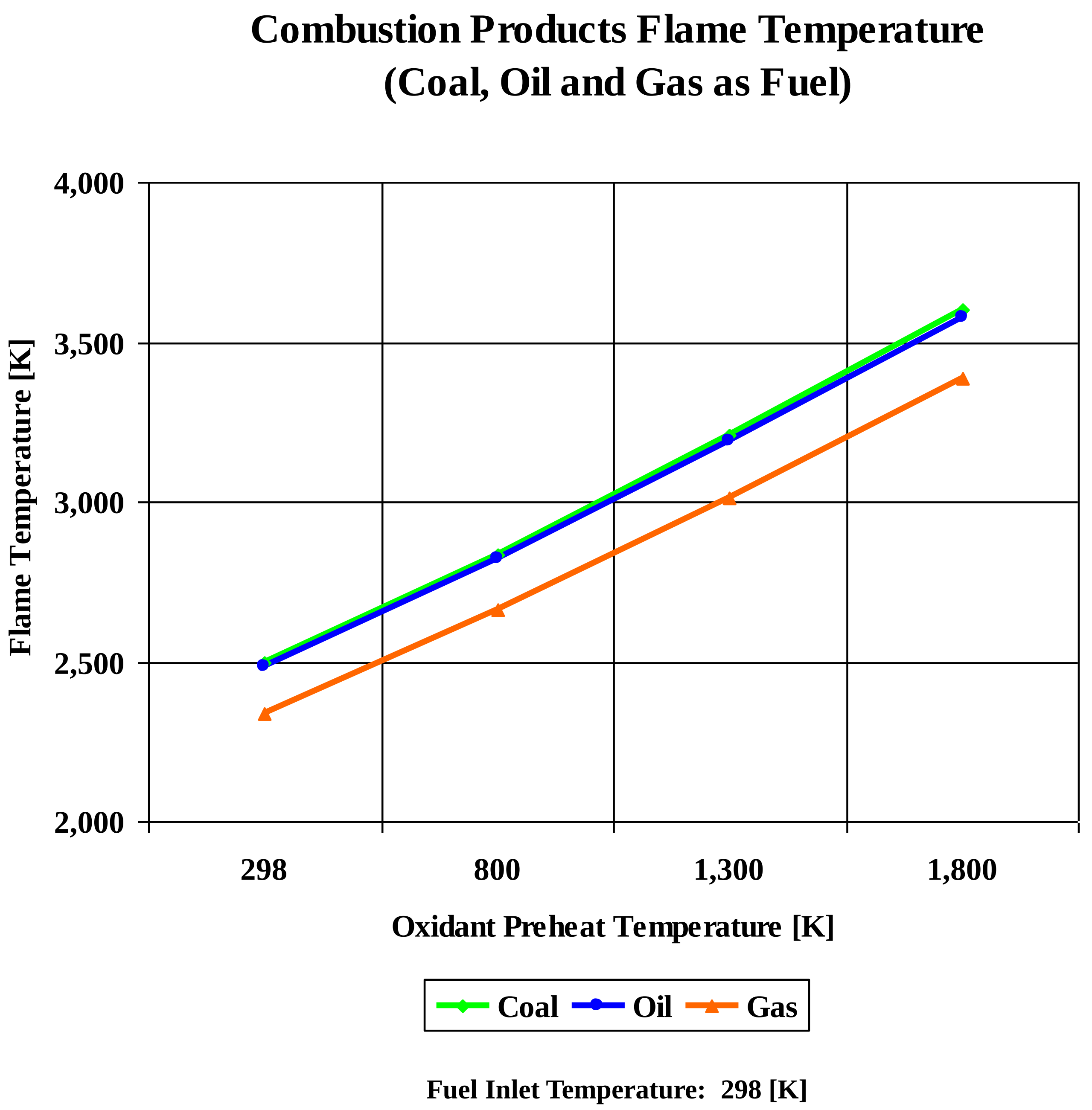


Fuel and Oxidant Inlet Temperature: 298 [K]

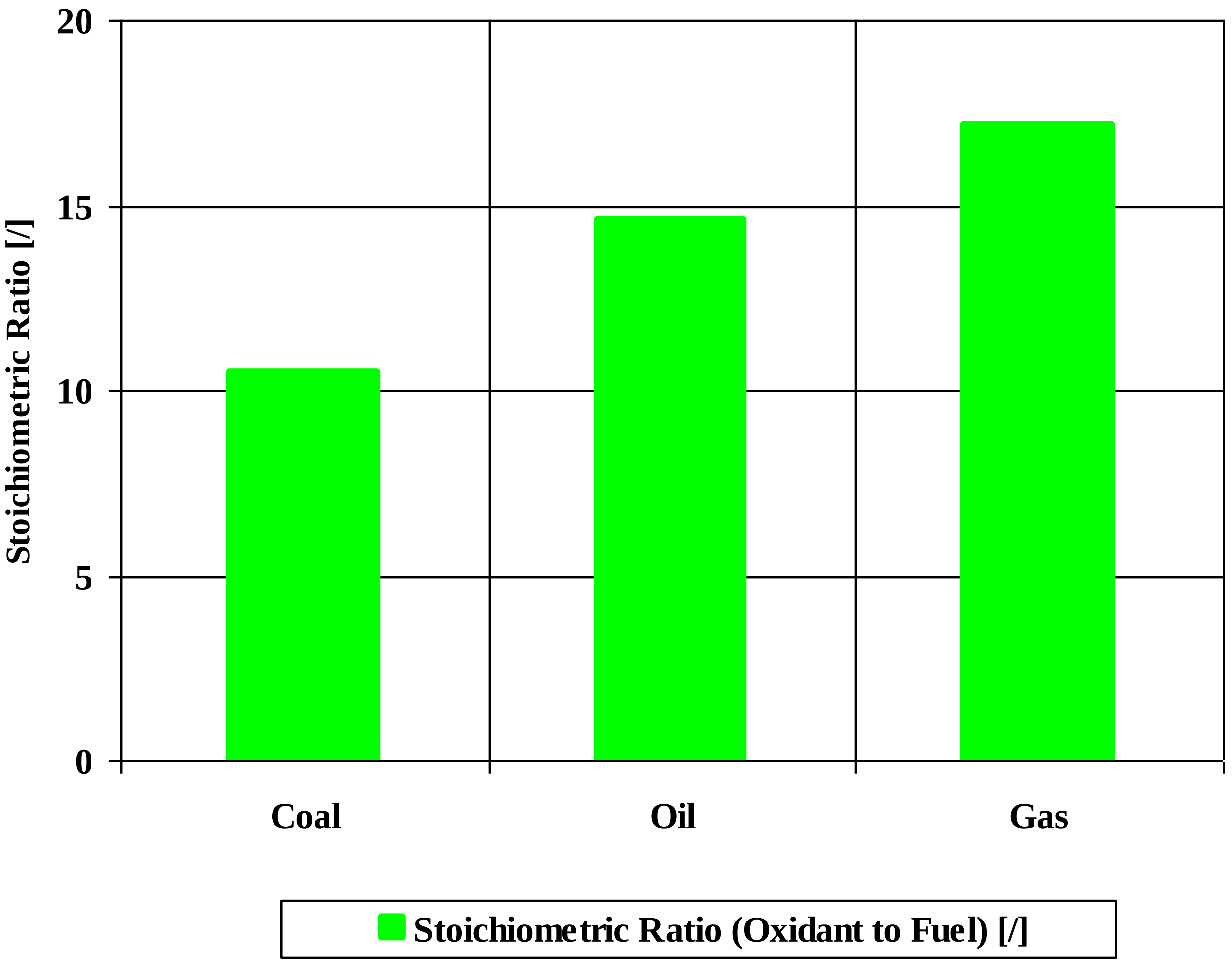
Combustion Products Flame Temperature



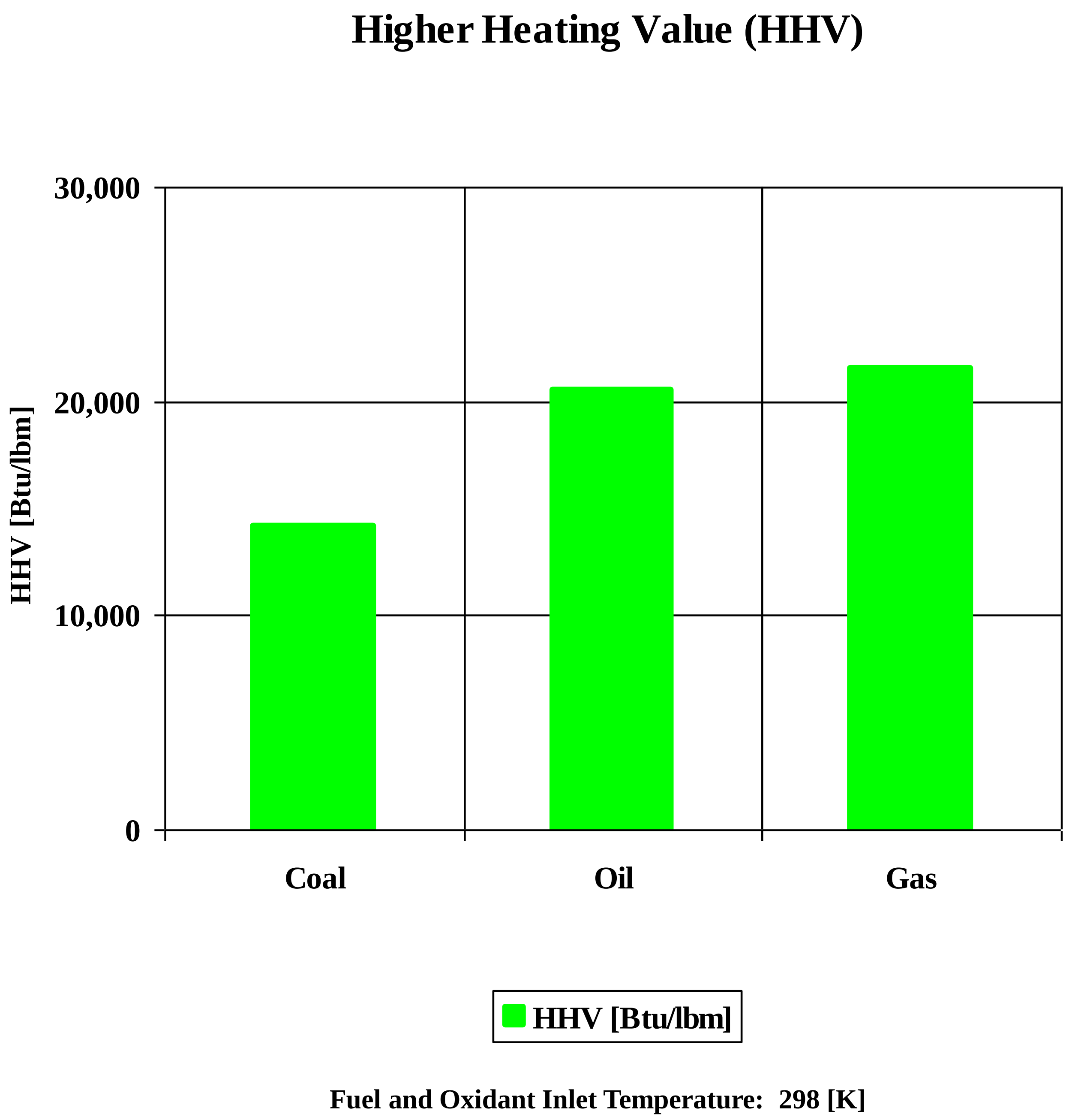
Fuel and Oxidant Inlet Temperature: 298 [K]


Combustion Products Flame Temperature
(Coal, Oil and Gas as Fuel)
4,000
3,500
3,000
2,500
2,000
Flame Temperature [K]
298
800
1,300
1,800
Oxidant Preheat Temperature [K]
Coal
Oil
Gas
Fuel Inlet Temperature: 298 [K]

Combustion Stoichiometric Ratio



Fuel and Oxidant Inlet Temperature: 298 [K]


Higher Heating Value (HHV)
30,000
20,000
10,000
0
HHV [Btu/lbm]
Coal
Oil
Gas
HHV [Btu/lbm]
Fuel and Oxidant Inlet Temperature: 298 [K]

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Combustion Analysis

Here are some of the basic combustion information and plots when considering carbon, hydrogen, sulfur, coal, oil and gas as the fuel and air as the oxidant.

Combustion Assumptions

- Fuel Temperature 298 [K]

- Oxidant Temperature 298 [K]

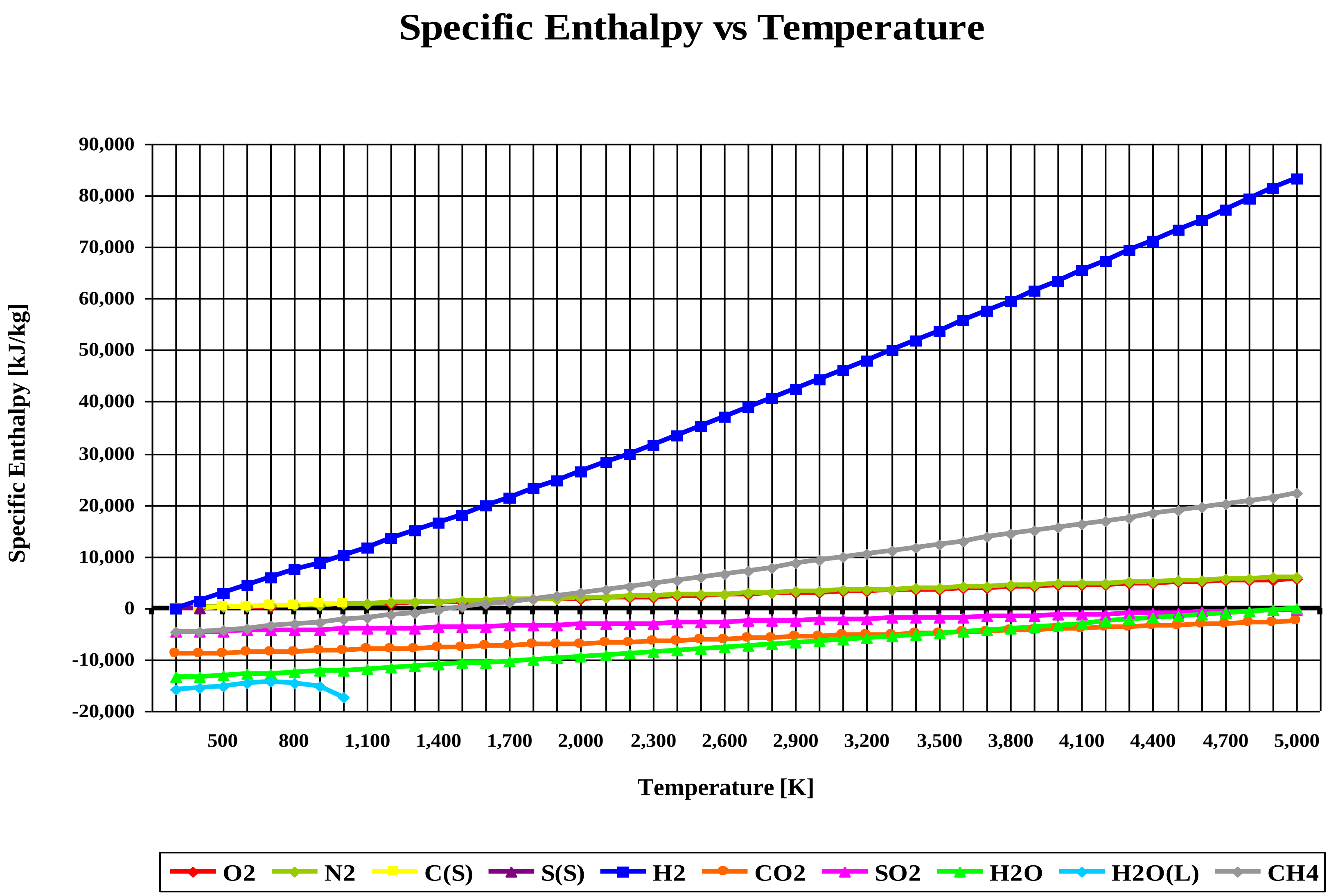
- Stoichiometric Combustion

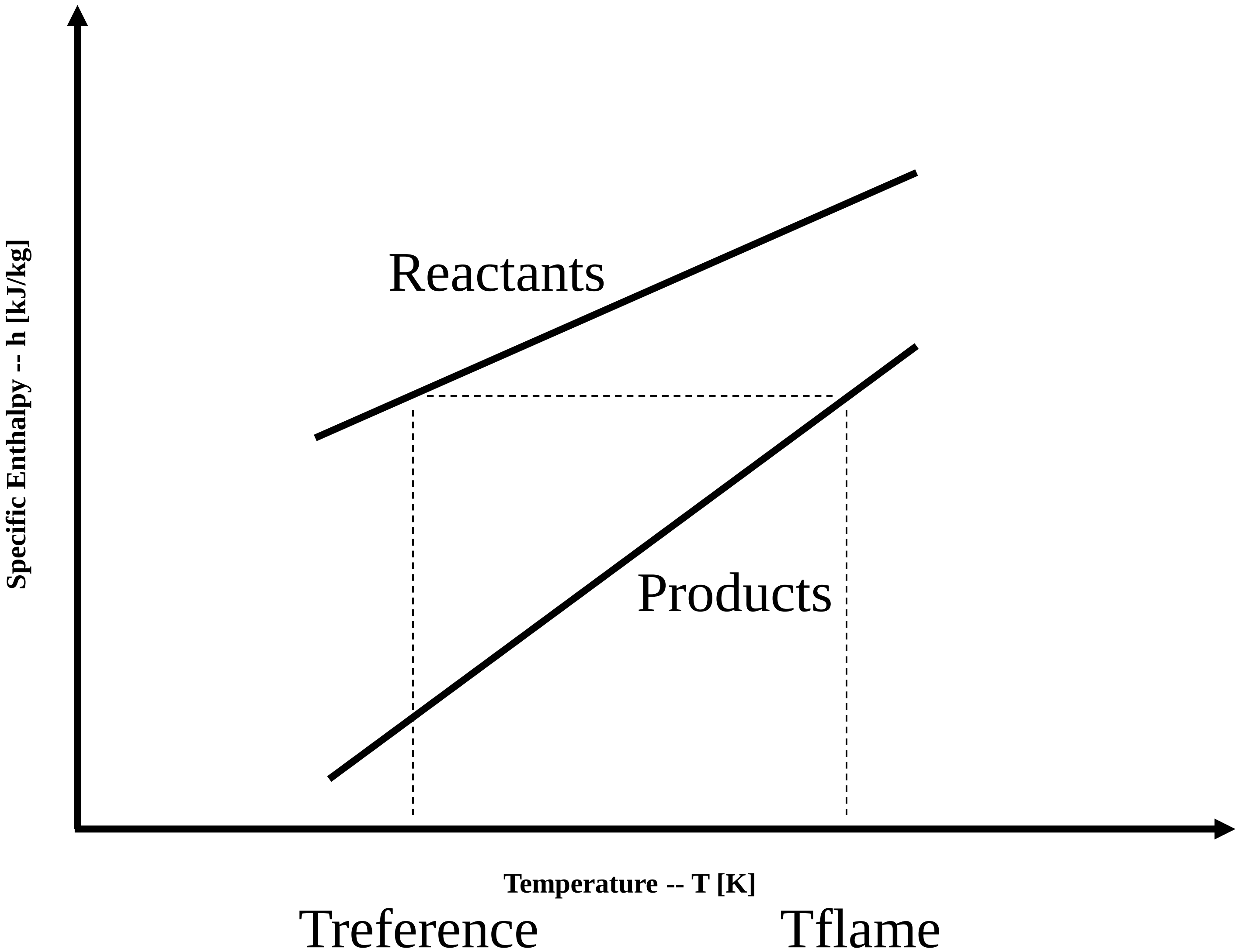
- No Heat Losses

Oxidant (Air) Composition

Element	Weight [kg/kg]	Mole [kmol/kmol]
N	0.767	0.790
O	0.233	0.210

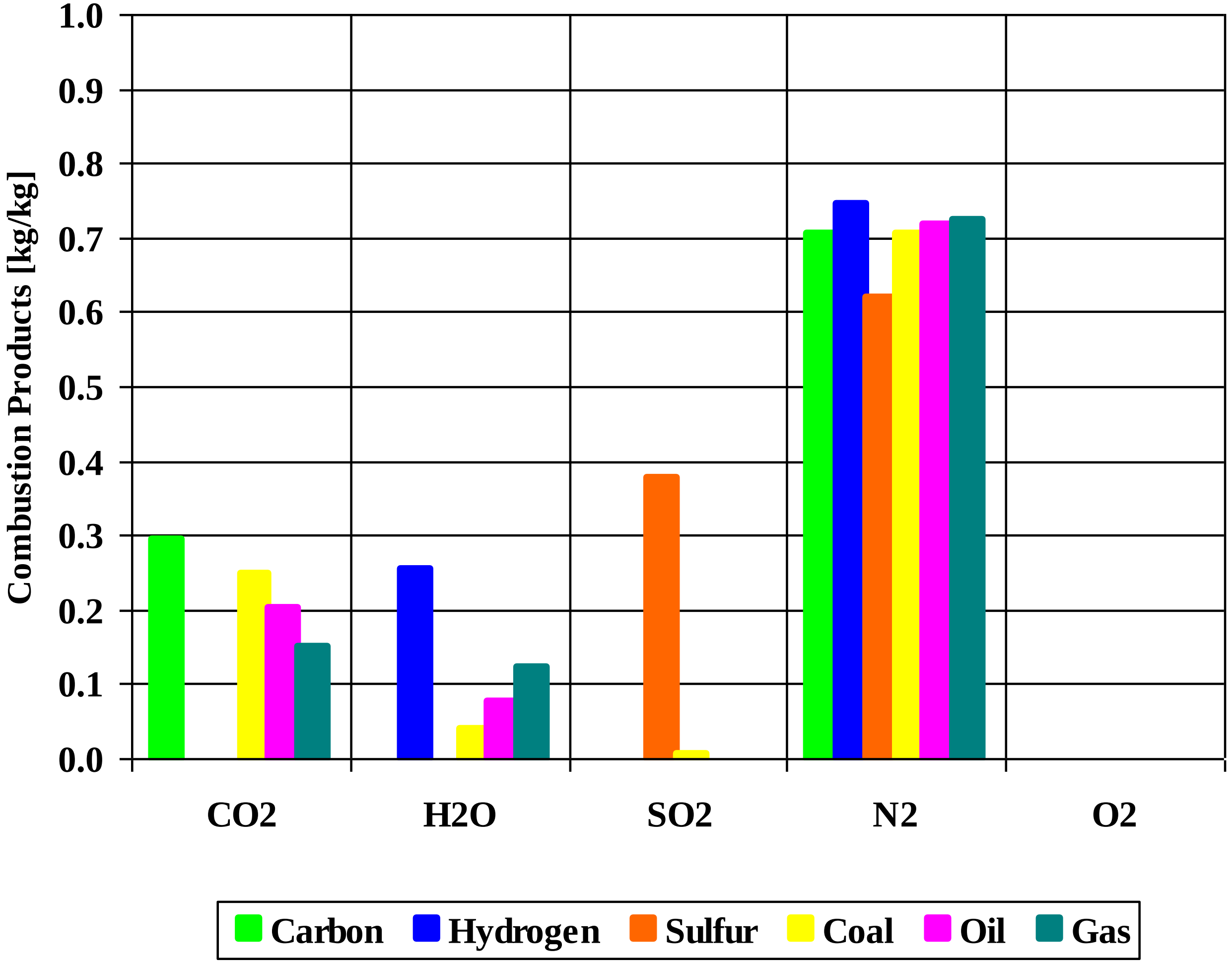
Combustion Schematic Layout


Specific Enthalpy vs Temperature
Specific Enthalpy [kJ/kg]
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
-10,000
-20,000
500
800
1,100
1,400
1,700
2,000
2,300
2,600
2,900
3,200
3,500
3,800
4,100
4,400
4,700
5,000
Temperature [K]
O2
N2
C(S)
S(S)
H2
CO2
SO2
H2O
H2O(L)
CH4



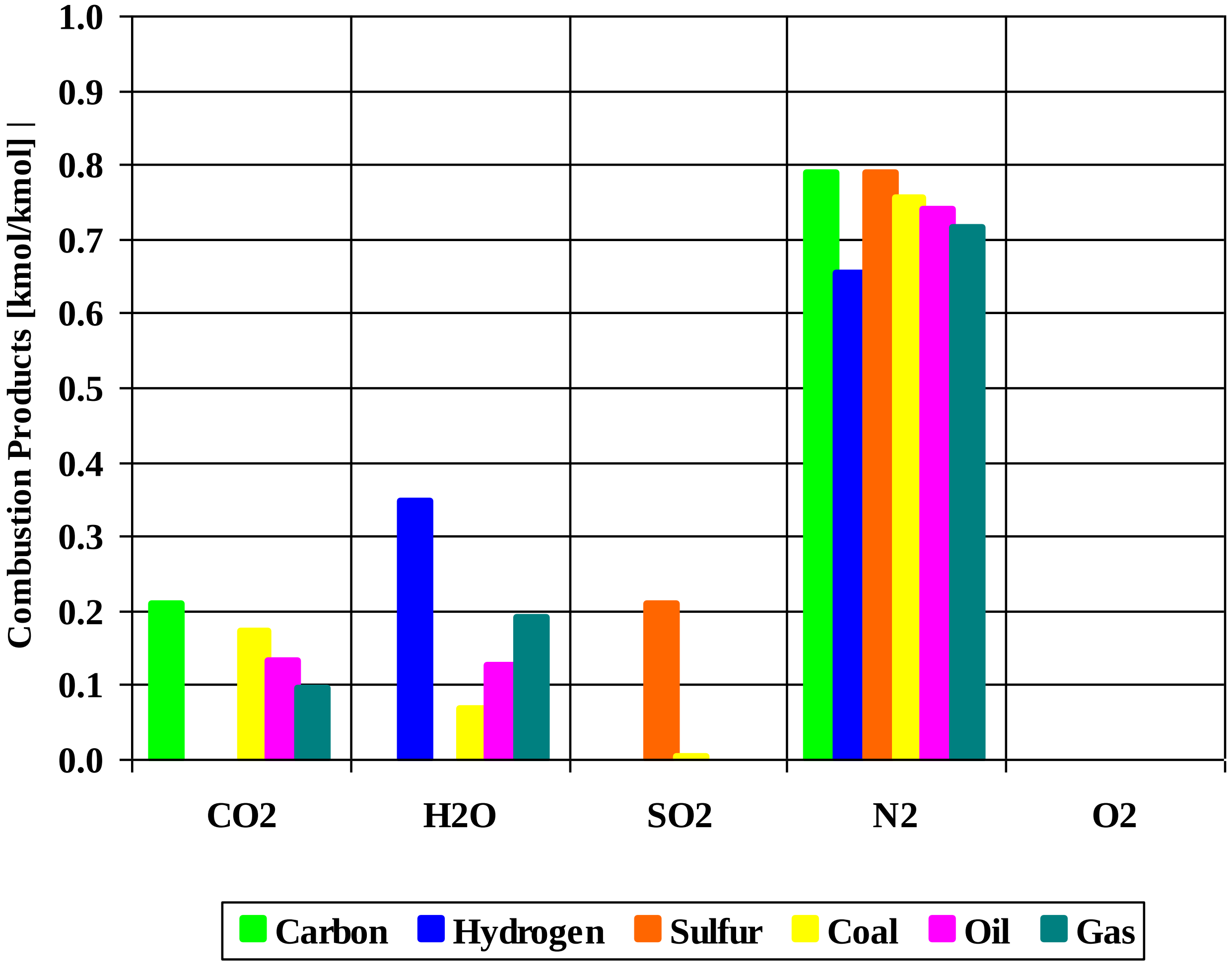
Combustion h - T Diagram

Combustion Products -- Weight Basis

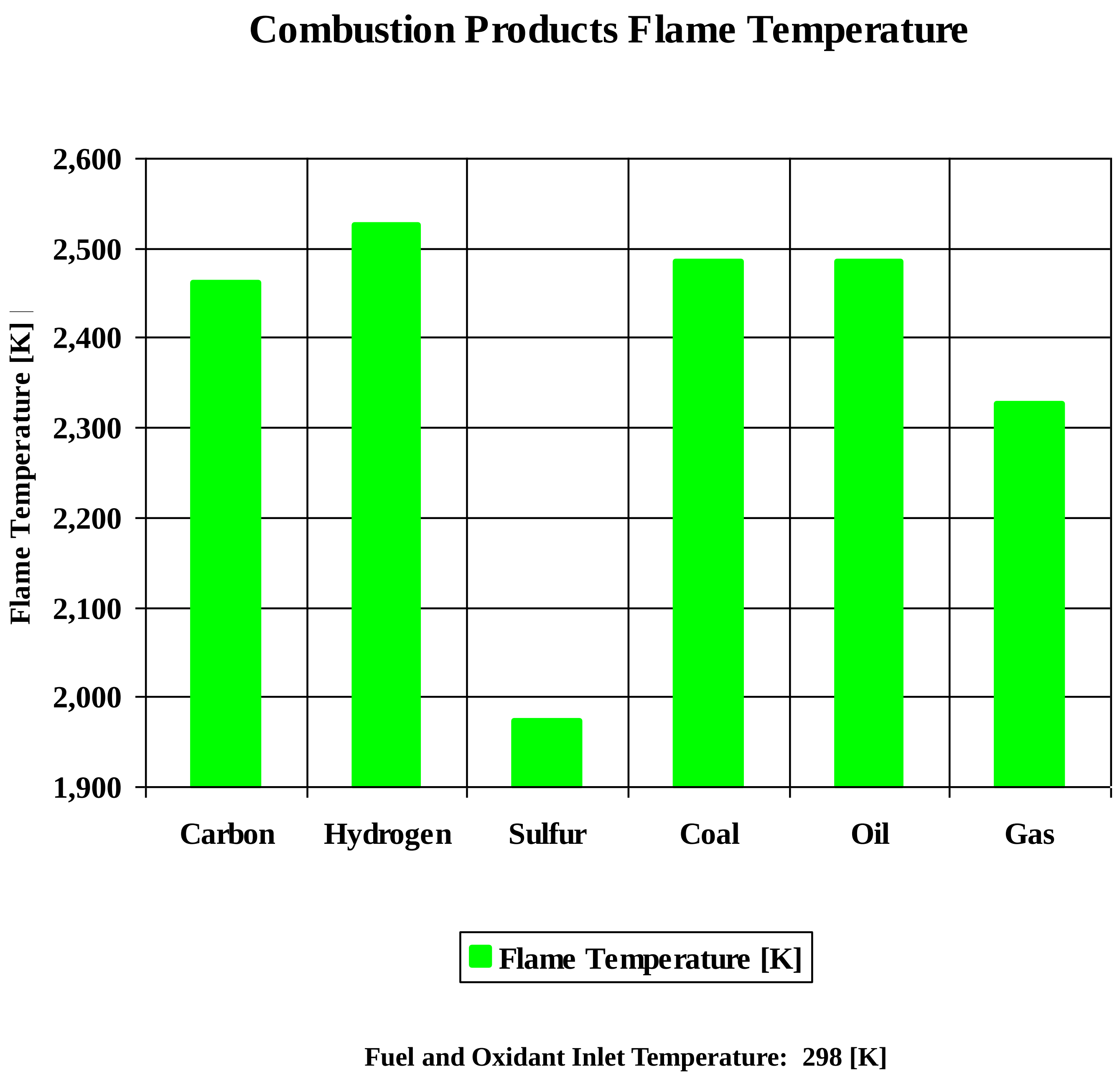


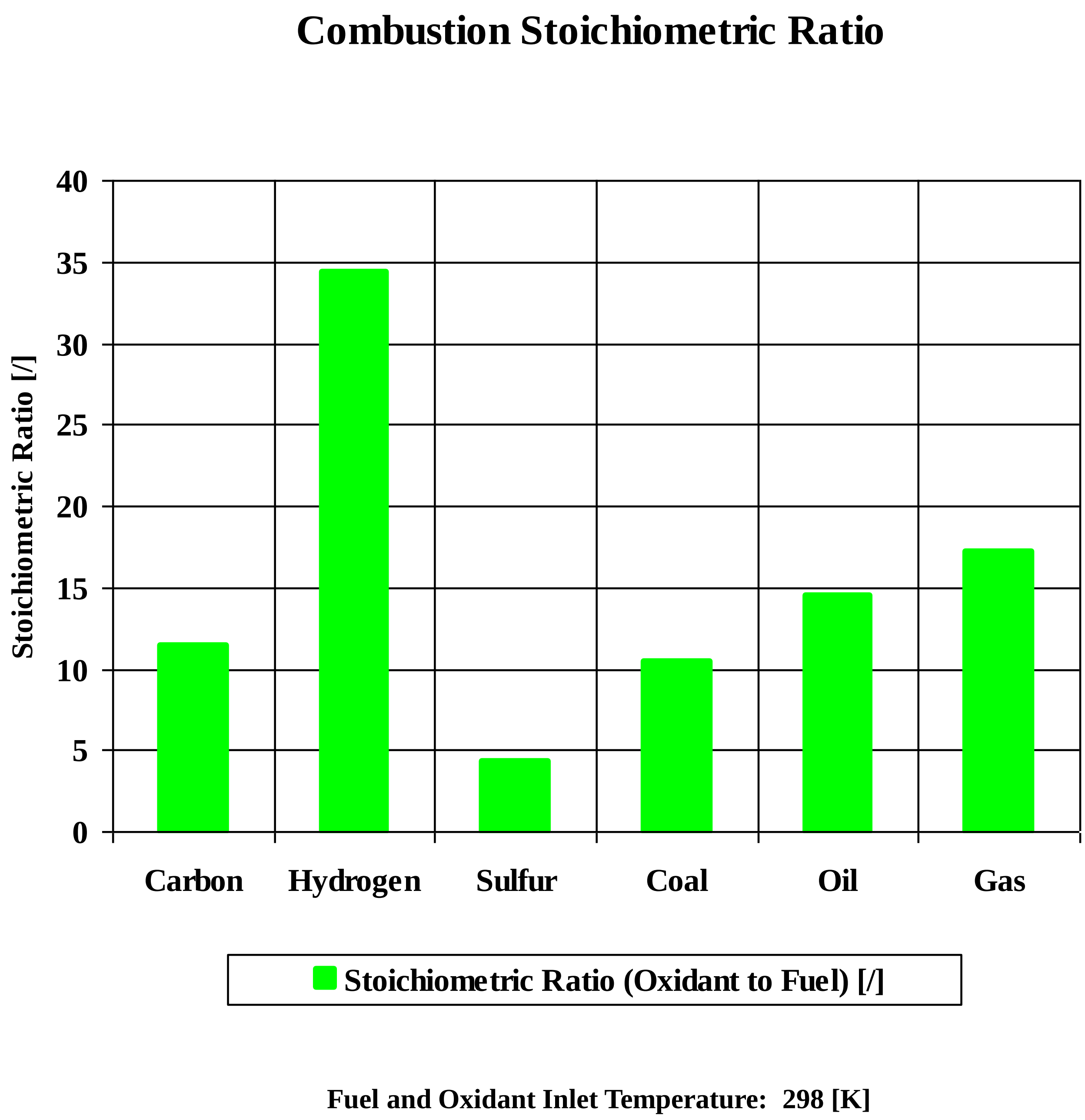
Fuel and Oxidant Inlet Temperature: 298 [K]

Combustion Products -- Mole Basis

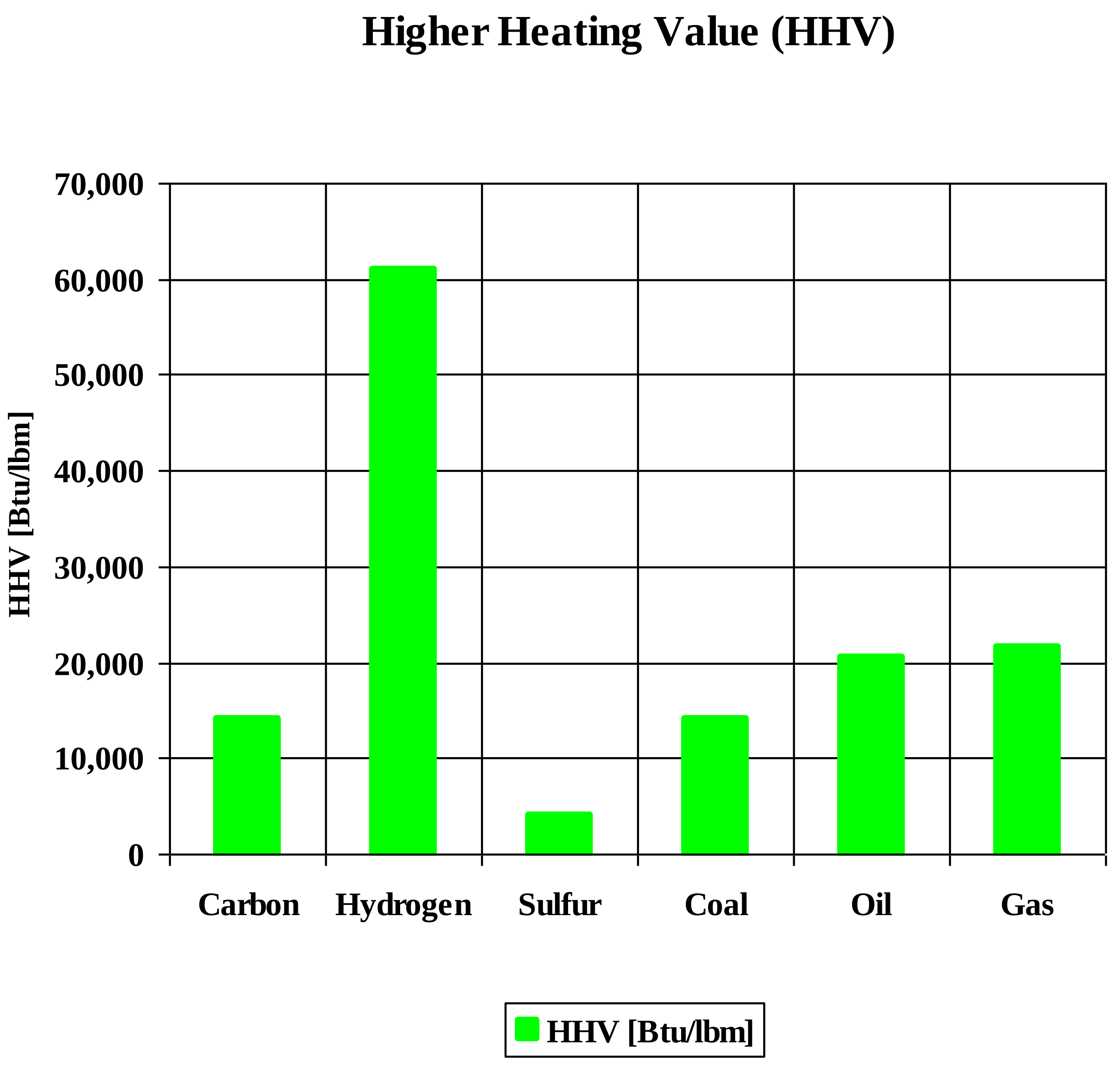


Fuel and Oxidant Inlet Temperature: 298 [K]


Combustion Products Flame Temperature
2,600
2,500
2,400
2,300
2,200
2,100
2,000
1,900
Flame Temperature [K]
Carbon
Hydrogen
Sulfur
Coal
Oil
Gas
Flame Temperature [K]
Fuel and Oxidant Inlet Temperature: 298 [K]



Combustion Stoichiometric Ratio
Stoichiometric Ratio [/]
40
35
30
25
20
15
10
5
0
Carbon
Hydrogen
Sulfur
Coal
Oil
Gas
Stoichiometric Ratio (Oxidant to Fuel) [/]
Fuel and Oxidant Inlet Temperature: 298 [K]



Fuel and Oxidant Inlet Temperature: 298 [K]

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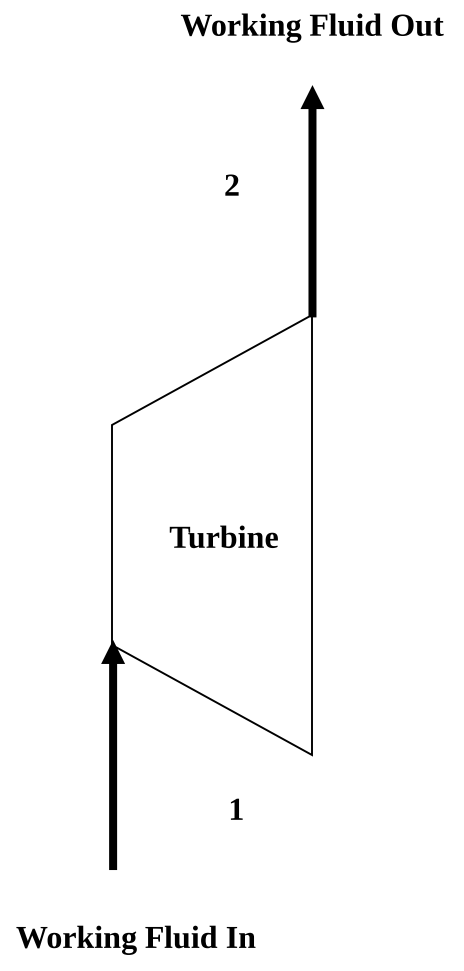
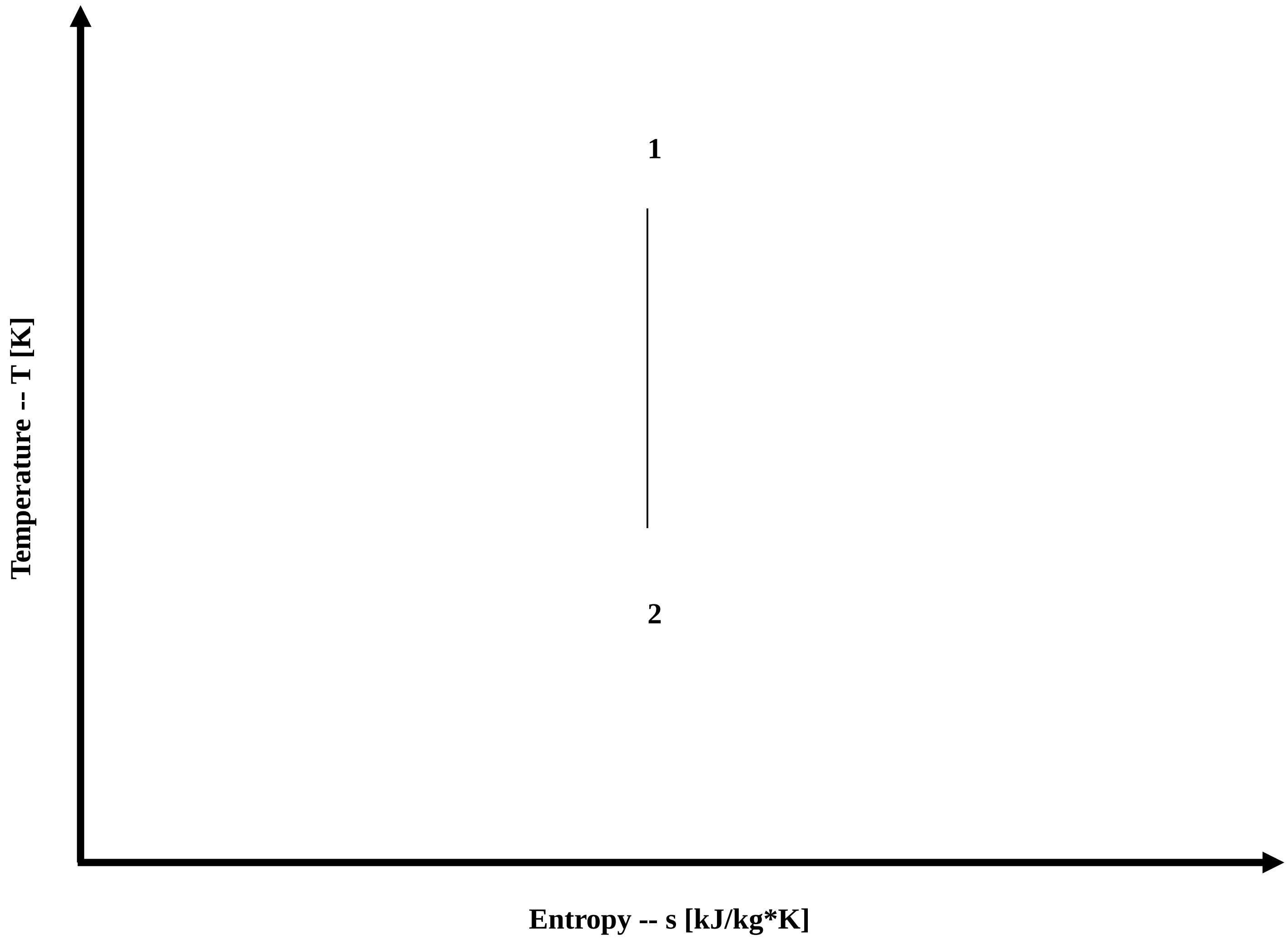
Expansion

Here are some of the basic isentropic expansion plots.

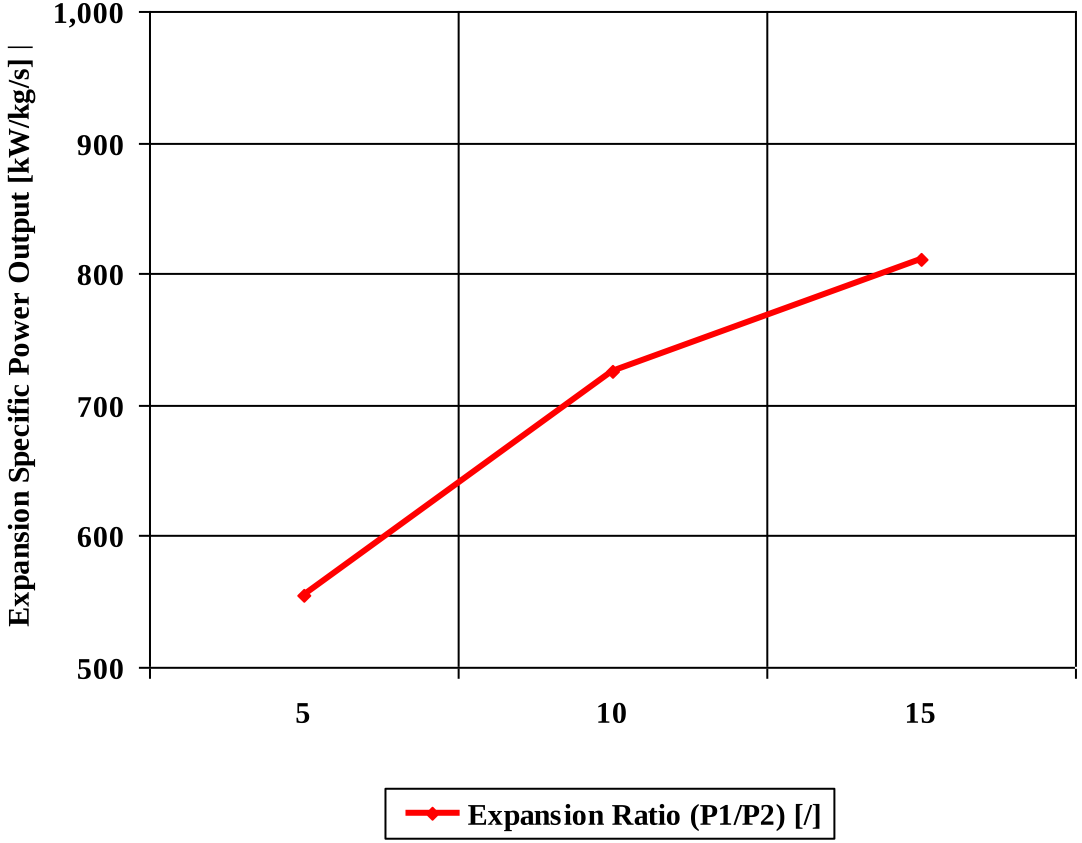


Expansion Schematic Layout



Expansion T - s Diagram

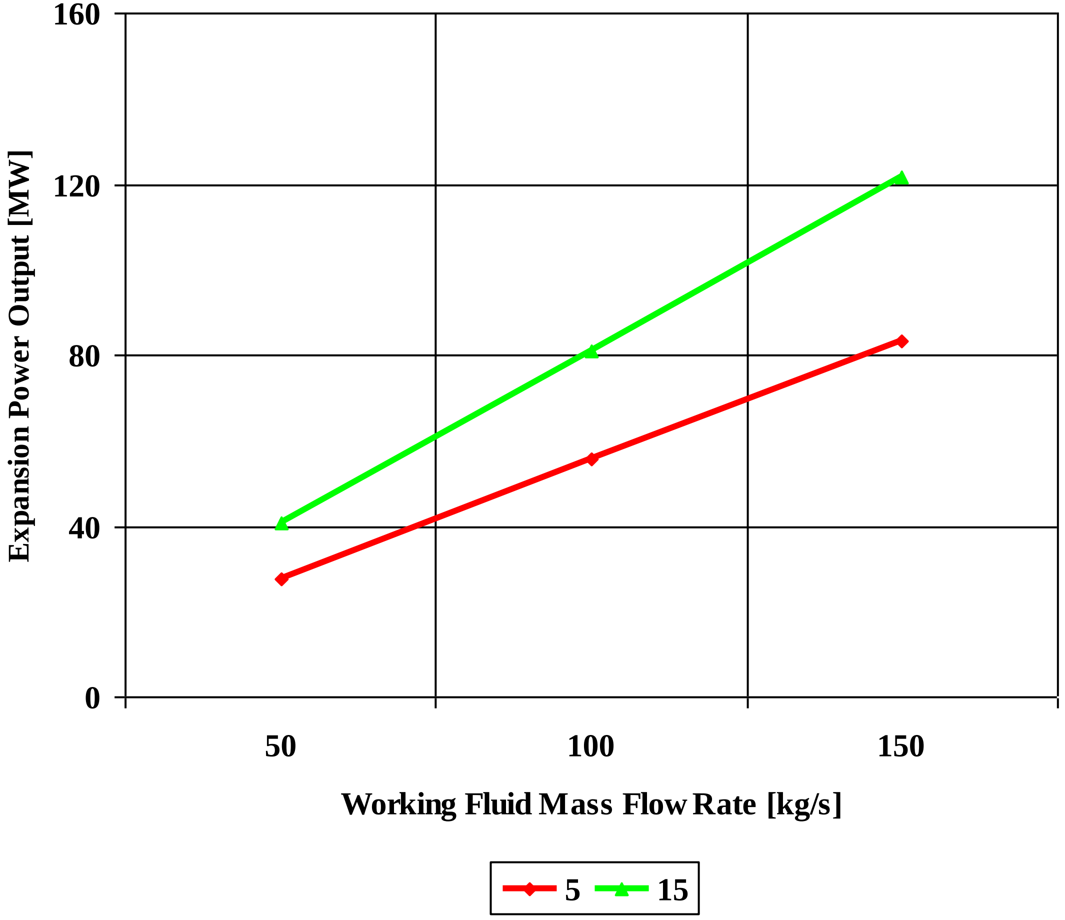
Expansion Specific Power Output



Working Fluid: Air

Turbine Inlet Temperature: 1,500 [K]

Expansion Power Output



Expansion Ratio (P1/P2) [/]
Working Fluid: Air

Turbine Inlet Temperature: 1,500 [K]

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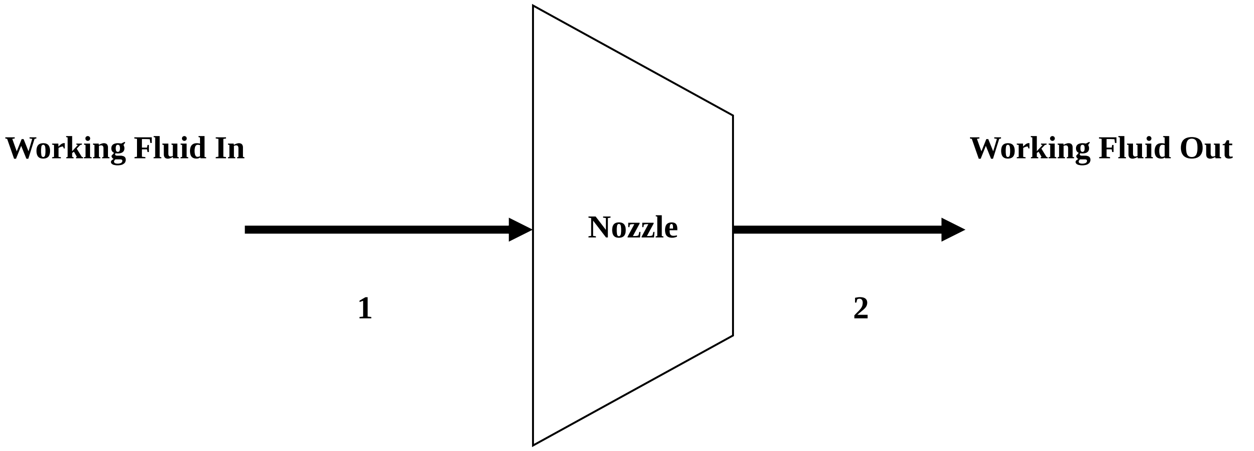
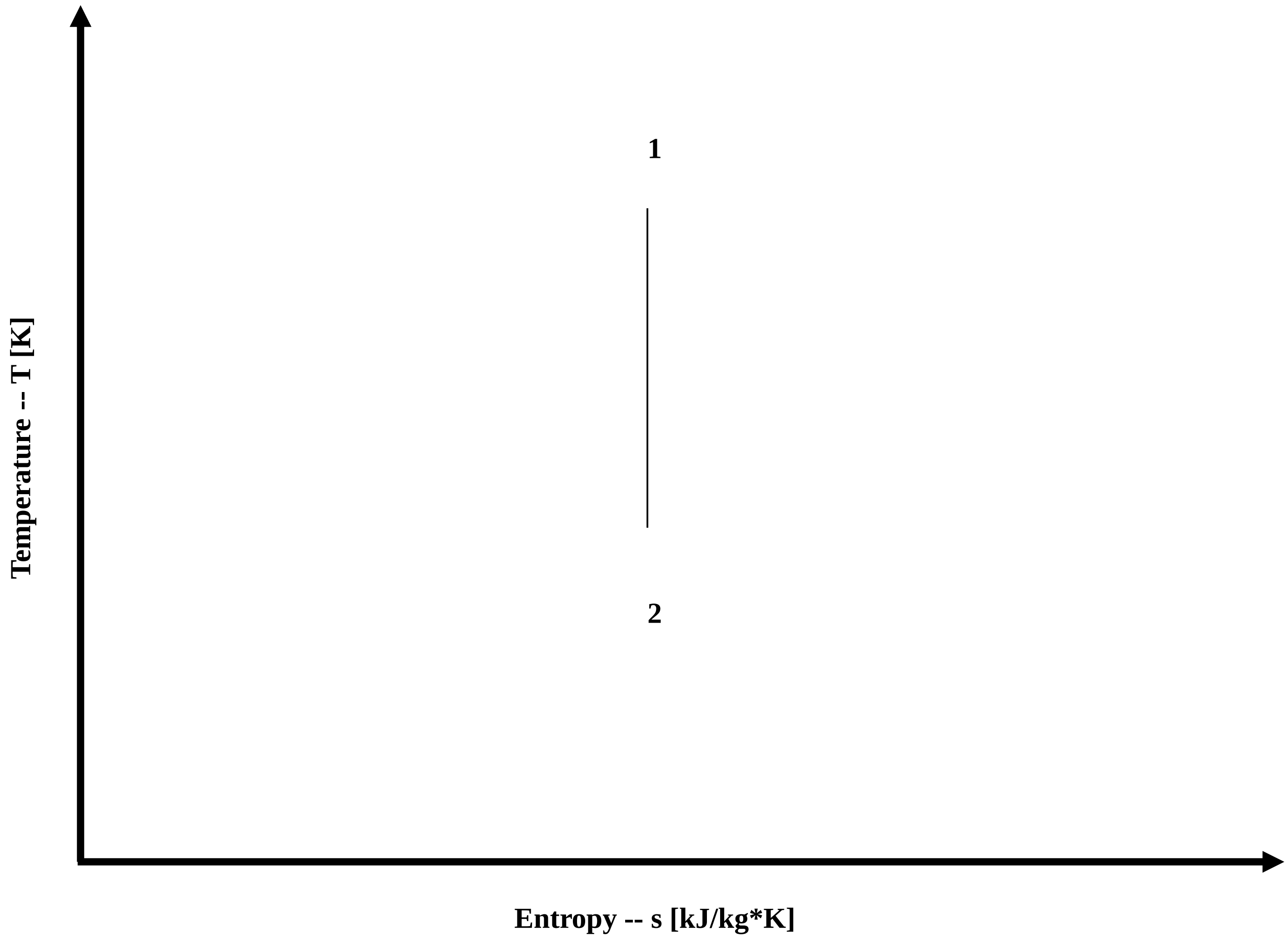
Nozzle

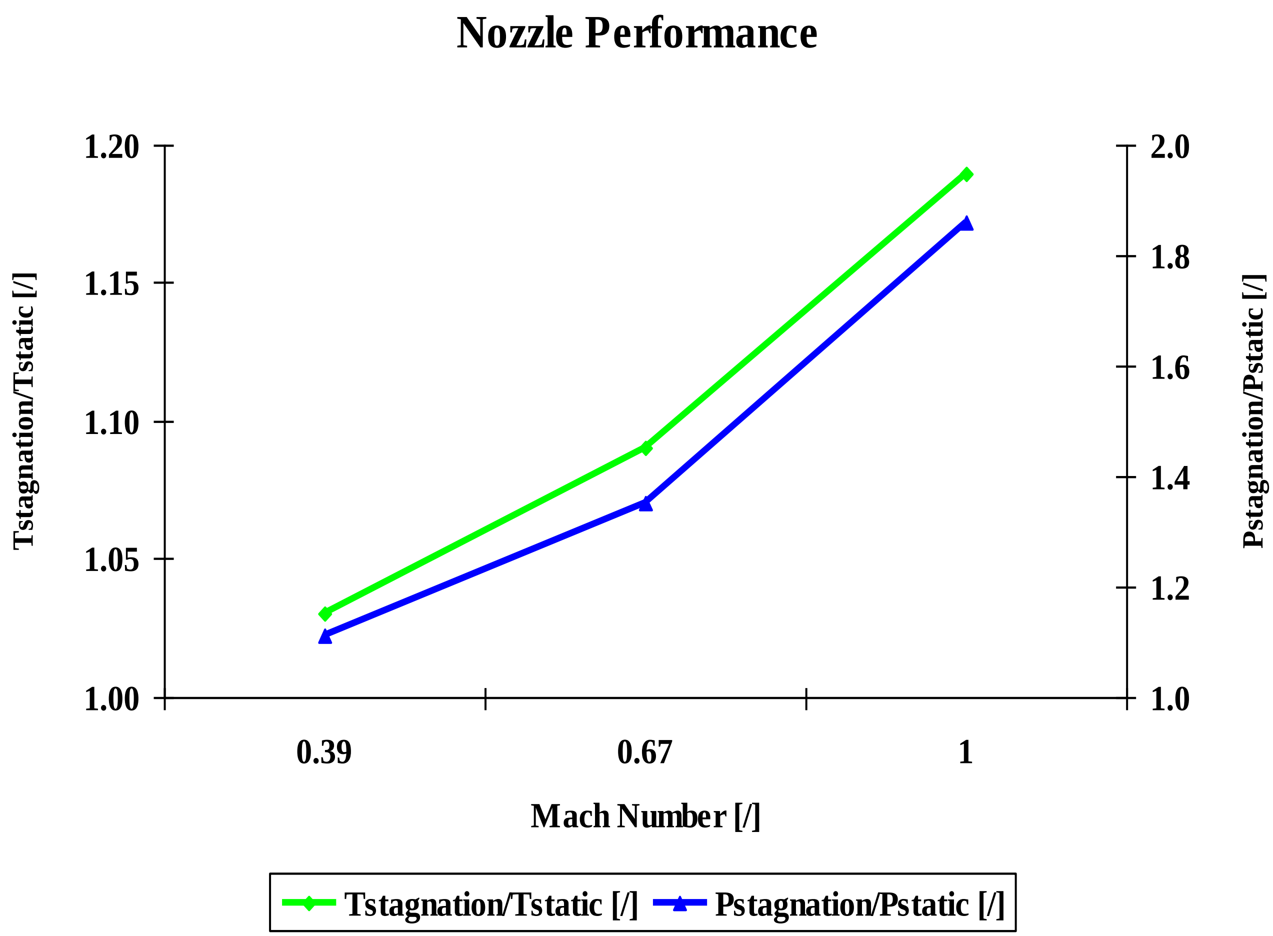
Here are some of the basic sonic and subsonic isentropic nozzle plots.



Nozzle Schematic Layout



Nozzle T - s Diagram



Working Fluid: Air

Nozzle Inlet Stagnation Conditions -- Temperature: 1,500 [K] and Pressure: 10 [atm]

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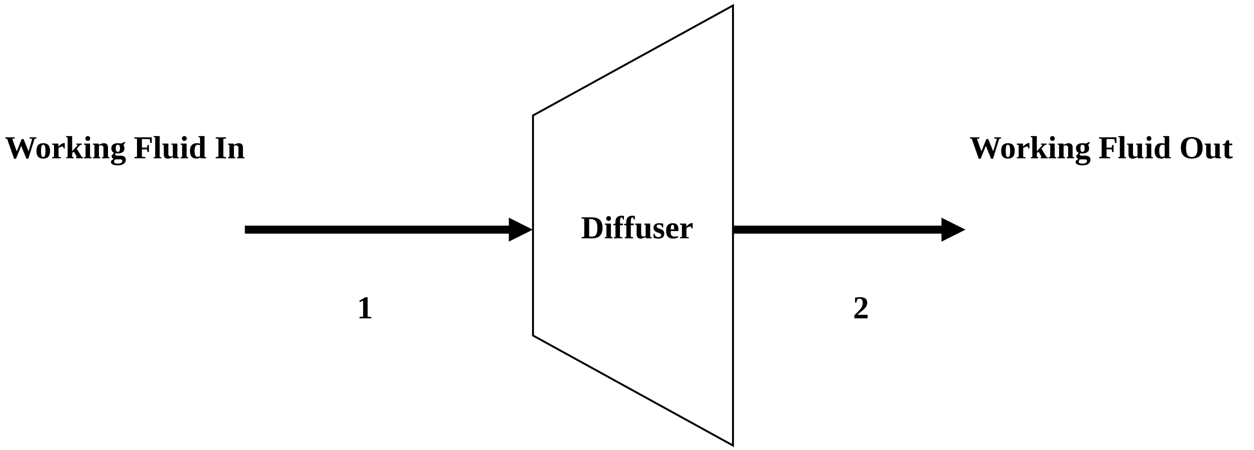
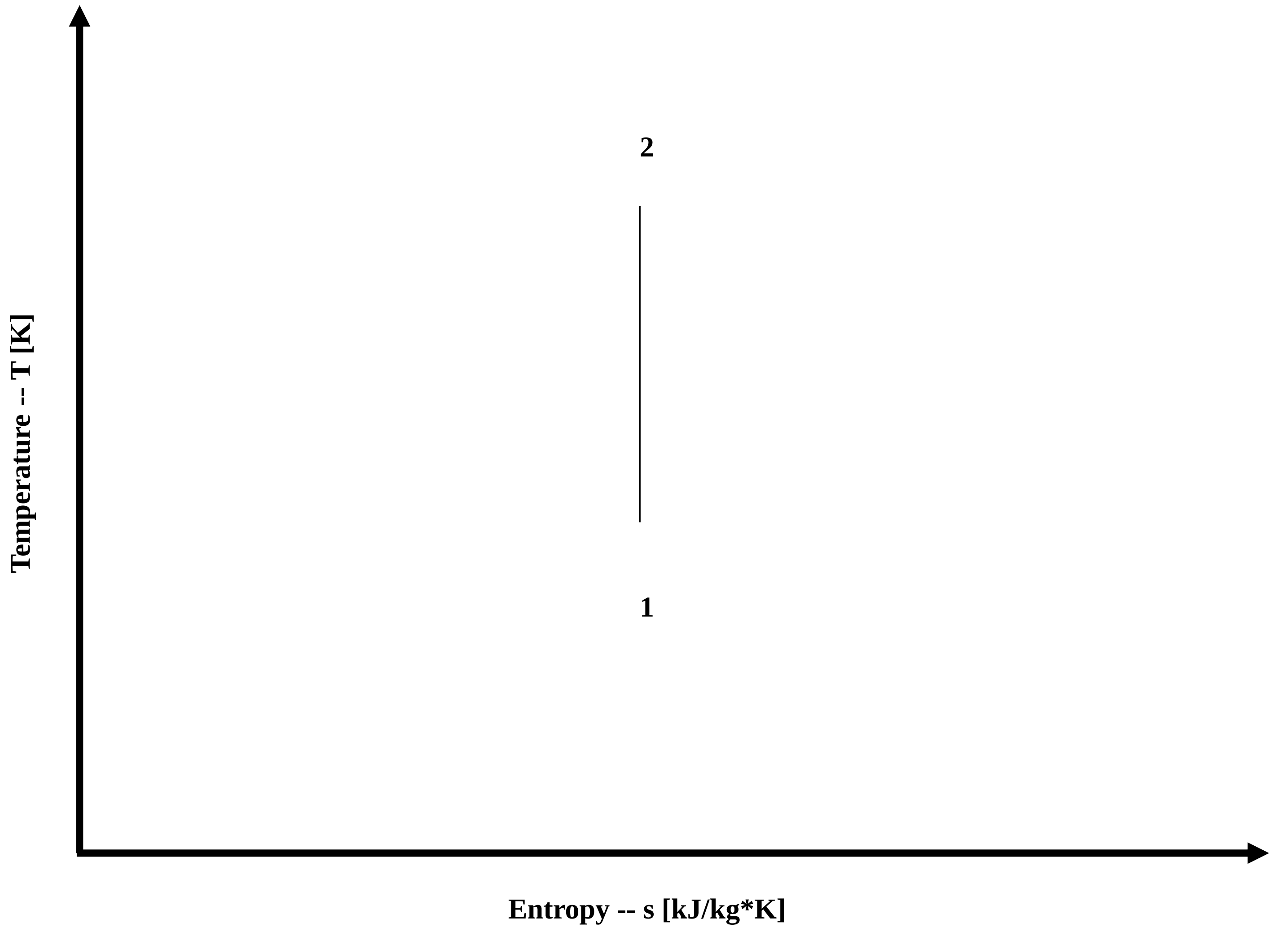
Diffuser

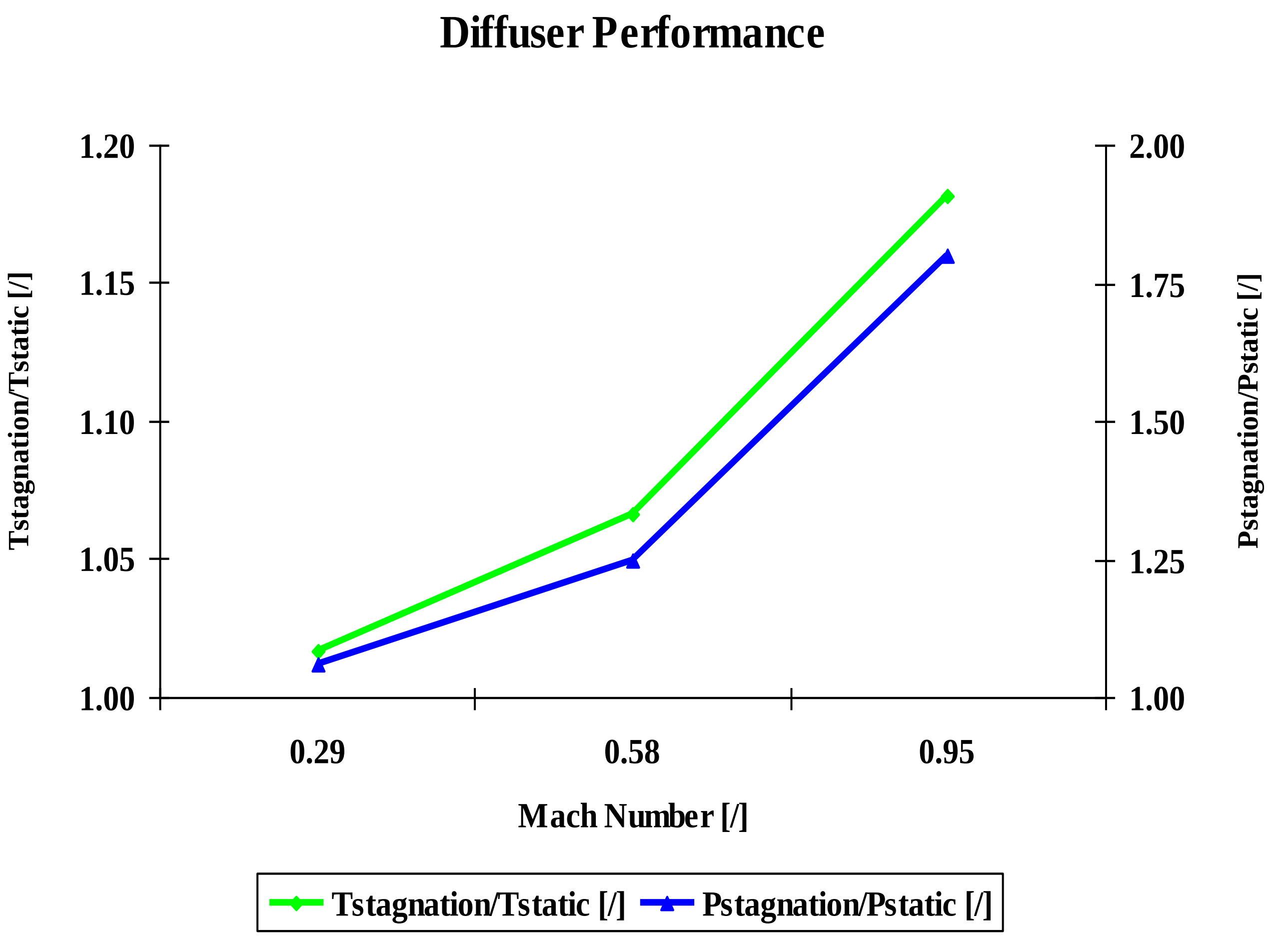
Here are some of the basic subsonic isentropic diffuser plots.



Diffuser Schematic Layout



Diffuser T - s Diagram



Working Fluid: Air

Diffuser Inlet Static Conditions -- Temperature: 298 [K] and Pressure: 1 [atm]

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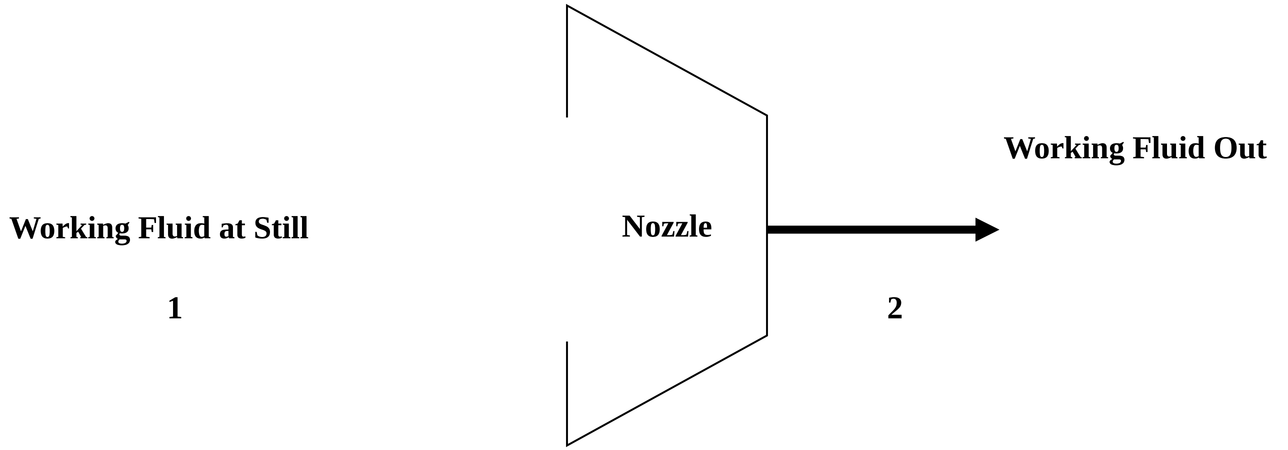
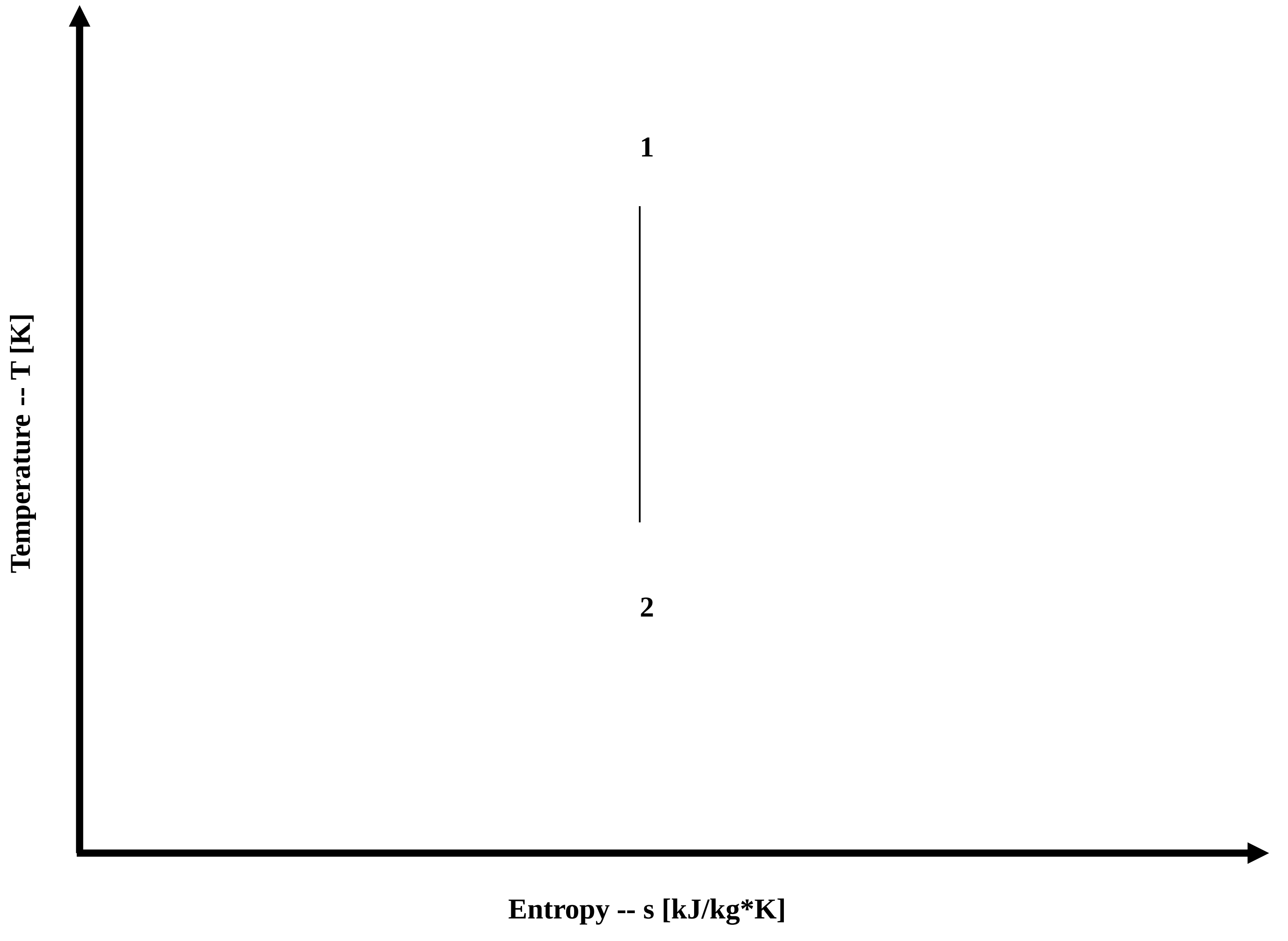
Thrust

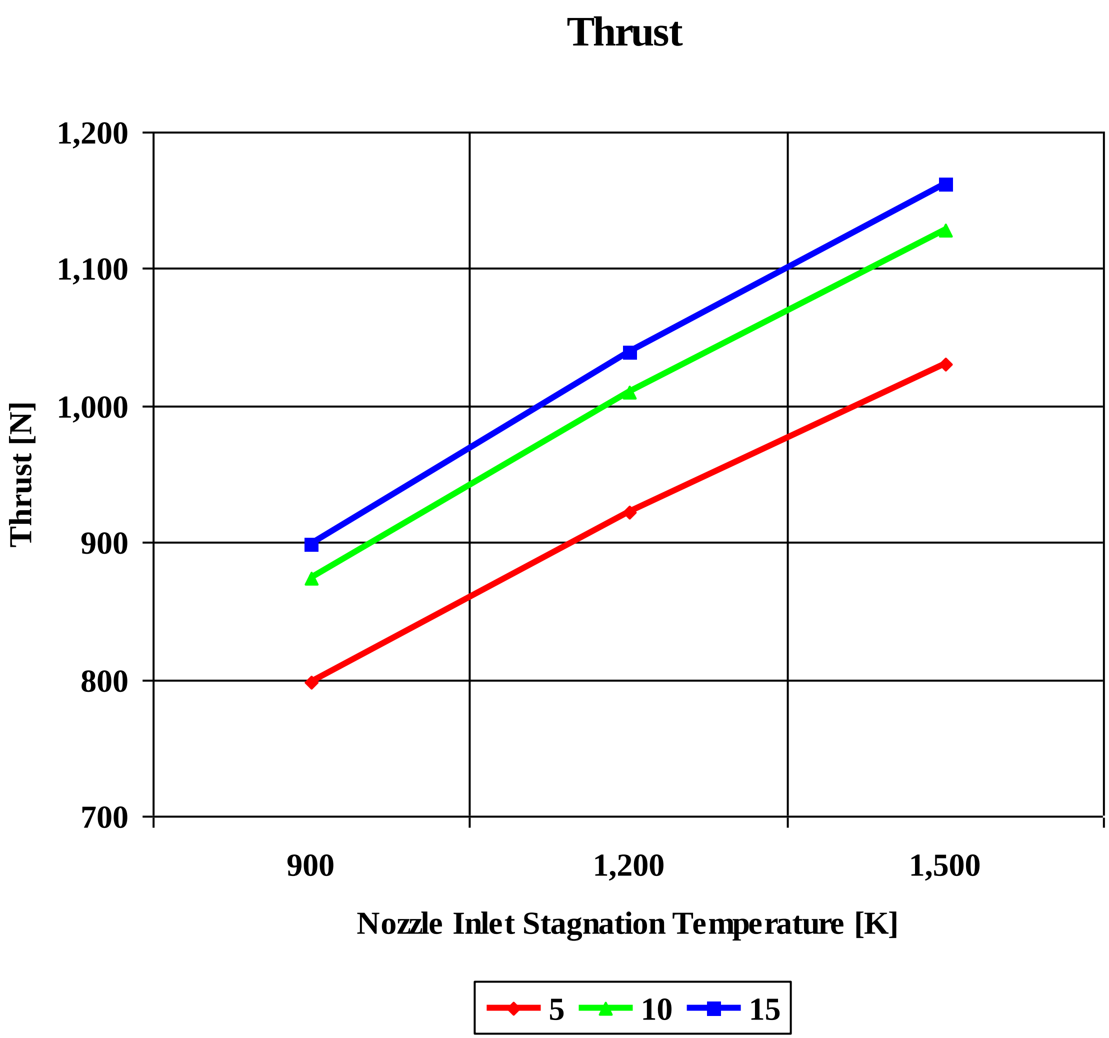
Here are some of the basic subsonic isentropic thrust plots.



Thrust Schematic Layout



Thrust T - s Diagram



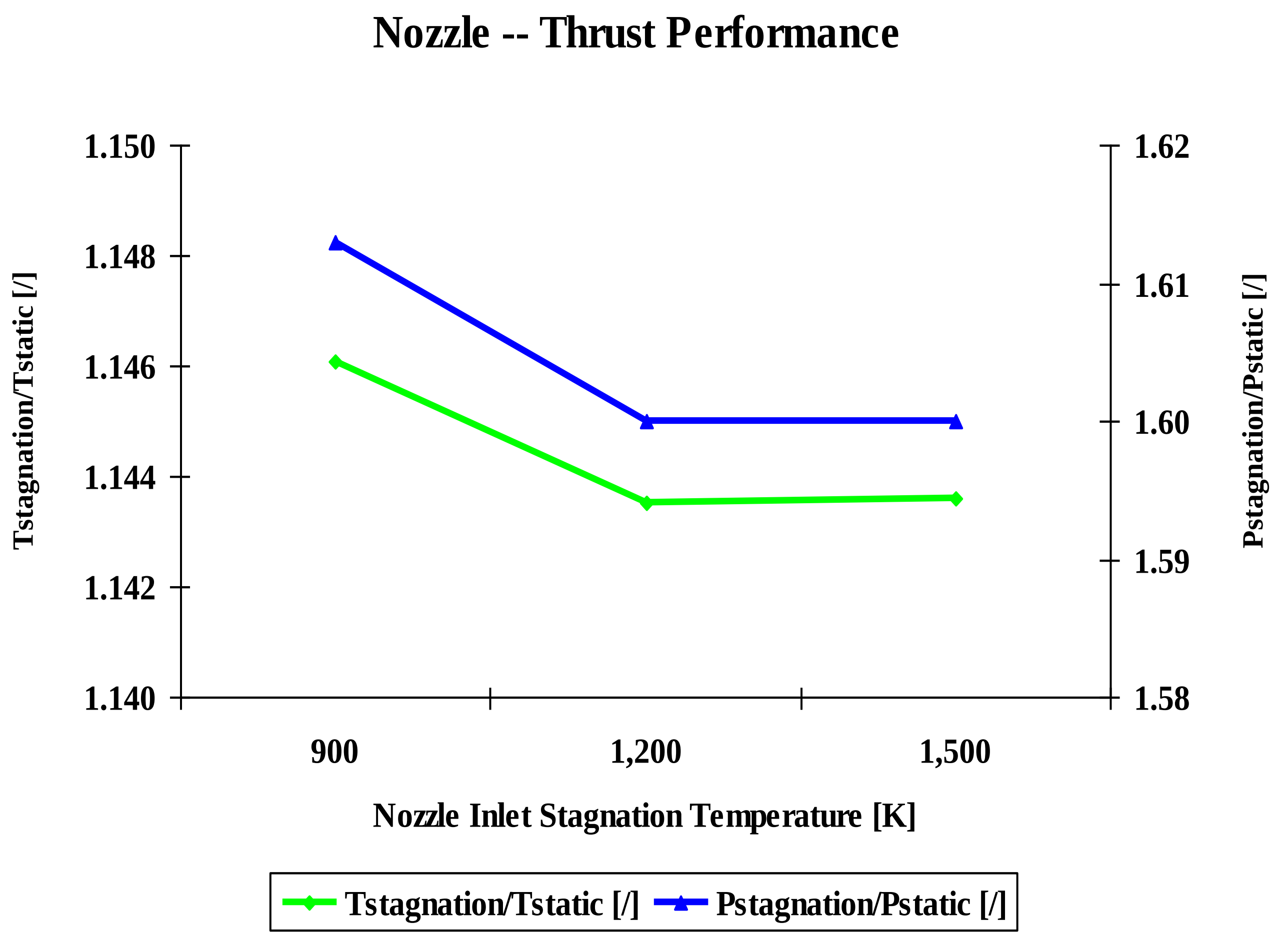
Nozzle Inlet Stagnation Pressure [atm]

Working Fluid: Air

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

Nozzle Outlet Static Conditions -- Mach Number: 0.85 [/]

Ambient Conditions -- Pressure: 1 [atm]



Working Fluid: Air

Nozzle Inlet Stagnation Conditions: Pressure 10 [atm]

Nozzle Outlet Static Conditions -- Mach Number: 0.85 [/]

Ambient Conditions -- Pressure: 1 [atm]

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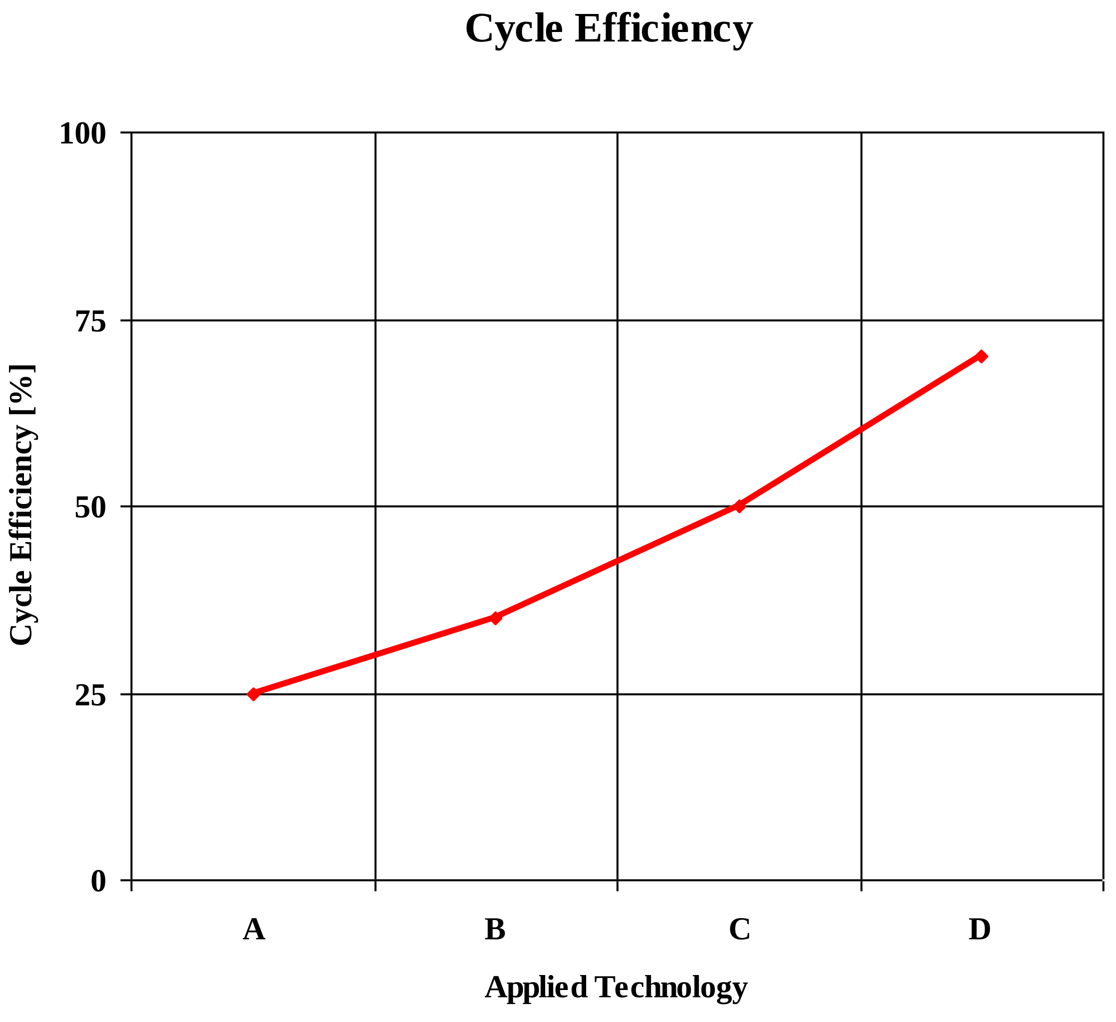
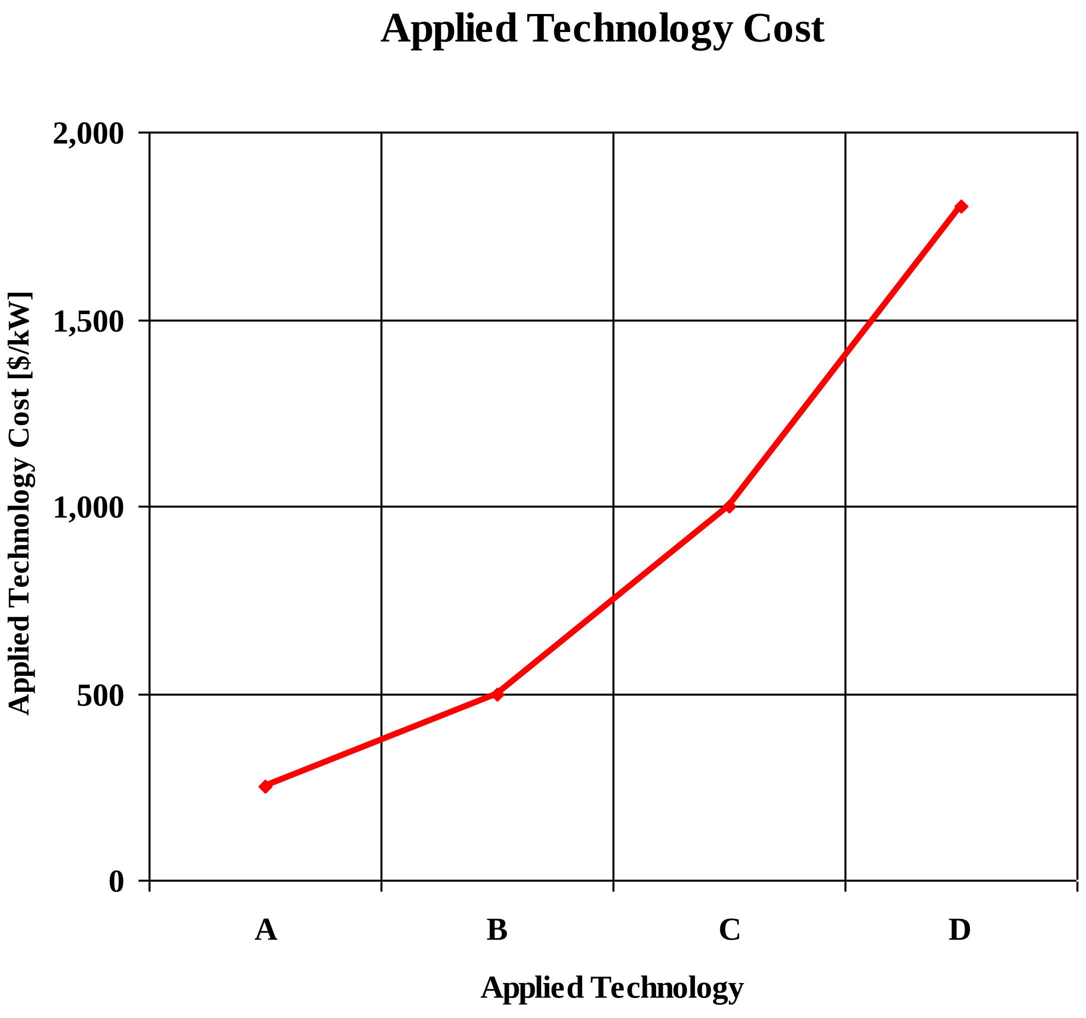
Energy Conversion Costs

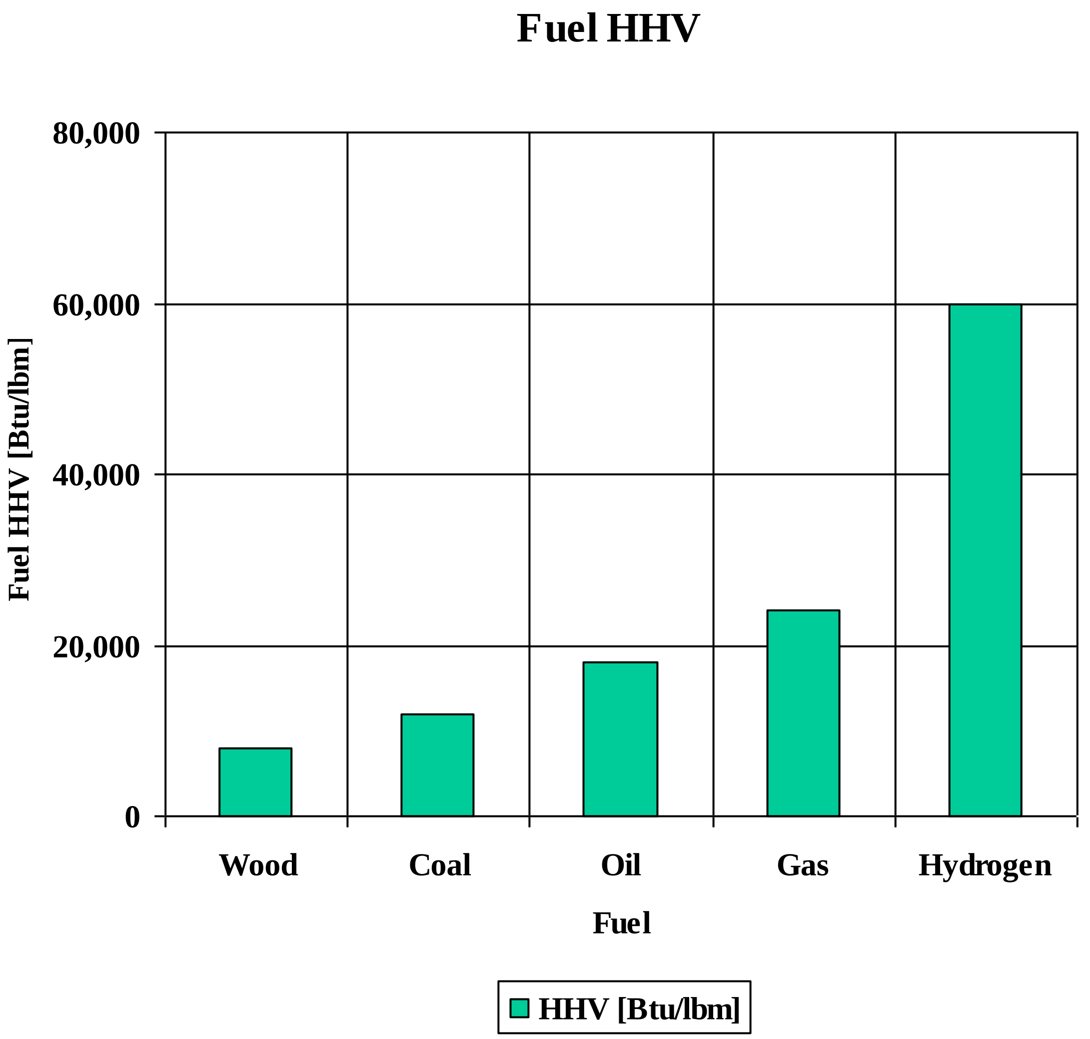
Here are some of the basic engineering costs related to energy conversion systems -- the engineering costs have been generated by the **Engineering Software** product line.



Cycle Efficiency
100
75
50
25
0
Cycle Efficiency [%]
A
B
C
D
Applied Technology



Applied Technology Cost
Applied Technology Cost [$/kW]
2,000
1,500
1,000
500
0
A
B
C
D
Applied Technology



Fuel HHV
80,000
60,000
40,000
20,000
0
Fuel HHV [Btu/lbm]
Wood
Coal
Oil
Gas
Hydrogen
Fuel
HHV [Btu/lbm]

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Basic Engineering Equations

Here are some of the basic engineering equations related to the conservation of mass, momentum and energy and energy conversion systems.

Basic Conservation Equations

Continuity Equation

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

Momentum Equation

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

Energy Equation

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

Energy Conversion Systems Equations

State Equation for Ideal Gas

$$pv = RT \text{ [kJ/kg]}$$

Perfect Gas

$$c_p = \text{constant [kJ/kg*K]}$$

Kappa

$$\chi = c_p/c_v \text{ [/]}$$

Energy Conversion Systems Equations

Isentropic Compression

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

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

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

Energy Conversion Systems Equations

Flame Temperature [K]

$$h_{reactants} = h_{products} \text{ [kJ/kg]}$$

Energy Conversion Systems Equations

Isentropic Expansion

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

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

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

Energy Conversion Systems Equations

Sonic Velocity

$$v_s = (\chi RT)^{1/2} \text{ [m/s]}$$

Mach Number

$$M = v/v_s \text{ [/]}$$

Thrust

$$\text{Thrust} = vm + (p - p_{atm})A \text{ [N]}$$

Energy Conversion Systems Equations

Isentropic Flow

$$T_t/T = (1 + M^2(\chi - 1)/2) \ [/]$$

$$p_t/p = (1 + M^2(\chi - 1)/2)^{\chi/(\chi-1)} \ [/]$$

$$h_t = (h + v^2/2) \ [kJ/kg]$$

$$T_t = (T + v^2/(2c_p)) \ [K]$$

Energy Conversion Systems Equations

Cycle Efficiency

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

Heat Rate

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

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