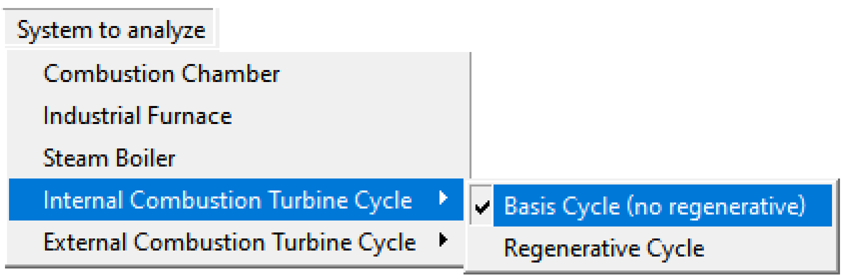
Exercise 3 (Brayton cycle)

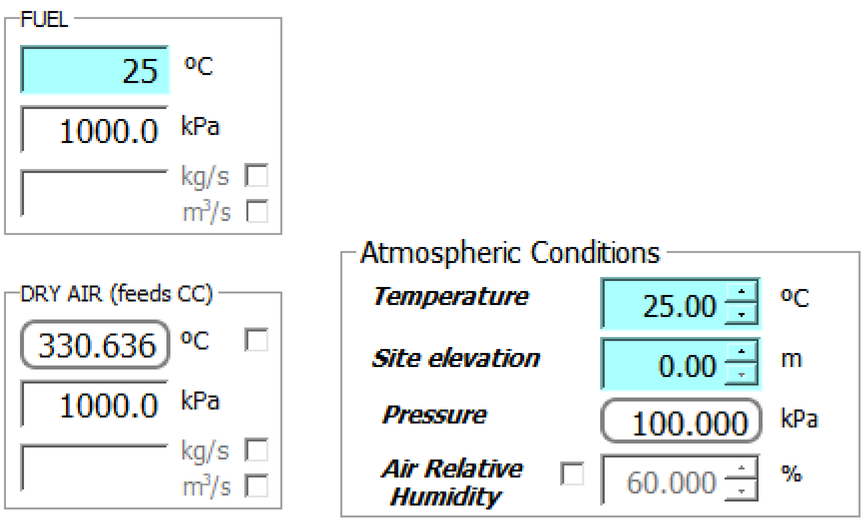
A mixture of hydrocarbons is used as fuel in a Brayton cycle. Air enters with 190% excess. The environmental conditions are 25ºC and 100 kPa and it is mixed with the fuel that enters the same conditions, before combustion. The temperature reached by the combustion gases is 1200ºC and the combustion chamber works at 1000 kPa, without pressure drop. The isentropic efficiencies of both turbomachines are 89%. The pressure in the exhaust is 100kPa.

C_8H_{18}	84 %
C_5H_8O	10 %
C_4H_8O	6 %

Get:
a) Energy analysis with Sankey diagram
b) Exergy analysis with Grassmann diagram

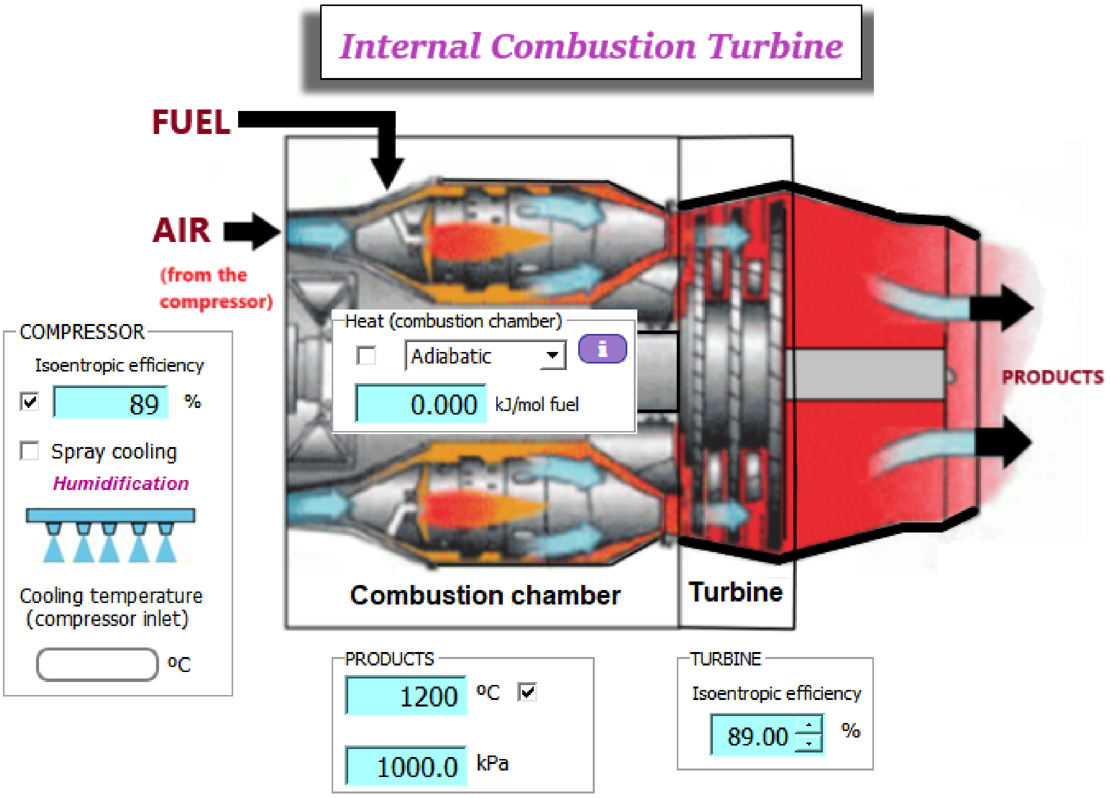
Study the effect of evaporative cooling of the air before entering the compressor.



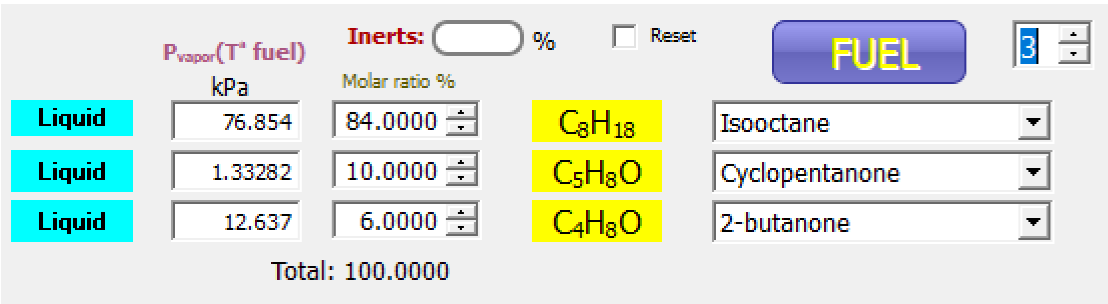


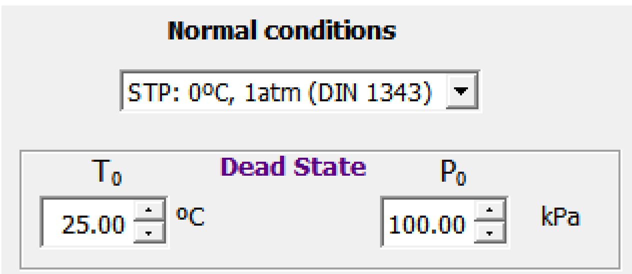
ThermoCombustion
Hidrocarbon Fuels

ThermoSuite
Technical Software Suite



The Brayton cycle analysis is used to predict the thermodynamic performance of gas turbine engines. The Brayton Cycle is a thermodynamic cycle that describes how gas turbines operate. The idea behind the Brayton Cycle is to extract energy from flowing air and fuel to generate usable work which can be used to power many vehicles by giving them thrust. The THERMOCombustion computer program, uses the Brayton cycle to determine the thermodynamic variables, including energy and exergy analysis of an engine design for specified values of component performance.





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FLUE GAS (Combustion Products)

☑ On wet basis ☐ On dry basis

	☑ mol/mol fuel	☐ kg/kg fuel	Mole %	Mass %
CO_2	7.460000	3.020633	6.9044	10.5727
CO				
H_2O	8.200000	1.359143	7.5893	4.7572
N_2	82.054663	21.148539	75.9438	74.0231
O_2	10.331972	3.041886	9.5625	10.6471
SO_2				
H_2				
Ar				
unburned				
TOTAL	108.0466	28.5702	100.00 %	100.00 %

	Lower Heating, LHV		Higher Heating, HHV	
NET	4668.52	kJ/mol fuel	5029.40	GROSS
	42952.54	kJ/kg fuel	46272.82	
	208297.69	kJ/Nm³	224399.24	

Model Substances (oxidizer and combustion products) ▸
Combustion Products ▸
Reactants ▸
Streams of AIR/FUEL ▸

Actual Gas
✔ Ideal gas
Perfect gas

Products Temperature

1200.00 ºC

Adiabatic Flame Temperature

For λ = 1.9000 **(Actual)** 1515.50 ºC

For λ = 1.0 (max) **(Theoretical)** 2121.35 ºC (25ºC, 1atm)

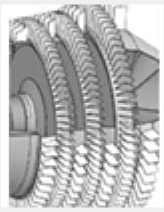
ThermoCombustion
Hidrocarbon Fuels

ThermoSuite
Technical Software Suite

Results of the Energy Analysis

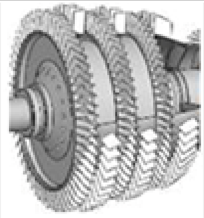
ADIABATIC TURBINE

STAGE, HP



Enthalpy at the entrance	4301.66	kJ/mol fuel
Specific work	2096.55	kJ/mol fuel
Stack discharge	2205.11	kJ/mol fuel
Stack losses temperature	659.87	ºC
Isoentropic efficiency ?		%
Isoentropic stack losses temperature	589.99	ºC

ADIABATIC COMPRESSOR



Specific work	937.53	kJ/mol fuel
Isoentropic efficiency ?	89.000	%

Thermal efficiency (Plant)

24.83 %

Net work

1159.02 kJ/mol fuel

ThermoCombustion
Hidrocarbon Fuels

ThermoSuite
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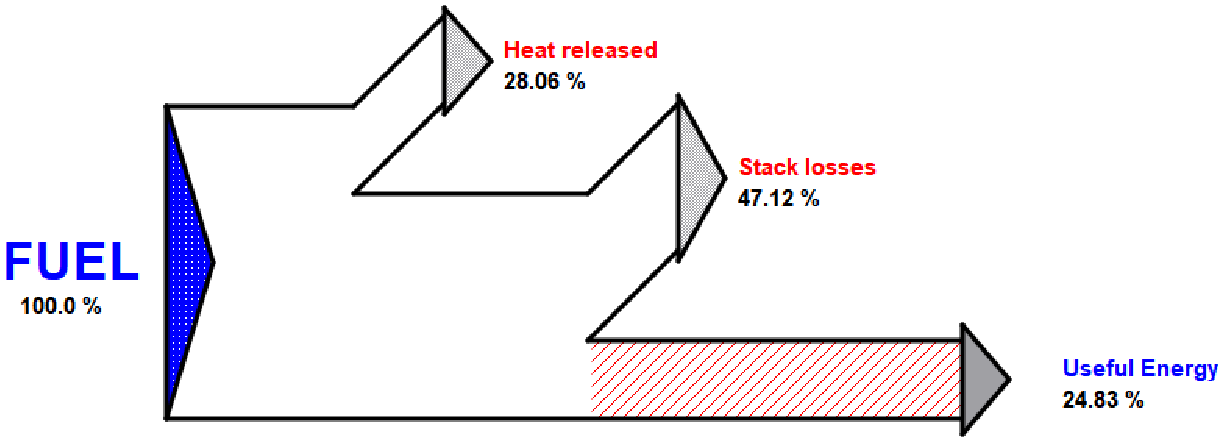


Method Exergy Applied to Chemically Reactive Systems

Normal conditions

STP: 0ºC, 1atm (DIN 1343)

Dead State

T_0 25.00 ºC

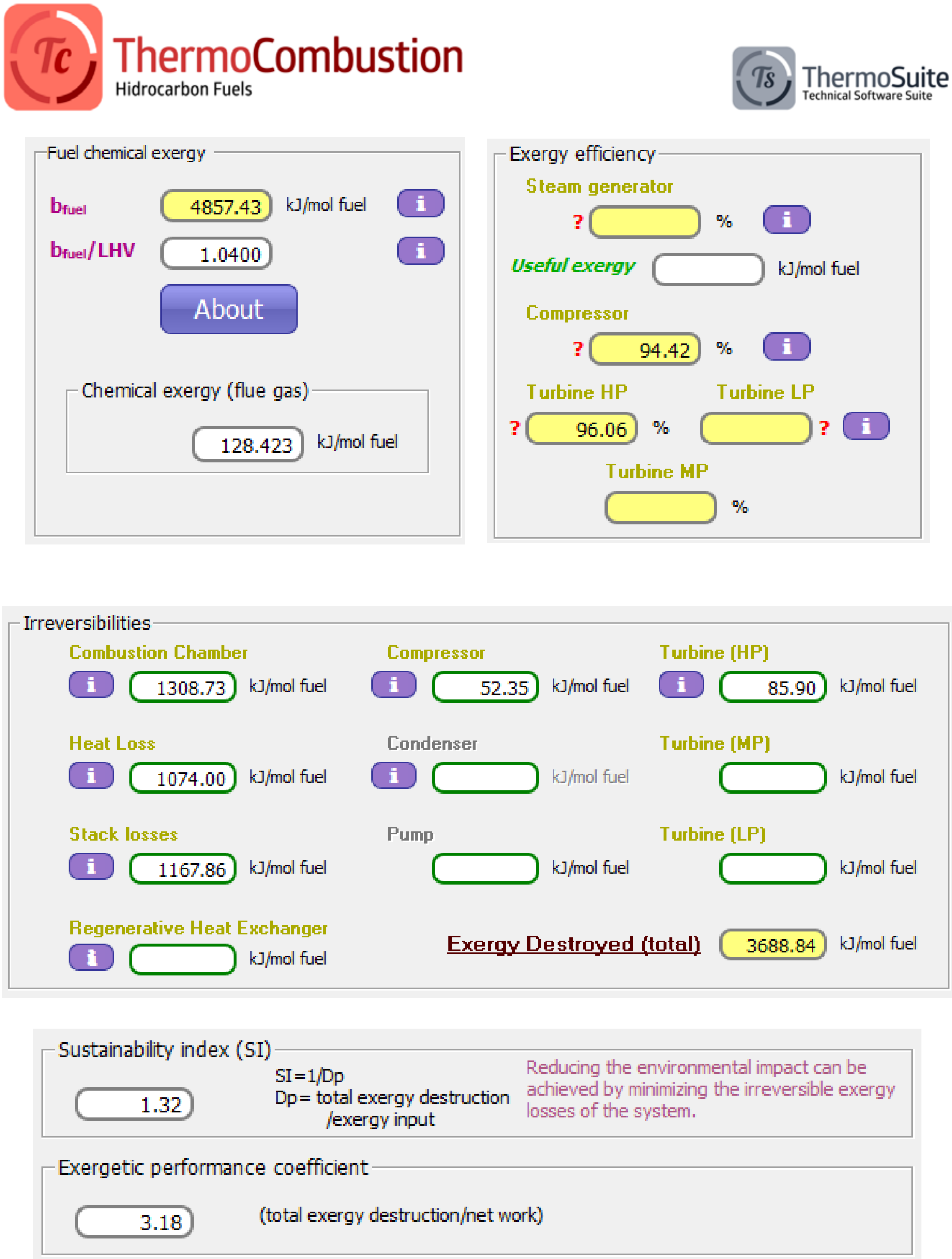
P_0 100.00 kPa

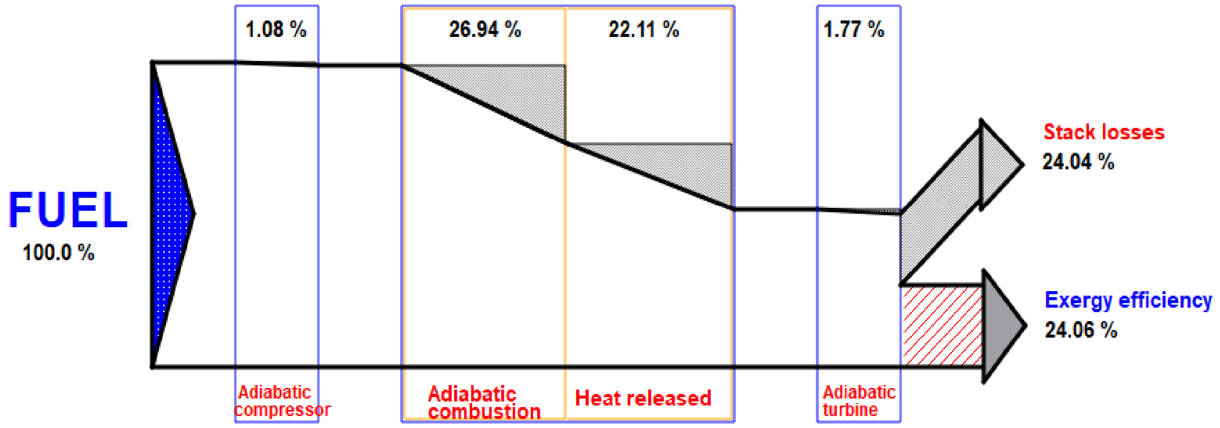
Fuel Properties

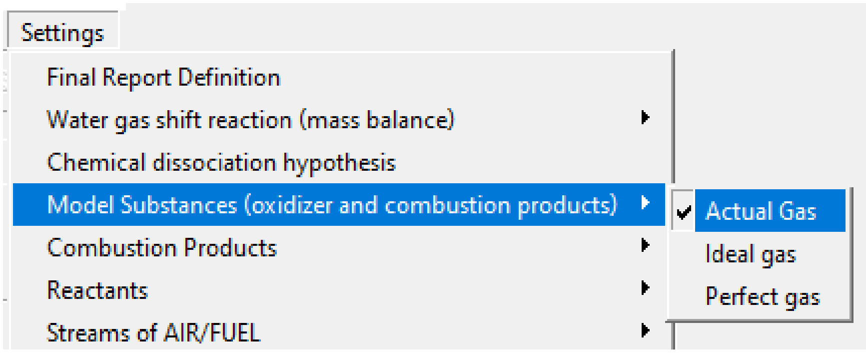
Enthalpy of formation	-247.975	kJ/mol fuel
Absolute entropy (1 atm & 25ºC)	323.5500	J/mol fuel K
Standard chemical exergy	4857.43	kJ/mol fuel
Standard Gibbs Free Energy of Formation	5.83	kJ/mol fuel

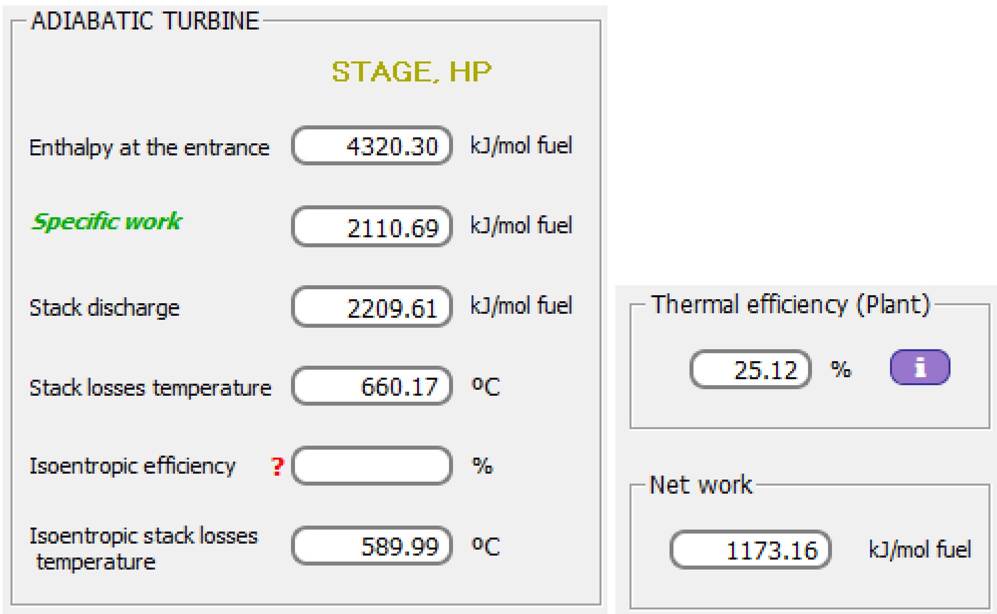
☑ Experimental correlation
Kotas

☑ Thermocombustion database


ThermoCombustion
Hidrocarbon Fuels
ThermoSuite
Technical Software Suite
Fuel chemical exergy
b fuel 4857.43 kJ/mol fuel
b fuel/LHV 1.0400
About
Chemical exergy (flue gas)
128.423 kJ/mol fuel
Exergy efficiency
Steam generator
? %
Useful exergy kJ/mol fuel
Compressor
? 94.42 %
Turbine HP
? 96.06 %
Turbine LP
?
Turbine MP
%
Irreversibilities
Combustion Chamber
1308.73 kJ/mol fuel
Compressor
52.35 kJ/mol fuel
Turbine (HP)
85.90 kJ/mol fuel
Heat Loss
1074.00 kJ/mol fuel
Condenser
kJ/mol fuel
Turbine (MP)
kJ/mol fuel
Stack losses
1167.86 kJ/mol fuel
Pump
kJ/mol fuel
Turbine (LP)
kJ/mol fuel
Regenerative Heat Exchanger
kJ/mol fuel
Exergy Destroyed (total) 3688.84 kJ/mol fuel
Sustainability index (SI)
1.32
SI=1/Dp
Dp= total exergy destruction /exergy input
Reducing the environmental impact can be achieved by minimizing the irreversible exergy losses of the system.
Exergetic performance coefficient
3.18
(total exergy destruction/net work)


1.08 %
26.94 %
22.11 %
1.77 %
FUEL
100.0 %
Stack losses
24.04 %
Exergy efficiency
24.06 %
Adiabatic compressor
Adiabatic combustion
Heat released
Adiabatic turbine


Settings
Final Report Definition
Water gas shift reaction (mass balance)
Chemical dissociation hypothesis
Model Substances (oxidizer and combustion products)
Combustion Products
Reactants
Streams of AIR/FUEL
Actual Gas
Ideal gas
Perfect gas


ADIABATIC TURBINE
STAGE, HP
Enthalpy at the entrance
4320.30
kJ/mol fuel
Specific work
2110.69
kJ/mol fuel
Stack discharge
2209.61
kJ/mol fuel
Stack losses temperature
660.17
ºC
Isentropic efficiency
?
%
Isentropic stack losses temperature
589.99
ºC
Thermal efficiency (Plant)
25.12
%
Net work
1173.16
kJ/mol fuel

ThermoCombustion
Hidrocarbon Fuels

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ADIABATIC TURBINE

STAGE, HP

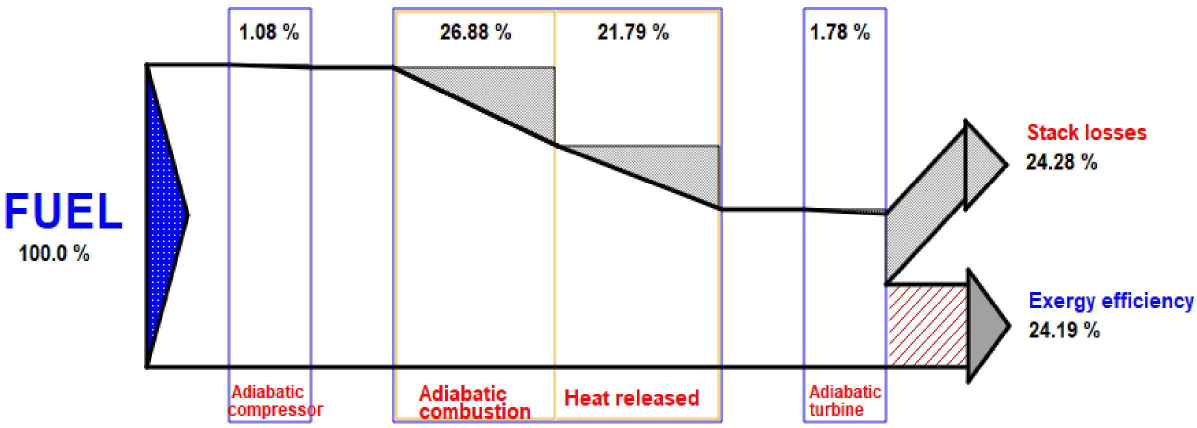
Enthalpy at the entrance	4320.30	kJ/mol fuel
Specific work	2110.69	kJ/mol fuel
Stack discharge	2209.61	kJ/mol fuel
Stack losses temperature	660.27	ºC
Isentropic efficiency ?		%
Isentropic stack losses temperature	589.99	ºC

Exergy efficiency

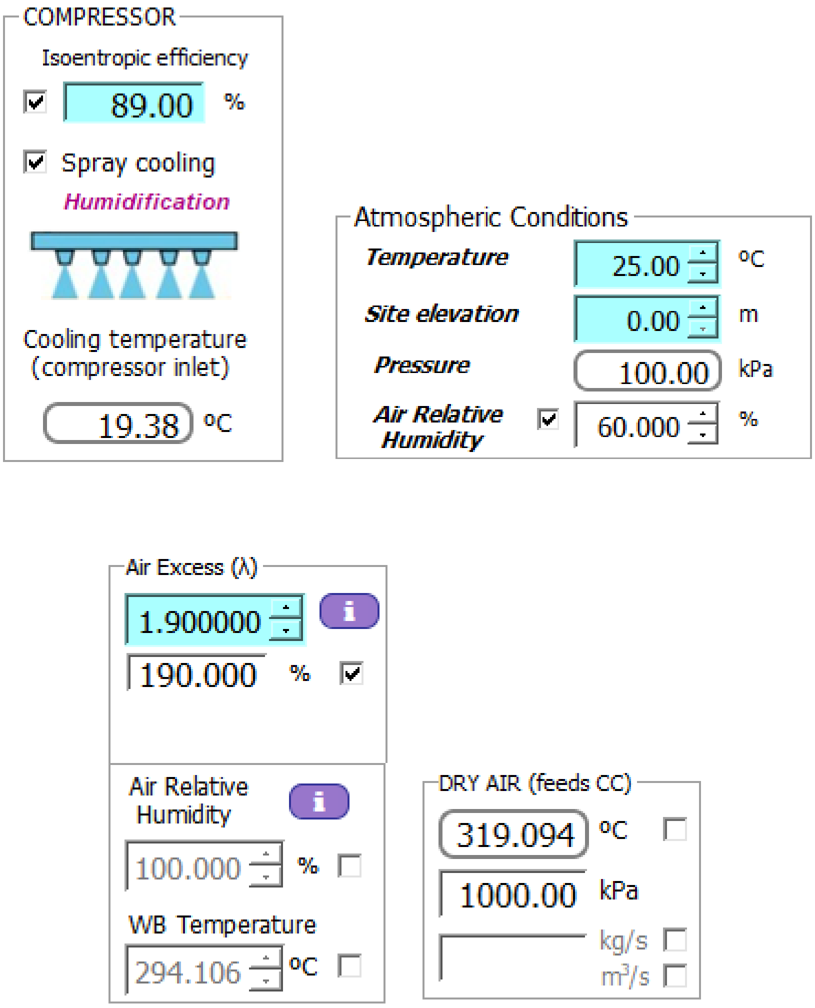
Steam generator ?		%
Useful exergy		kJ/mol fuel
Compressor ?	94.42	%
Turbine HP ?	96.39	%
Turbine LP ?		
Turbine MP		%

Irreversibilities

Combustion Chamber	1305.75	kJ/mol fuel
Compressor	52.35	kJ/mol fuel
Turbine (HP)	86.55	kJ/mol fuel
Heat Loss	1058.34	kJ/mol fuel
Condenser		kJ/mol fuel
Turbine (MP)		kJ/mol fuel
Stack losses	1179.58	kJ/mol fuel
Pump		kJ/mol fuel
Turbine (LP)		kJ/mol fuel
Regenerative Heat Exchanger		kJ/mol fuel
Exergy Destroyed (total)	3682.57	kJ/mol fuel



Study of the effect of evaporative cooling of the air before entering the compressor.



ThermoCombustion
Hidrocarbon Fuels

ThermoSuite
Technical Software Suite

FLUE GAS (Combustion Products)

☑ On wet basis ☐ On dry basis

	☑ mol/mol fuel	☐ kg/kg fuel	Mole %	Mass %
CO_2	7.460000	3.020633	6.8288	10.5563
CO				
H_2O	10.591845	1.755589	9.6957	6.1353
N_2	82.054663	21.148539	75.1123	73.9085
O_2	9.136049	2.689789	8.3631	9.4001
SO_2				
H_2				
Ar				
unburned				
TOTAL	109.2426	28.6145	100.00 %	100.00 %

- Model Substances (oxidizer and combustion products) ▸
  - Actual Gas
  - ✔ Ideal gas
  - Perfect gas
- Combustion Products ▸
- Reactants ▸
- Streams of AIR/FUEL ▸

Products Temperature

1200.00 ºC

Adiabatic Flame Temperature

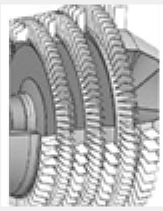
For λ = 1.9000 **(Actual)**: 1492.10 ºC

For λ = 1.0 (max) **(Theoretical)**: 2121.35 ºC (25ºC, 1atm)

Results of the Energy Analysis

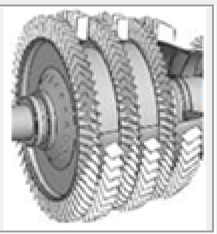
ADIABATIC TURBINE

STAGE, HP



Enthalpy at the entrance	4366.28	kJ/mol fuel
Specific work	2123.02	kJ/mol fuel
Stack discharge	2243.26	kJ/mol fuel
Stack losses temperature	661.57	ºC
Isoentropic efficiency ?		%
Isoentropic stack losses temperature	591.99	ºC

ADIABATIC COMPRESSOR



Specific work	942.33	kJ/mol fuel
Isoentropic efficiency ?	89.000	%

Thermal efficiency (Plant)

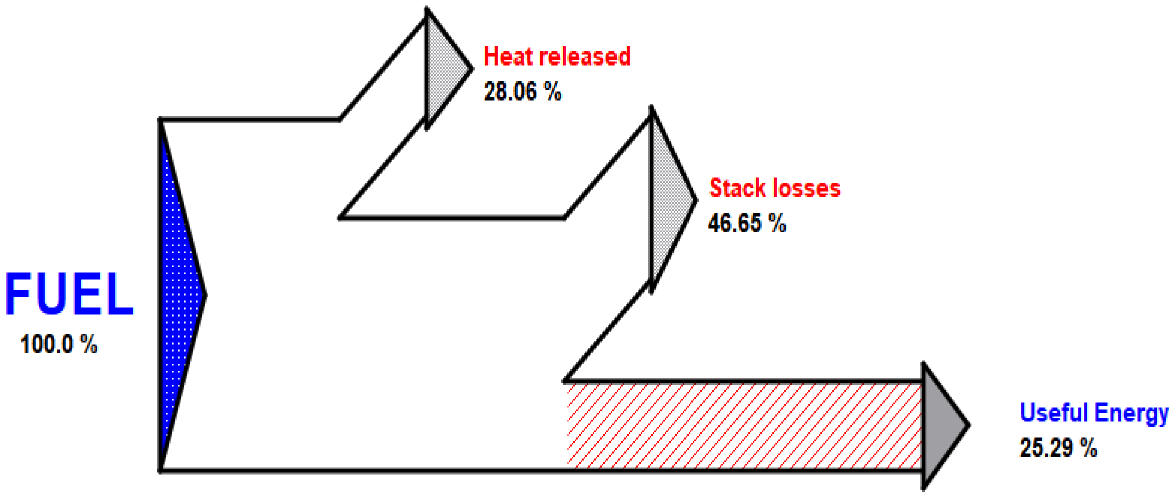
25.29 %

Net work

1180.69 kJ/mol fuel

ThermoCombustion
Hidrocarbon Fuels

ThermoSuite
Technical Software Suite



Method Exergy Applied to Chemically Reactive Systems

Fuel chemical exergy

b_{fuel}	4951.77	kJ/mol fuel
b_{fuel}/LHV	1.0607	

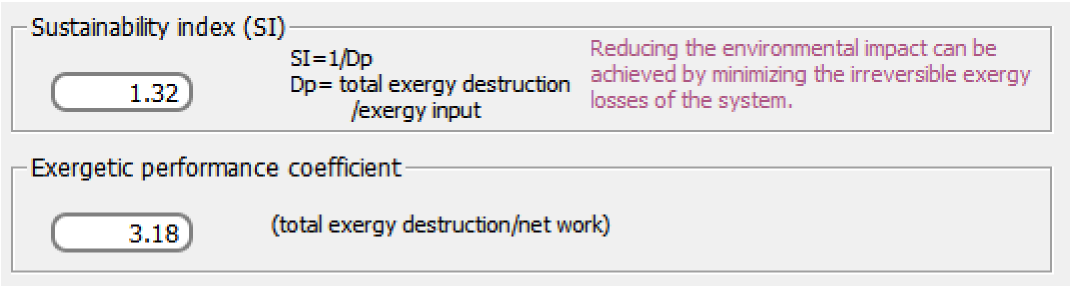
About

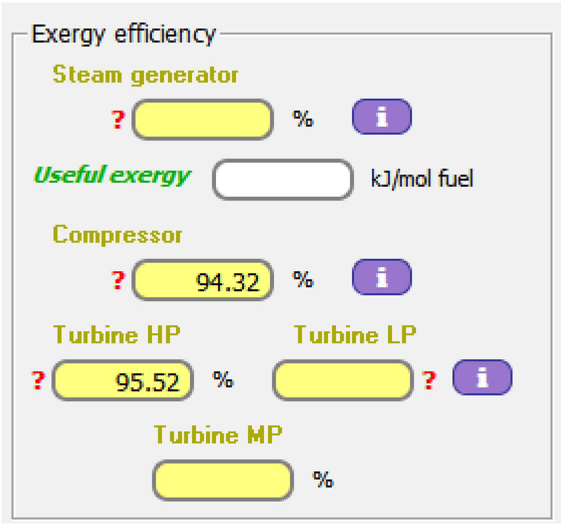
Chemical exergy (flue gas)

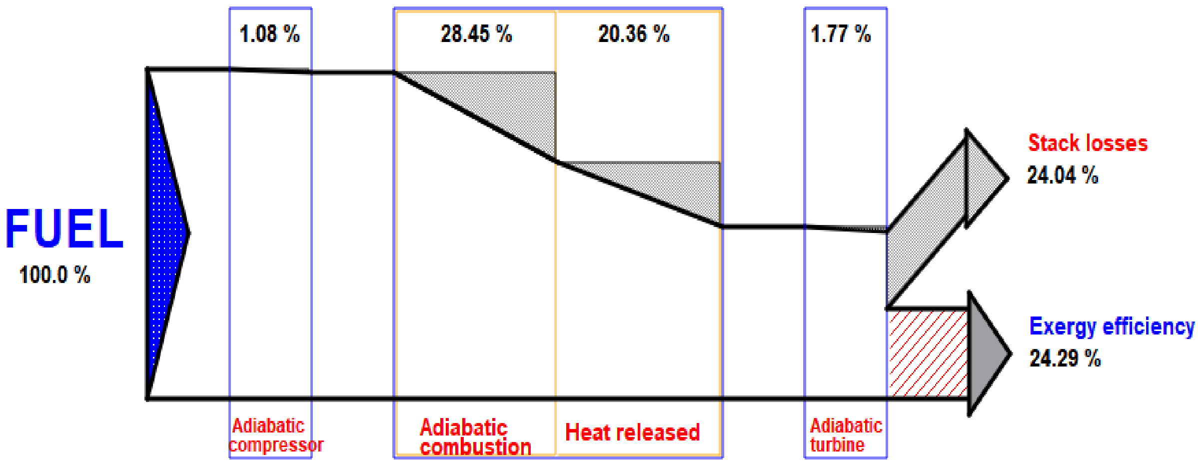
144.307 kJ/mol fuel

Irreversibilities

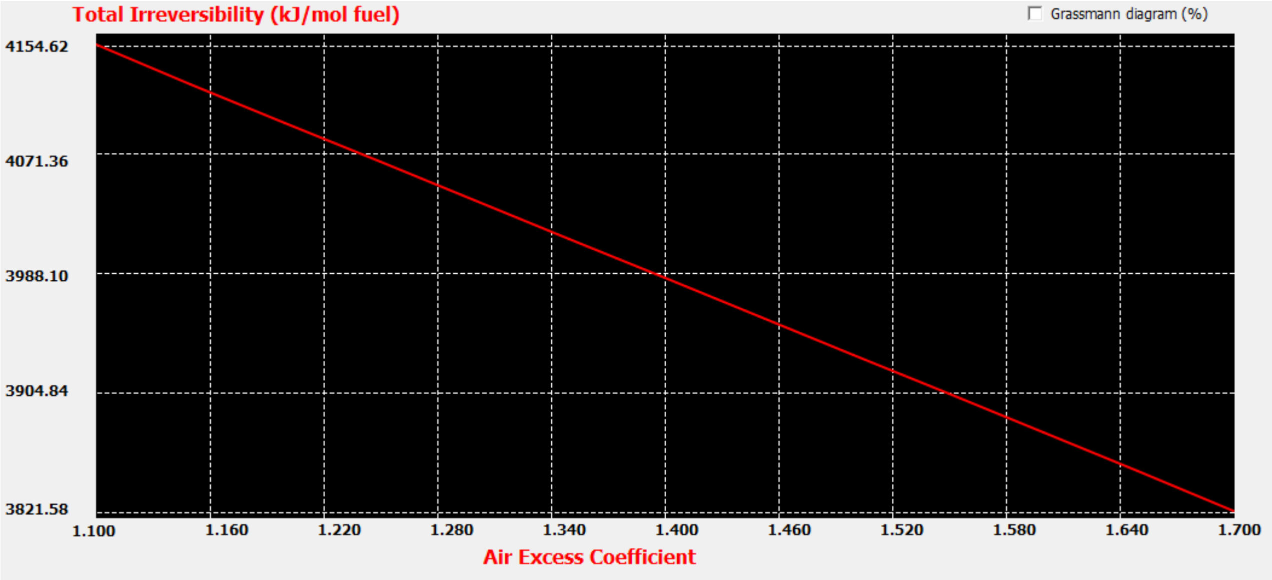
Combustion Chamber	1408.62	kJ/mol fuel
Compressor	53.53	kJ/mol fuel
Turbine (HP)	87.72	kJ/mol fuel
Heat Loss	1008.25	kJ/mol fuel
Condenser		kJ/mol fuel
Turbine (MP)		kJ/mol fuel
Stack losses	1190.63	kJ/mol fuel
Pump		kJ/mol fuel
Turbine (LP)		kJ/mol fuel
Regenerative Heat Exchanger		kJ/mol fuel
Exergy Destroyed (total)	3748.75	kJ/mol fuel

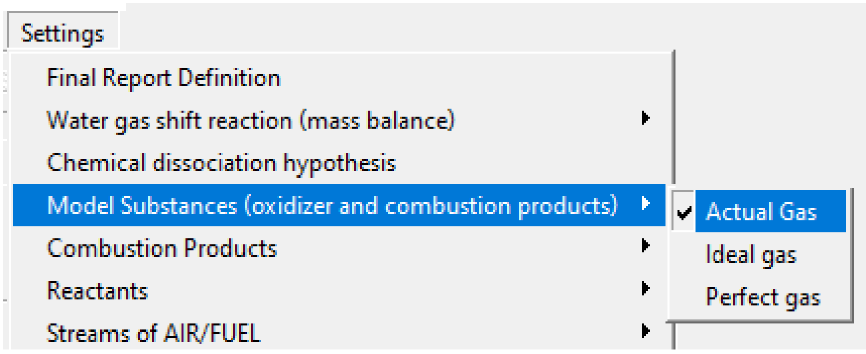


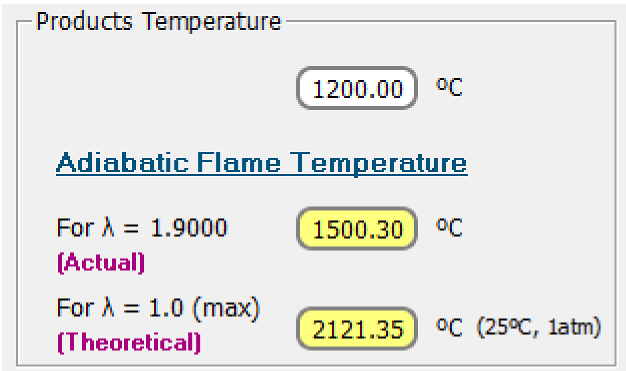


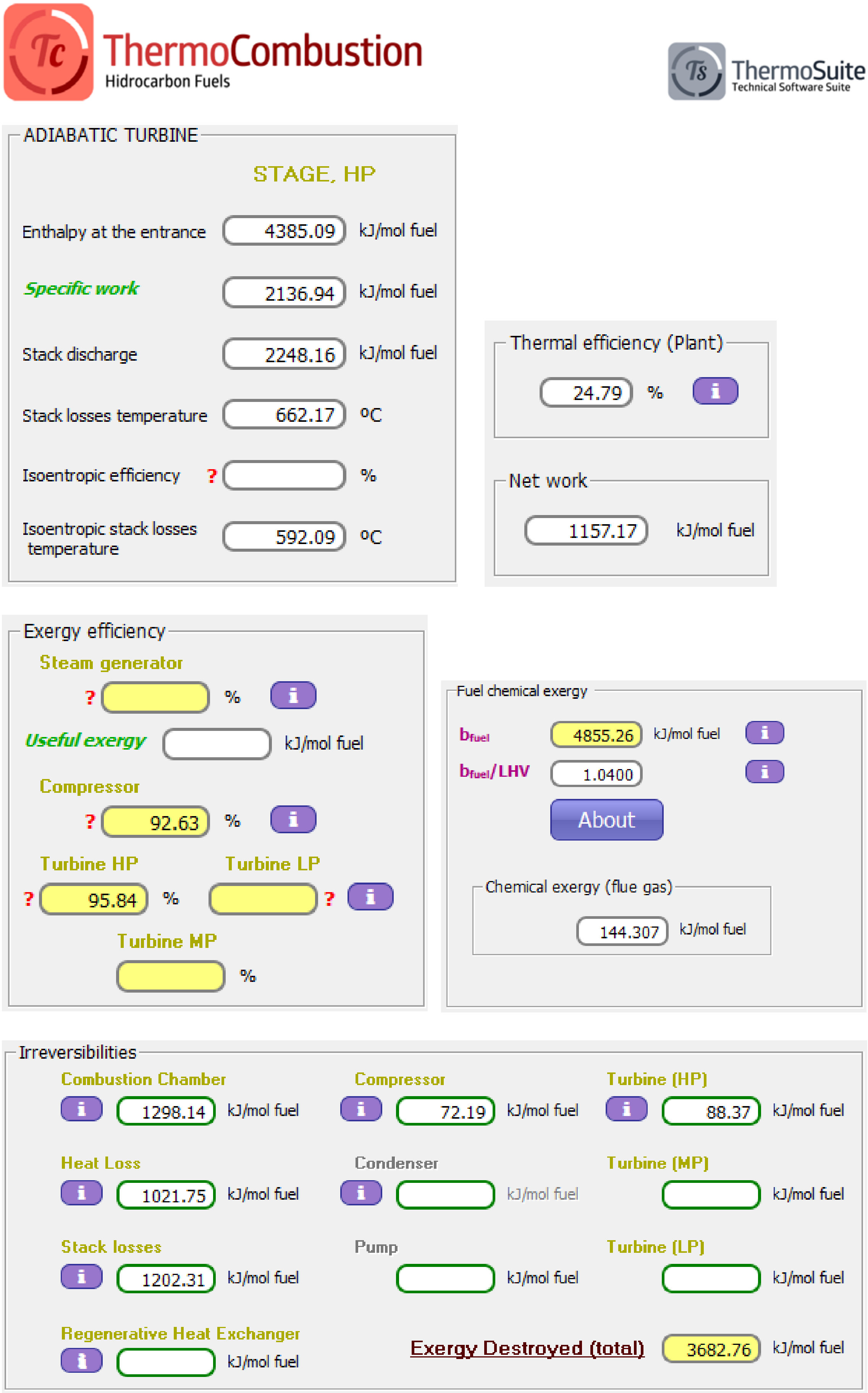


The analysis of entropy generation and exergy loss is used for optimizing the performance of energy conversion systems such as gas turbines. Exergy loss in the combustor of 30%–50% is the largest of all component losses in the gas turbine systems. The sources of the large exergy loss during the combustion process can be evaluated by analyzing local entropy generation of irreversible processes.


Total Irreversibility (kJ/mol fuel)
Grassmann diagram (%)
4154.62
4071.36
3988.10
3904.84
3821.58
1.100
1.160
1.220
1.280
1.340
1.400
1.460
1.520
1.580
1.640
1.700
Air Excess Coefficient


Settings
Final Report Definition
Water gas shift reaction (mass balance)
Chemical dissociation hypothesis
Model Substances (oxidizer and combustion products)
Combustion Products
Reactants
Streams of AIR/FUEL
Actual Gas
Ideal gas
Perfect gas


Products Temperature
1200.00
ºC
Adiabatic Flame Temperature
For λ = 1.9000
(Actual)
1500.30
ºC
For λ = 1.0 (max)
(Theoretical)
2121.35
ºC (25ºC, 1atm)


ThermoCombustion
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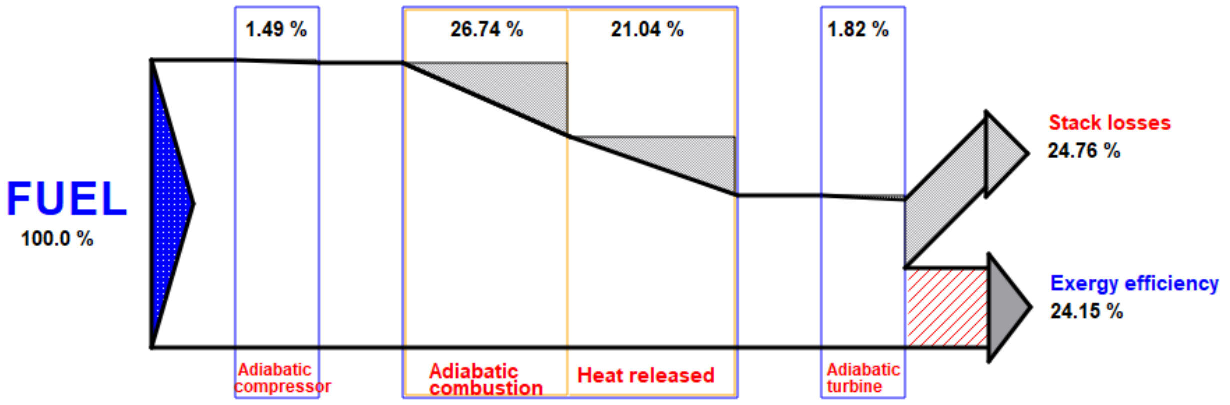
ADIABATIC TURBINE
STAGE, HP
Enthalpy at the entrance 4385.09 kJ/mol fuel
Specific work 2136.94 kJ/mol fuel
Stack discharge 2248.16 kJ/mol fuel
Stack losses temperature 662.17 ºC
Isoentropic efficiency ? %
Isoentropic stack losses temperature 592.09 ºC
Thermal efficiency (Plant)
24.79 %
Net work
1157.17 kJ/mol fuel
Exergy efficiency
Steam generator
? %
Useful exergy kJ/mol fuel
Compressor
? 92.63 %
Turbine HP
? 95.84 %
Turbine LP
?
Turbine MP
%
Fuel chemical exergy
bfuel 4855.26 kJ/mol fuel
bfuel/LHV 1.0400
About
Chemical exergy (flue gas)
144.307 kJ/mol fuel
Irreversibilities
Combustion Chamber
1298.14 kJ/mol fuel
Compressor
72.19 kJ/mol fuel
Turbine (HP)
88.37 kJ/mol fuel
Heat Loss
1021.75 kJ/mol fuel
Condenser
kJ/mol fuel
Turbine (MP)
kJ/mol fuel
Stack losses
1202.31 kJ/mol fuel
Pump
kJ/mol fuel
Turbine (LP)
kJ/mol fuel
Regenerative Heat Exchanger
kJ/mol fuel
Exergy Destroyed (total) 3682.76 kJ/mol fuel


1.49 %
26.74 %
21.04 %
1.82 %
FUEL
100.0 %
Stack losses
24.76 %
Exergy efficiency
24.15 %
Adiabatic compressor
Adiabatic combustion
Heat released
Adiabatic turbine