Fundamental Impact Of Firing Syngas In Gas Turbines

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Gas Turbine Need

- **Gas turbines fired on syngas has increased power output compared to the one fired on natural gas.**

- **Increased power output is accompanied by increased moisture content of combustion products.**

- **Both higher hydrogen content of the syngas and the increased moisture content result in overheating of turbine components.**

- **OEMs agreed on reducing firing temperature similar to that of natural gas firing to mitigate the impact of overheating but not on criteria selected to achieve this.**

Project Objectives

- **Analyze the fundamental impacts of firing syngas in gas turbines.**

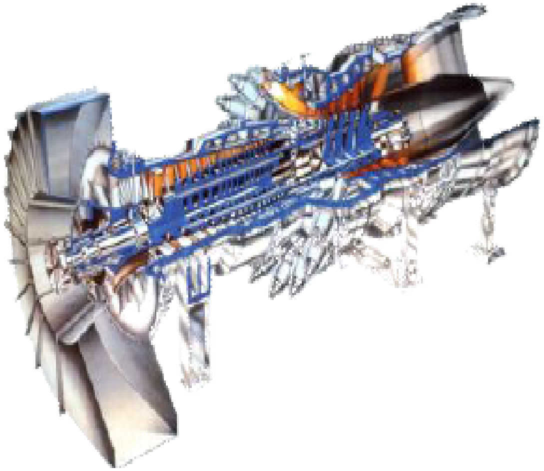
- **Indicate appropriate amount of reduction in firing temperature needed to maintain the same hot section metal temperature as experienced with natural gas firing.**

Approach

- Modeling of typical IGCC power plant was done using GateCycle software (GateCyle software is a product of GE Enter Software).

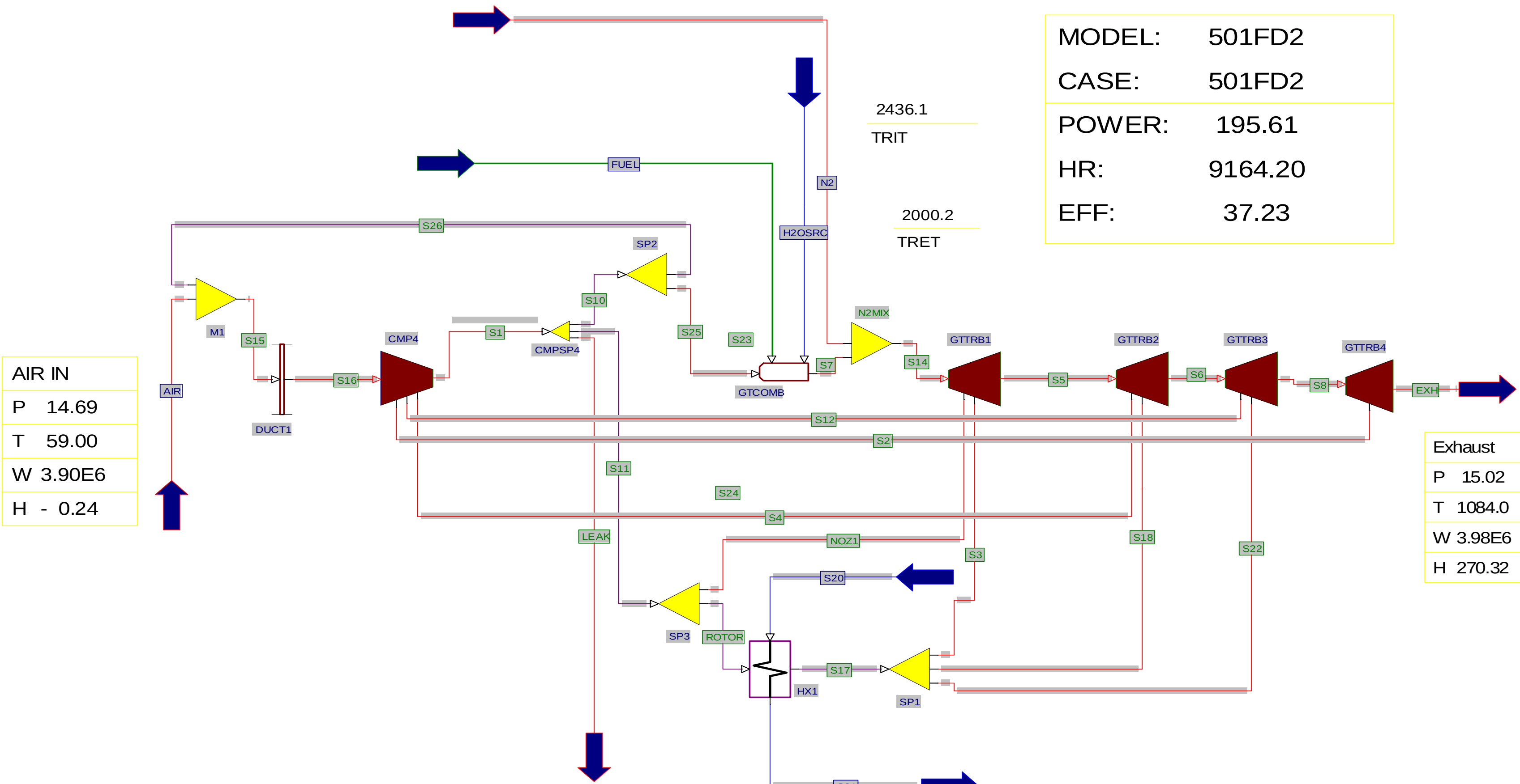
- Baseline case plant was established using Siemens SGT6-5000F as expander and natural gas as a baseline fuel.

- Engine parameters were matched at ambient conditions with the ones from the Siemens Plant Performance Estimation Program (SIPEP).



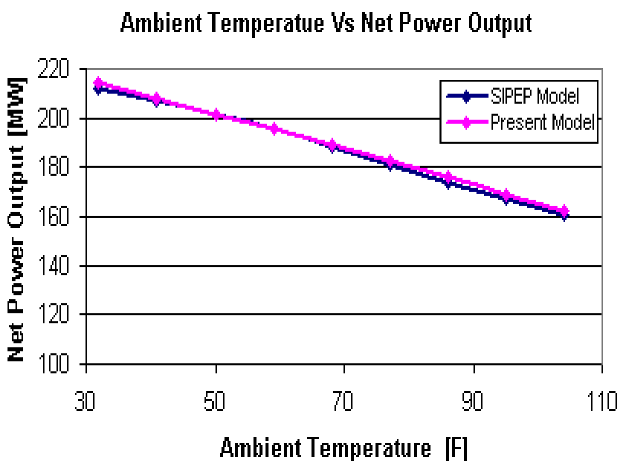
Siemens SGT6-5000F gas turbine

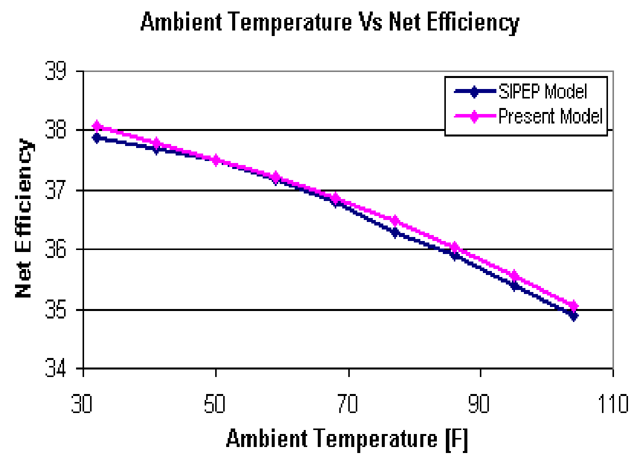
Approach Contd.

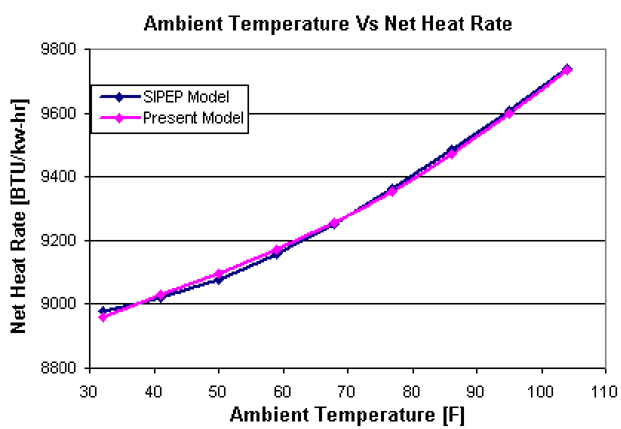


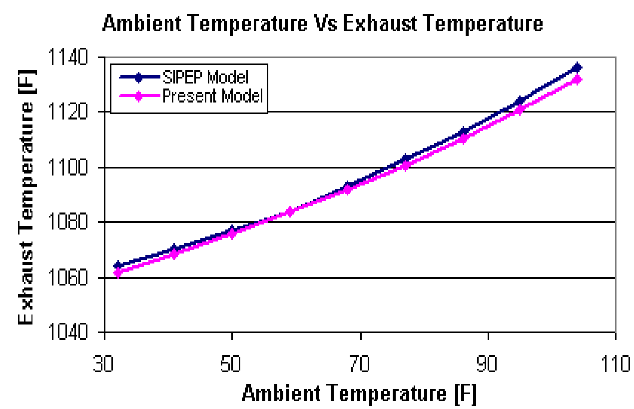
Model block diagram showing design conditions for natural gas

Approach Contd.









Matched result of present model with that of SIPEP

Syngas Model

- Gas turbines fired on natural gas required only minor changes to fired the same gas turbine on syngas (combustor and the fuel nozzle are vital).

- Syngas has low heating value compared to natural gas and consequently required a larger fuel flow supply.

- Nozzle area performance factor for syngas model was increased by 20% to accommodate increased flow.

- cooling flow for the syngas model is calculated using the equation;

$$M_{cool} = M_{coolref}\left(\frac{P_{cool}}{P_{ref}}\right)\left(\frac{T_{ref}}{T_{cool}}\right)^{0.5} \quad (1)$$

Where:
M = cooling flow rate; T = cooling flow temperature (absolute units)
P = cooling flow pressure (absolute units); cool = current cooling gas value
ref = value at reference (design) condition

Syngas Model Contd.

- The metal temperature in GateCycle is calculated using the cooling correlation based on the turbine inlet temperature, cooling flow rate determined in Equation (1) and specific heat transfer with the reference values of some cooling parameters.

$$M_{cool} = M_{coolref}\left(\frac{C_{pref}}{C_p}\right)_{cool}\left(\frac{C_p}{C_{pref}}\right)_{gas}\left(\frac{\left(\frac{T_g - T_{metal}}{T_g - T_{cool}}\right)}{\left(\frac{T_g - T_{metal}}{T_g - T_{cool}}\right)_{ref}}\right)^{1.1} \qquad \textbf{(2)}$$

Where:
M = cooling flow rate; Cp = specific heat; T=temperature; gas =inlet gas value
cool = cooling gas value; ref = value at reference condition

- The metal temperature is determined by applying Equation (2) backwards.

Gas Fuel Specification

Component	Primary Design Case	Fuel A (mol.)	Fuel B (mol.)	Fuel C (mol.)
H_2	0.0000	0.1214	0.1861	0.3998
O_2	0.0000	0.0009	0.0000	0.0000
CH_4	1.0000	0.0005	0.0013	0.0014
CO	0.0000	0.2503	0.1952	0.0092
CO_2	0.0000	0.0012	0.0890	0.0292
N_2	0.0000	0.5042	0.3995	0.4744
SO_2	0.0000	0.0000	0.0000	0.0000
Ar	0.0000	0.0047	0.0058	0.0061
H_2S	0.0000	1.286E-05	0.0000	0.0000
COS	0.0000	9.171E-06	0.0000	0.0000
H_2O	0.0000	0.0067	0.1230	0.0800
LHV (Btu/Ib)	21501.0	1823.0	1862.0	2495.0
LHV (Btu/scf)	959	120	120	120

Part Life Analysis

- Increased metal temperature affects both creep life and the oxidation/ corrosion rates of turbine hot parts.

- Time to creep of hot parts can be estimated using Larson-Miller Parameter (LMP)

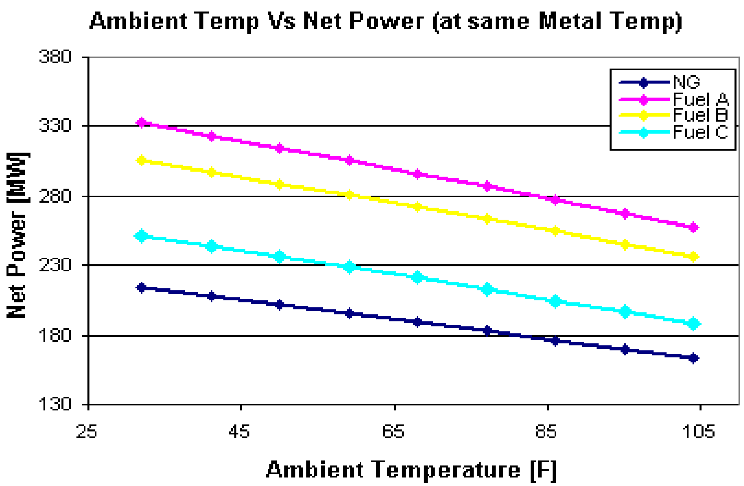
$$LMP = (T + 460)\ (20 + \log10\ t)*10^{-3} \qquad (3)$$

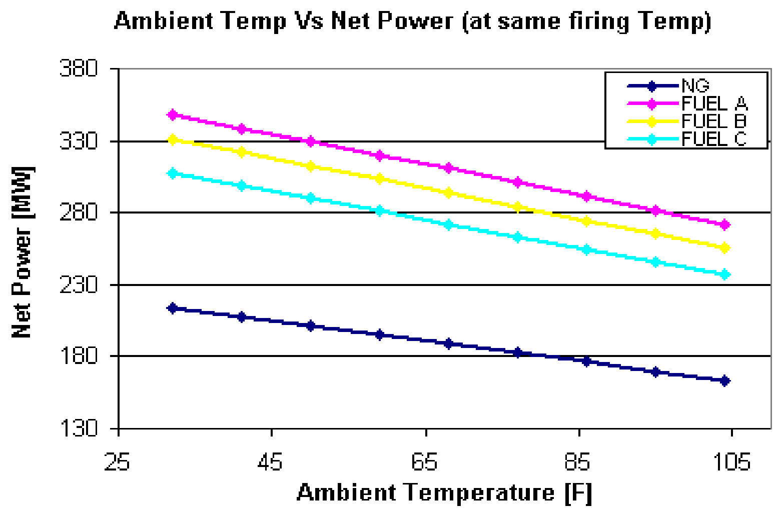
Where
T = temperature, ºF ; T = time, hr

- Design condition of SGT6-5000F first stage nozzle and rotor blades;
  - creep life of 48000 hours (based on manufacturer's recommendation
  - metal temperature is estimated at 1619ºF

- LMP is calculated to be 51310

Results Contd.



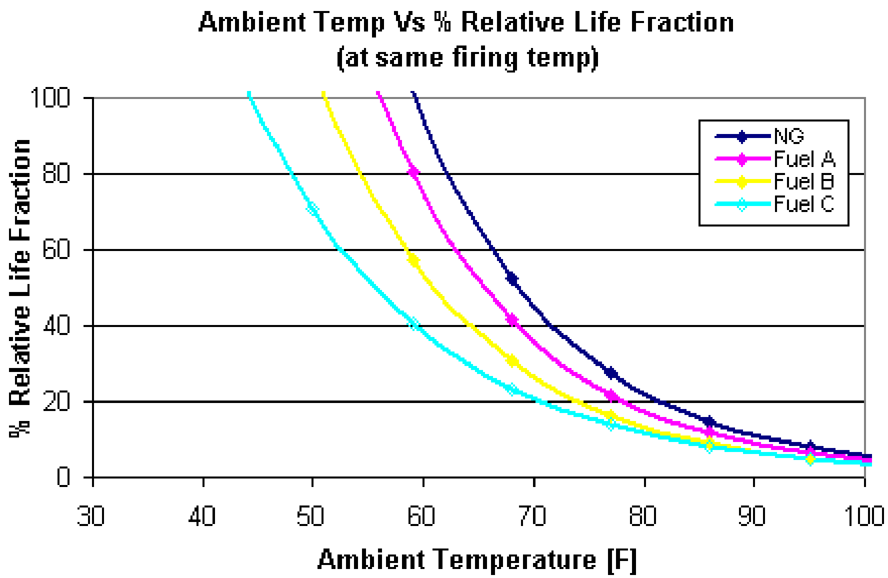


Influence of ambient temperature on power output

- **Gas turbine fired with syngas produce more power, up to an increase of 20% when fired to the same metal temperature as the natural gas.**

- **When fired at the same firing temperature as the natural gas, the power output of gas turbine using fuels A, B and C show a respective average power output increase of about 5, 8 and 23 percent compared to the same turbine fired with the same metal temperature as the natural gas.**

Results Contd.



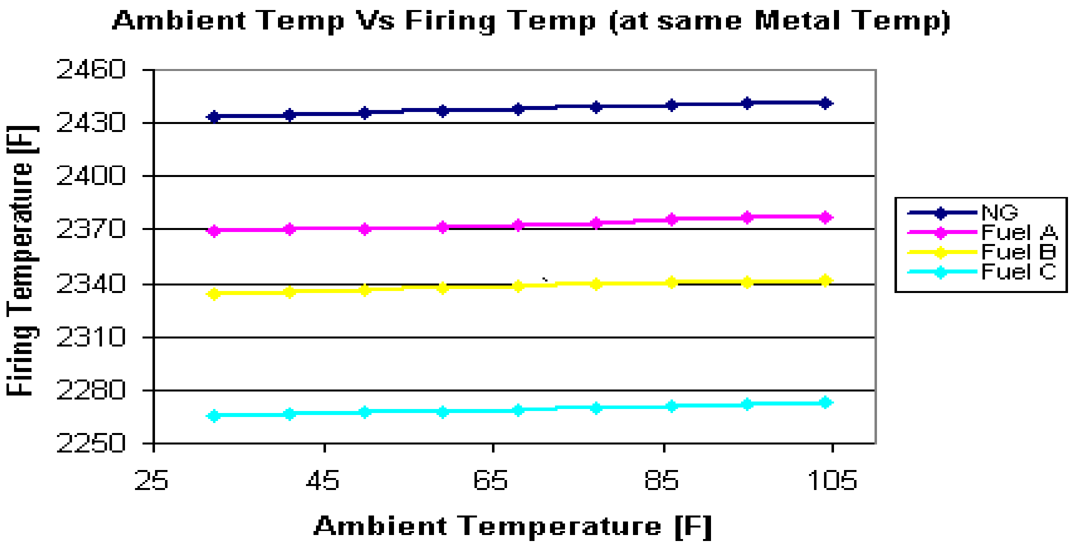
Relative life of turbine hot sections

- **For a syngas with only 12.1 % by volume of H_2 (fuel A), the creep life is reduced by about 20% when compared with the natural gas at 59ºF ambient temperature.**

- **The percentage by volume of hydrogen and the moisture contents in the syngas fuels significantly impact the life of the hot sections.**

- **This analysis does not represent an exhaustive analysis of all factors affecting turbine hot section life.**

Results Contd.

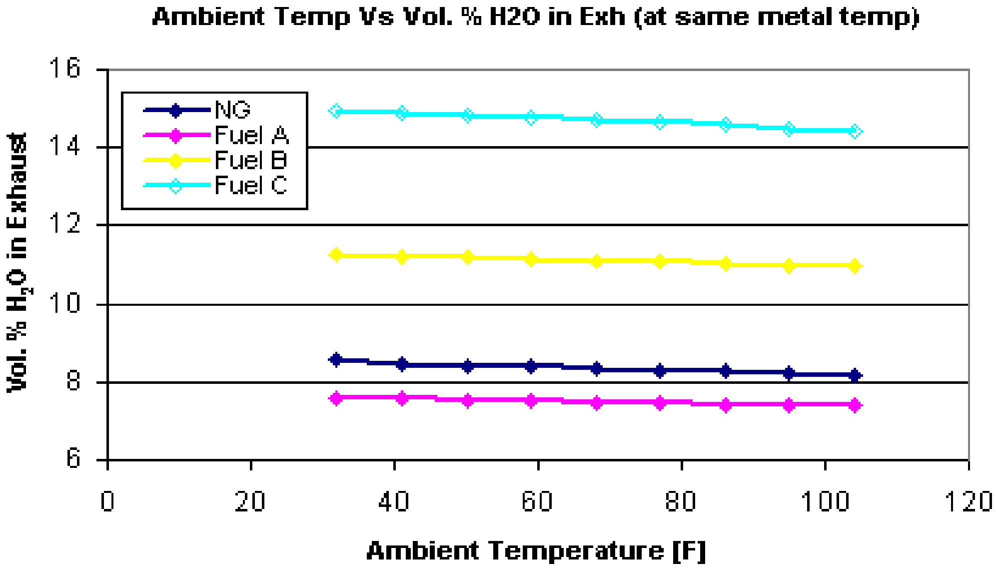


Derated firing temperature necessary to maintain metal temperature

- **Hydrogen content and the H_2O of the exhaust gas of the syngas combustion play a significant role in the "derated" temperatures.**

- **The higher the hydrogen contents , the higher the H_2O in the exhaust and also the more the firing temperature must be "derated" compared to the natural gas firing.**

Results Contd.



Variation of exhaust water content with ambient temperature

- **As the hydrogen content in the fuel increases from fuel A to C, the water content of the combustion products also increase in the same order.**

- **The higher the water content of the products of combustion, the shorter the life of the turbine hot section.**

Summary/Conclusion

- The percentage by volume of hydrogen content in the syngas fuels significantly impact the life of the hot sections as a result of higher flame temperature for hydrogen-rich fuels and also the moisture content of combustion products.

- Correlations were obtained indicating the level of firing temperature reduction necessary for hot section durability as;
  - $T_f = 13.312(\text{Vol. \% } H_2)^{0.69}$
  - $T_f = 5x10^{-07}(LHV)^{2.52}$

- Establishing both thermal and environmental degradation behavior and potential lifing of turbine hot sections requires the consideration of wide range of factors that needed further investigation.

Acknowledgement

The Gas turbine Industrial Fellowship Program is funded by the U.S Department of Energy as part of the University Turbine Systems Research Program at South Carolina Institute for Energy Studies, Clemson University, South Carolina.

The author acknowledged the guidance of Dr. J. N. Phillips and the support of Electric Power Research Institute (EPRI), Charlotte, NC through the use of their facilities.

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