INCREASING OF OPERATIONAL STABILITY IN LOW NOx GT COMBUSTORS BY RADICALS INJECTION

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GENERAL DESCRIPTION OF THE PROBLEM

- Necessity of NO\textsubscript{x} reduction in GT stimulates research for new combustion methods.

- Lean combustion is a combustion method where low combustion temperatures is used. It enables to lower NO\textsubscript{x} formation.

- Lowering temperature reduces the reaction rate of the hydrocarbon–oxygen reactions and the associated heat release. This deteriorates combustion stability.

- Combustion instability may cause severe damage to turbine.
The objective: To investigate the possibility to enhance the combustion stability limit for lean premixed operation mode by injection of radicals.

How did we try to achieve this objective?
Methodology

- The study is based on the assumption that there is a correlation between the starting point of unstable operation and lean blow out of the premixed fuel and air flame. Such correlation was observed in earlier studies.


4 Flame stability and lean blowout limits of hydrogen–enriched methane
   (a) air–methane, (b) H$_2$ added
Methodology (cont.)

• We assumed that if we will be able to decrease the lower limit of the blow out temperature, the lower limit of temperature, which leads to instability, will reduced.

• The effect of radicals on combustion stability was studied.

• Radicals were produced through combustion of rich fuel–air mixture inside a pilot combustor as source of radicals.

• Tests were carried out under atmospheric pressure.
Methodology (cont.)

- CFD simulations were performed to obtain:
  1) a detailed description of the combustion process;
  2) test combustor design;
  3) for the CHEMKIN simulations.

- The CHEMKIN simulations were carried out for conditions as in industrial GT combustor.
Concept of industrial gas turbine combustor

Experimental burner unit.

Turbine’s combustor with its 6 burners

Combustor with radicals injection (schematic)
Experimental set-up (schematic)
Cone angle and measurement probes position were obtained from CFD simulation (described later)
Test Results

Temperature evolution

- Pilot combustor: $\phi_1=1.5$, fuel fraction = 5% of main combustor.
- For low global eq. ratio, $\phi_0$, maximum temperature is achieved at downstream of the pilot combustor.
- This means that lean mixture requires longer reaction time.
- Typical lower limit in GT is $0.52 \sim 0.55$; present value = 0.45
Temperature evolution along radius

Temperature across the flame, 130 mm downstream of pilot burner exit

For low global $\phi_0$, maximum temperature is achieved at intermediate radius, whereas for high $\phi_0$ it is closer to the combustor axis.
Test Results

The presence of radicals was recorded by spectrometer.

Emission spectrum for a premixed hydrocarbon fuel.
The experimental study showed that using a pilot combustor with high equivalence ratio can help to stabilize the combustion process in the main combustor. This allows to operate at reduced global temperatures. Thus, it presents a potential method to lower NO\textsubscript{x}. 

Summary of experimental results
Cone angle was chosen according to inner boundary of the recirculation zone for different values of $\phi_0$.

Simulations were carried out for atmospheric pressure.

Velocity and temperature distributions inside the combustor

Velocity Vectors Colored By Static Temperature [K]

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FLUENT 6.3 (axi. dp, pbns, ske)
Contours of “burning out” across the combustor length. Blue—unburned region (0), Red—complete reaction field (1).

15 CFD simulation of Lean Premixed Combustor
PSR – perfectly stirred reactor; A – air; F – fuel; Blue region – fresh fuel-air mixture; Red region – burning is completed ($T \geq 0.9 \ T_{ad}$). Burning out exists in Plug Reactor (also red region, $T \geq 0.98 \ T_{ad}$)

(PRE)MIXED FRESH AIR & FUEL

FLAME FRONT (PSR1-10.16)

COMBUSTION PRODUCTS (PSR11-15)

COMBUSTION ZONE

POST-COMBUSTION ZONE (PLUG R.)

Contour of Progress Variable

FLUENT 6.3 (axi., dp; Ens. std)

(CFD) CHEMKIN simulations:
Link between CFD and CHEMKIN

(T $\geq 0.9 \ T_{ad}$)  $T \geq 0.98 \ T_{ad}$)
CO evolution with time in a Plug Reactor

Simulation results of the "lean" combustion.
Conditions:
T_{ad}=1472\,K;\ \Phi_0\, (R1-R16)=0.4962;\ \text{Tair}=300\,K;\ \text{Pair}=1\,\text{atm}\ \tau=20\ \text{ms}

<table>
<thead>
<tr>
<th>Reactor</th>
<th>Reactor</th>
<th>Plug reactor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>T, K</td>
<td>1360</td>
<td>1458</td>
</tr>
<tr>
<td>CO, ppm</td>
<td>9299.0</td>
<td>666.0</td>
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</table>

SIMULATION RESULTS ARE IN SATISFACTORY AGREEMENT WITH EXPERIMENTS.
Effect of fuel fraction on combustion temperature (Elevated pressure)

- The same combustion model was used for elevated pressure.

- Effect of fuel fraction of pilot combustor on the lower limit of temperature which provides stable combustion at $\Phi_1 = 1.5$.
- Lower limit of global equivalence ratio, $\Phi_0$, reduces with increasing fuel fraction at the pilot combustor, hence combustion temperature decreases.

CHEMKIN simulations results
• Effect of fuel fraction at pilot combustor on NO\textsubscript{x} emission (for lower limit of temperature).
• There is an optimal fuel fraction at pilot combustor where NO\textsubscript{x} achieve their minimum.

CHEMKIN simulations results
Elevated pressure
CONCLUSIONS

• It was found that radicals can help to stabilize the combustion process at lean equivalence ratios.

• Radicals’ injection allows operation at lower temperatures which reduces the NO\textsubscript{x} emission and pollution.

• The CHEMKIN model was built according to CFD simulations.

• Distribution of air and fuel flow rates between the PSR reactors and Plug reactor in the CHEMKIN model enables to describe and model the combustion process.
CONCLUSIONS (cont.)

- CHEMKIN simulations confirm that the use of the pilot combustor with high equivalence ratio creates better conditions for stable combustion.

- These results are in satisfactory agreement with experimental data. They can serve as a base for lean premixed industrial combustor simulation and design.

- Further investigations for reducing of the temperature limit of stable combustion should include improvement of the combustion model by taking into account flow recirculation, heat losses, and preliminary mixture heating within the combustor.
THANK YOU FOR YOUR ATTENTION