Applying simulation and additive manufacturing to the development of next generation of hydrogen combustion

Professor Jenny Larfeldt
Senior Combustor Expert
Fundamentals on H₂

Wobbe index

\[ \text{Wobbe-index} = \frac{LHV}{\sqrt{\rho_{rel}}} \]

\[ (\rho_{rel} = \frac{\rho_{gas}}{\rho_{air}}) \]

Heavy hydrocarbons

Standard range NG  WI: 42 to 53 MJ/nm³

120

30/70 H₂/NG  60/40 H₂/NG  90/10 H₂/NG

60/40 H₂/N₂

30/70 H₂/N₂  90/10 H₂/N₂
Fundamentals on H₂ co-firing

H₂ has ten times higher flame speed compared to natural gas.

Co-firing H₂ and CH₄/C₂H₆/C₃H₈
- H₂ < 60 vol-%: slight increase in burning velocity and chemistry hydrocarbon dominated
- 60 < H₂ < 90 vol-% intermediate regime
- H₂ > 90 vol-% dramatic increase in laminar burning velocity and chemistry is hydrogen dominated.

Φ=1.0 and p=3 atm.
Industrial gas turbine
SGT-800 / 57MW core engine

- 30 DLE burners of so called 3rd generation in an annular combustor
- Air entering combustor with about 20 bar and 430°C

Fleet Reliability: 99.6%
Fleet Availability: 97.7%
From fundamentals to real engines 1(3) - Numerical simulations
LES OF HYDROGEN ENRICHED METHANE/AIR COMBUSTION IN THE SGT-800 BURNER AT REAL ENGINE CONDITIONS

From fundamentals to real engines 2(3)
Atmospheric combustion rig test

SIEMENS
Ingenuity for life
From fundamentals to real engines 3(3)
Pressurized single burner test
Additive manufacturing of SGT-600/700/800 standard burner
Rapid prototyping speeds up development

Traditionally manufactured burner front
- 13 machined parts, joined by 18 welds.
- External pilot gas feed
- Weight: 4.5 kg

SLM adapted burner front
- 1 single part
- Pilot gas feed integrated in structure
- Lead time reduction of >75%
- Weight: 3.6 kg

Jenny Larfeldt & Vladimir Navrotsky
Full-scale hydrogen test
SGT-800 string test August 2017, Finspong, Sweden

- 2 test days: 2.8 metric tonnes of hydrogen at 210 bar gas pressure.
- Combustion stability, pulsation levels flashback margin and emissions were continuously monitored at H₂ levels of 20, 30, 40 and 50 vol%.
- NOx emissions was not affected for low H₂ contents, up to 15 vol%. By lowering TIT the gas turbine operated 17 ppm NOx@15%O₂ and can be offered for hydrogen levels up to 30 vol%.
- The gas turbine was operated on 40 and 50 vol% H₂ respectively with emissions below 25 ppm@15%O₂. In practice the NOx penalty will be less significant at part load since H₂ has such stabilizing effect.
Fuel flexibility of Siemens industrial gas turbines

<table>
<thead>
<tr>
<th>Gas Fuel Constituents</th>
<th>SGT-800</th>
<th>SGT-750</th>
<th>SGT-700</th>
<th>SGT-600</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mole%</td>
<td>mole%</td>
<td>mole%</td>
<td>mole%</td>
</tr>
<tr>
<td>Methane, CH4</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Ethane, C2H6</td>
<td>100</td>
<td>70</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Propane, C3H8</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Butanes and heavier alkanes, C4+</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Hydrogen, H2</td>
<td>50</td>
<td>15</td>
<td>55</td>
<td>60</td>
</tr>
<tr>
<td>Carbon monoxide, CO</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Inerts, N2/CO2</td>
<td>50/40</td>
<td>50/40</td>
<td>50/40</td>
<td>50/40</td>
</tr>
</tbody>
</table>

Future work

- SGT-600 test >50 vol% H₂ co-firing (Aug 2018)
- Co-firing H₂ in SGT-800 at Industriepark Höchst, Frankfurt under discussion.
- Burner design for 100% H₂ to be tested (ongoing R&D).
- SGT-750 laboratory scale burner tests for NH₃ / N₂ / H₂ mixtures together with university and oil&gas industry
Siemens DLE Hydrogen Gas Turbines for our sustainable future
THE MISSION; Zero CO₂ emissions with 100% H₂

Hydrogen Capabilities and NOx compliance

✔ SGT-600 → 60% H₂ @ ≤25 ppm NOx
✔ SGT-700 → 55% H₂ @ ≤25 ppm NOx
✔ SGT-800 → 50% H₂ @ ≤25 ppm NOx

Product synergies and long experience

✔ The general geometry of the burners are identical for the SGT-600, 700 & 800
✔ Full string test in SGT-800 @ 100% load, 2017 (≥50%H₂)
✔ High pressure test in SGT-750, 2016
✔ Engine test in SGT-700, 2012 and 2014
✔ SGT-700 continuous operation since Sept. 2014 (>10%H₂)
✔ High pressure and atmospheric tests, 2008, 2009 and 2012

Applications / Customer benefits…

- In Combined cycle BACT* is fulfilled with Siemens DLE Hydrogen products, e.g. 2ppm NOx, CO, and VOC with a SCR
- Power to gas, solar and wind power into H₂ energy storage
- Grid support within 10 minutes up to full load on renewables
- Reduce CO footprint and NOx with 3rd Gen DLE
- Operate on Refinery Fuel Gas with high H₂ content

* Best Available Control Technology

World class leader with Hydrogen in DLE combustion
Thank you for your attention

Professor Jenny Larfeldt
Senior Combustor Expert
PG PR R&D GTP GTI
Slottsvagen 3
612 38 Finspång
Phone: +46 122 82 789
Mobile: +46 70 180 14 147
E-mail: jenny.larfeldt@siemens.com

siemens.com