Fuels, Combustion and Environmental Considerations in Industrial Gas Turbines - Introduction and Overview
AGENDA

Fuels, Combustion and Emissions

- Introduction
- Environmental Impact
- Combustion Systems
- Fuel Types
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Introduction

- Industry requires Energy
  - Electricity
  - Mechanical Power
  - Heat

- Most commonly provided through the combustion of fossil fuels

- Number of technologies can be used
  - Gas Turbines
  - Boiler / Steam Turbines
  - Reciprocating Engines

For this Symposium subjects covered include Fuels and Emissions issues surrounding Gas Turbines
Some of the fluids entering or exiting the gas turbine core or package
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## Environmental Impact

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Effect</th>
<th>Method of Control</th>
</tr>
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<tbody>
<tr>
<td>Carbon Dioxide</td>
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<td>Cycle Efficiency</td>
</tr>
<tr>
<td>Sulphur Oxides</td>
<td>Acid Rain</td>
<td>Fuel Treatment</td>
</tr>
<tr>
<td>Nitrogen Oxides</td>
<td>Ozone Depletion</td>
<td>Combustion System</td>
</tr>
<tr>
<td></td>
<td>Smog</td>
<td></td>
</tr>
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<td>Combustion system</td>
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<td></td>
</tr>
<tr>
<td>Smoke</td>
<td>Visible Pollution</td>
<td>Combustion System</td>
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</table>
Environmental Impact

DLE - Introduction / Drivers

- Improve the environmental impact
- More stringent environmental limits
- Customer goals and requirements
- Improved operational reliability
- Simple design with simple operating philosophy required
- Minimal impact of product cost
- Easy to understand
- Easy to maintain
- Wide fuel range coverage
- Part load capable
NOx Formation

Equivalence ratio $\Phi [-] = 1/excess$ air ratio $\lambda$

- Combustor GT Lean Pre-mix
- Combustor GT Diffusion
- NOx stoichiometric mixing
- NOx real mixing

Flame temperature

$P_{V2} = 16$ bar
$T_{V2} = 400^\circ$ C
$\tau = 20$ ms
Emission Abatement Options

Emissions Abatement

Diffusion Flame

- WI
- SSI
- PSI

Dry Low Emissions

Wet Injection Methods:
WI = Water Injection
PSI = Primary Steam Injection
SSI = Secondary Steam Injection
Combustion

**NOx Impact**

- Diffusion flame
  - Produces high combustor primary zone temperatures
  - NOx is a function of temperature
  - Results in high thermal NOx formation
  - Use of wet injection (Water or Steam) directly into the primary zone
  - Lowers combustion temperature
    - Reduced NOx formation

- Dry Low Emissions
  - Lean pre-mixed combustion
  - Results in low combustion temperature
    - Low NOx formation
  - Low NOx across a wide load and ambient range

![Graph showing NOx Impact](attachment:image.png)

Flame Temperature as a function of Air/Fuel ratio
Environmental Aspects

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<td>DLE System</td>
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- **Combustion Aspects**
  - Diffusion Flame
  - Lean Pre-mix
  - Operability

**Temperature**
- Diffusion Flame (Pressure Jet burner)
  - 1675°C
  - 2175°C
Introduction

Fuels, Combustion and Emissions

- Introduction
- Fuels Types
- Combustion Systems
- Environmental Impact
Combustion

Combustion Systems Available

ANNULAR
- Used on aero engines
- Used on medium and large gas turbines
- Tends not to be site serviceable
- Requires major engine disassembly

CAN-ANNULAR
- Versatile
- Can be changed out at site
- Does not require engine disassembly

SILO
- Used in some medium and large gas turbines
- Can be single or dual combustors
Combustion Arrangements

Reverse Flow

In-Line Flow
Dry Low Emissions
Gas Fuel Injection/Mixing

gas/air mixing due to length of passage
Flame speed
Flame speed is determined by the combustion reaction rates and those rates depend on:

- Equivalence ratio $\phi$
- Fuel type
- Flow regime (laminar or turbulent)

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Max Flame Speed (cm/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane, CH4</td>
<td>37.3</td>
</tr>
<tr>
<td>Ethane, C2H6</td>
<td>44.2</td>
</tr>
<tr>
<td>Propane, C3H8</td>
<td>42.7</td>
</tr>
<tr>
<td>Hydrogen, H2</td>
<td>291.2</td>
</tr>
<tr>
<td>Carbon Monoxide, C,</td>
<td>42.9</td>
</tr>
</tbody>
</table>

Laminar Flame Stability

- If Air flow velocity > Flame speed (SL) Blow off
- If Air flow velocity < Flame speed (SL) Flashback
**Combustion**

**Combustion Types**

- More pilot means greater diffusion flame
  - Higher emissions and pilot temperature
- Less pilot means more premix
  - Less NOx but higher dynamics

![Combustion Diagram]

- High Pilot => High Pilot tip temperature
- Low Pilot => High Combustion Dynamics – “Instability”
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Fuels, Combustion and Emissions

• Introduction
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• Fuel Types
Fuel Type
Various fuel types - Gaseous Fuels

Vol %

Tailgas
Blast furnace
Air blown gasification
Syngas / O2 gasification
Wellhead - Very High Inert (50-85%)
Landfill / digester / sewage / MCV Refinery
Wellhead - High Inert (25-50%)
Coke Oven
H2
NG
NG with H2
LNG
HCV Refinery
Wellhead - High hydrocarbon
HCV Process
LPG

CO2
N2
CO
H2
C3H8
C2H6
CH4
Fuel Parameters
- gaseous fuel

Assessment requirements

- Fuel composition
- Include contamination
- Supply conditions
- Environmental requirements
Evaluation

<table>
<thead>
<tr>
<th>Species</th>
<th>Formulae</th>
<th>Mol %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>CH4</td>
<td>94</td>
</tr>
<tr>
<td>Ethane</td>
<td>C2H6</td>
<td>3.5</td>
</tr>
<tr>
<td>Propane</td>
<td>C3H8</td>
<td>1.2</td>
</tr>
<tr>
<td>Carbon Dioxide</td>
<td>CO2</td>
<td>0.5</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>N2</td>
<td>0.8</td>
</tr>
</tbody>
</table>

Simple things:
- Visual Inspection
  - Anything unusual? Wt%, Mol %, add to 100%, contaminants, …?

Step 2: Complete an assessment using gas analysis methods

- Can see other species that may be present in other fuels
- Calculations shown in lower section – OUTPUT, includes:
  - Lower Calorific (Heating) Value (LCV or LHV)
  - Wobbe Index (WI)
  - Dewpoint
  - Density
Fuel Assessment

**Assessment requirements**

**Wobbe Index (WI) parameter**
- Compares energy input of different gas fuel compositions, and indicates the inter-changeability of gas fuels

**Temperature Corrected Wobbe Index (TCWI)**
- Gas may be heated e.g. due to dew point

\[
WI = \frac{LCV}{\sqrt{sg}}
\]

*Cv = Net Calorific Value  sg = specific gravity*

\[
WI_T = WI_{15} \times \sqrt{\frac{T_{15}}{T_T}}
\]

\[
\Rightarrow WI_T = WI_{15} \times \sqrt{\frac{288}{T_T}}
\]

*Temp in Kelvin*
Gaseous fuels- Assessment

Diagram showing the relationship between pressure, temperature, and the presence of water and hydrocarbon liquids in a gas. The diagram includes:

- **Water Dew point**
- **Dew Points**
- **Water & Hydrocarbon liquids in gas**
- **Hydrocarbon liquids present in gas**
- **Hydrocarbon Dew point**
- **Dry gas**

The graph illustrates how changes in pressure and temperature affect the presence of these liquids and the dew points.
Hydrocarbon Dew Point

Importance of DEW Point

Ensure fuel gas is maintained in vapour phase
Normal to apply superheat margin

Let us look at the reasons for understanding dew point and the need to apply a margin of superheat
Hydrocarbon Dew Point

In the previous example the dew point for a typical pipeline gas fuel is very low so a minimum value is applied – this prevents freezing in the fuel system vent pipework.

Take an example where the C5 species is defined as 1.9%+

Assume all is C5:

\[
\text{Dew Point} = 2.6^\circ C
\]

Replacing C5 with a representative breakdown:

<table>
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<th>Parameter</th>
<th>Mol %</th>
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<tr>
<td>Oxygen, O2</td>
<td>0.37</td>
</tr>
<tr>
<td>Nitrogen, N2</td>
<td>9.54</td>
</tr>
<tr>
<td>Carbon Dioxide, CO2</td>
<td>8.00</td>
</tr>
<tr>
<td>Methane, C1</td>
<td>73.17</td>
</tr>
<tr>
<td>Ethane, C2</td>
<td>3.91</td>
</tr>
<tr>
<td>Propane, C3</td>
<td>1.91</td>
</tr>
<tr>
<td>Butane, C4</td>
<td>1.14</td>
</tr>
<tr>
<td>Propane+; C5+</td>
<td>1.96</td>
</tr>
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Revised dew point \(52.5^\circ C\)

This demonstrates the importance of providing and using the correct fuel composition.

Incorrect dew point – hence incorrect supply conditions – results in gas condensate and impact on turbine operation.
A brief overview in the use of fuels in a gas turbine and impact on the environment

Method of assessment and why it is important to declare as early as possible the full details of the composition

Combustion systems types and why DLE, DLN systems dominate new equipment sales

Aspects of Siemens Energy standard combustion system detailed

THANK YOU FOR YOUR ATTENTION