IMPACT OF FUEL CONTAMINANTS ON GAS TURBINE OPERATION

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IMPACT OF FUEL CONTAMINANTS ON GAS TURBINE OPERATION

- **Agenda**
  - Introduction
  - Fuel Types & Composition
  - Fuel Contaminants
  - Impact of contaminants
    - Engine operability – eg performance
    - Engine component life
Gas Turbine Installation
Sources of Contamination

- Combustion Air
- Ventilation Air
- Lubricating Oil – through cooler
- Compressed Air
- Exhaust Gas
- Gas and Liquid Fuels
Gas Turbine Installation
Sources of Contamination

Combustion
Air

Gaseous / Liquid fuels
Air Filtration

- Air filtration is a major topic in owns right
- Ensure design meets requirements for local environment
- Understand local issues
- Minimise break through of Particulate matter
- Reduces compressor degradation; pre-cursor to reduction in turbine power output
Air Filtration

- Air filtration is a major topic in owns right
- Ensure design meets requirements for local environment
- Understand local issues
Most applications specify good quality natural gas
- Some specify fuels with increasing inert content
- Fuels may contain higher hydrocarbons, or other burning components, eg hydrogen and carbon monoxide

Range of gaseous fuels starting with very weak fuels, eg blast furnace gas to very rich LPG type (i.e., contain high hydrocarbon species)
- Does not cover the whole story …
Fuel Sources

- Associated gas
- Non-associated gas
- Shale gas
- Besides the main gas constituent Methane, all can contain a variety of other species:
  - Higher hydrocarbons, ethane, propane, …
  - Inert species
  - Can be sour ie contain H2S and CO2
- Well head gas fuels contain contaminants
Fuel Contamination

- Pipeline quality gas is clean and dry and provided to tight specifications.
- For other gaseous fuels this is often not the case.
- Need to understand fuel composition, with reference to:
  - non ‘burnable’ species
  - other burnable species
- “Contaminants” often seen include:
  - Water
  - Non combustible diluents eg nitrogen, carbon dioxide …
  - Halogenated components/compounds
  - Alkaline metals
  - Hydrogen / Carbon monoxide
  - …
Impact of contaminants 1
diluent species

Nitrogen / Carbon dioxide

- Often found:
  - well head gases
  - Bio-gas from de-composition / fermentation of waste
    - Landfill gas
    - Anaerobic digester
    - Waste water treatment process

- For same volume flow lower energy content, hence to achieve same energy content higher flow rate necessary
- May require change to combustor geometry to accommodate increased flow rate without impacting system or combustion pressures

![Graph showing Wobbe and CO2 or N2 content of UK Natural Gas](image)
Impact of contaminants 2
water

- Water can be specified as part of the gas composition
- Maybe implicit by virtue of saturated gas

- Impact of water on dew point, hence supply temperature
- Necessary to provide gas at a suitable margin above dew point – minimum supply temperature
- Increased supply temperature reduces heating value
- Hydrate formation
- Corrosion impact
- May contain water soluble contaminants
Impact of contaminants 3.1
higher hydrocarbons

- Hydrocarbons other than methane
  - Ethane
  - Propane
  - Butane
  - Pentane

- Have an impact on hydrocarbon dew point, hence supply temperature
- Flame velocity increase
- Potential for ‘auto-ignition’
Impact of contaminants 3.2
higher hydrocarbons

- Auto ignition Temperature
- Lowest temperature where a hydrocarbon can spontaneously ignite
- Generally faster and more intense combustion affecting:
  - flame stability and combustion dynamics
  - flame position and the risk for flashback, temperature distribution in the combustion system
  - emissions of NOx and CO
  - behaviour of the engine control system
Impact of contaminants 4.1
other burnable species

- Hydrogen
- carbon monoxide

Highly reactive
- Impact on flame velocity
- Permitted levels differ with combustion types (less permitted in, for example, lean pre-mix combustor)

Flame speed vs fuel type

<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><strong>291.2</strong></td>
</tr>
<tr>
<td>Carbon Monoxide, CO</td>
<td>42.9</td>
</tr>
</tbody>
</table>

Flame speed determined by the combustion reaction rates and depend on:
- Equivalence ratio $\phi$
- Fuel type
- Flow regime (laminar or turbulent)
Impact of contaminants 4.2
other burnable species

Flashback and Blow-off

- If the flame speed does not match the flow speed of the reactants, the flame front will move.
- If the flame speed is too high, you can get flashback (flame moving upstream towards the fuel injection).
- If the flame speed is too low, you can get blow-off (flame pushed downstream).

\[ U_{\text{flow}} = U_{\text{flame}} \]

Stable flame

- CAN FLAME FAILURE
- ENGINE STOP
Impact of contaminants 5.1
other contaminants

- Hydrogen Sulphide, H$_2$S (Sour Gas)
- Gaseous fuels typically as H$_2$S or mercaptans
- Liquid fuel elemental sulphur or mercaptans

General observations
- poisonous even in small quantities
- relatively benign to a turbine combustion system
- ‘what goes in comes out’: Fuel treatment may be required
  - SO$_x$ is regulated around the World
- with water can result in the formation of acids
- H$_2$S + O$_2$ + H$_2$O = H$_2$SO$_3$ &/or H$_2$SO$_4$ (Acid Rain)
- presence of Na + K = sulphates; highly corrosive to nickel based turbine materials; high chromium content material better
- Presence of Va = complex corrosive vanates
- Sulphur may also be present in air!
Impact of contaminants 5.2
Sulphidation

- Where Fuels contain sulphur such as Hydrogen Sulphide
- Can result in accelerated corrosion (and oxidation) damage to critical turbine components
- Local fuel treatment may be necessary to achieve defined component life

- Possible Sulphur corrosion attack
Impact of contaminants 6
Other sources

- Biogas
  - de-composition / fermentation of waste
    - Landfill gas
    - Anaerobic digester
    - Waste water treatment process
- Inert Species (slide 9)
- Can also contain H2S (slides 16, 17)
- May contain silica type compounds, generally referred to as Siloxanes

- Siloxane:
  - Converts to Silica Oxides in combustion process
  - Sublimes onto turbine blades
  - Results in performance degradation
Liquid Fuels
- All models able to operate on high quality liquid fuels such as diesel and kerosene
  - Emissions abatement available either from “dry” (DLE) or “wet” (WLE) depending on gas turbine model
- SGT-500 able to operate on poor quality liquid fuels such as HFO and crude oil
  - Up to kinematic viscosities of around 1000cSt @ 50°C
Liquid fuel Challenges

- **Carbon Residue**
  - Carbon Residue is the percentage of coked material remaining after a sample of fuel has been exposed to high temperatures
  - Indicates:
    - The tendency of fuel to form carbon deposits during combustion
    - Complexity of hydrocarbon constituents in the fuel
    - Difficulty in combusting the fuel and time for complete combustion
    - Affects ability to operate at low loads
  - High CR content may require start-up on a more conventional fuel

- **Alkali metals**
  - Dissolved in water present in the fuel
  - Create corrosive constituents during combustion; deposit on hot components
  - Remove by water washing / centrifuging

- **Heavy metals (Vanadium etc)**
  - Dissolved in the oil itself
  - Create corrosive constituents during combustion; deposit on hot components
  - Corrosive effect reduced by chemical dosing (magnesium-based inhibitors)

- **Water**
  - Free water leads to corrosion and fuel degradation; encourages microbial growth that produces a corrosive slime
  - Employ correct fuel storage and handling system design
- **House keeping / storage**
  - **Quality control procedure**
    - Fuel specification
    - Cleanliness
    - Monitoring / recording
- **Delivery**
  - Tankers used for same fuel
  - No cross contamination
- **Storage**
  - Receiving and settling tanks
  - Centrifuge, filter, coalescer fitted to minimise impact of water and particulate matter
- **Forwarding**
  - Day tanks
  - Fine filtration (polishing) applied to each tank

### Property Unit Specification Test

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Specification</th>
<th>Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cetane Number</td>
<td></td>
<td>52 – 54</td>
<td>ISO 5165</td>
</tr>
<tr>
<td>Density @15°C kg/m³</td>
<td></td>
<td>833 – 837</td>
<td>ISO 3675</td>
</tr>
<tr>
<td>Distillation (vol. % recovered) °C</td>
<td></td>
<td></td>
<td>ISO 3405</td>
</tr>
<tr>
<td>- 50% point</td>
<td>°C</td>
<td>245 –</td>
<td></td>
</tr>
<tr>
<td>- 95% point</td>
<td>°C</td>
<td>345 – 350</td>
<td></td>
</tr>
<tr>
<td>- final boiling point</td>
<td>°C</td>
<td>- 370</td>
<td></td>
</tr>
<tr>
<td>Flash point °C</td>
<td></td>
<td>55 –</td>
<td>EN 22719</td>
</tr>
<tr>
<td>CFPP °C</td>
<td></td>
<td>- – -5</td>
<td>EN 116</td>
</tr>
<tr>
<td>Viscosity @40°C mm²/s</td>
<td>m²/s</td>
<td>2.5 – 3.5</td>
<td>ISO 3104</td>
</tr>
<tr>
<td>Polycyclic aromatic hydrocarbons % wt.</td>
<td>%</td>
<td>3 – 6</td>
<td>IP 391, EN 12916</td>
</tr>
<tr>
<td>Sulfur contenta mg/kg</td>
<td>mg/kg</td>
<td>- – 300*</td>
<td>ISO/DIS 14596</td>
</tr>
<tr>
<td>Copper corrosion Class 1</td>
<td></td>
<td>-</td>
<td>ISO 2160</td>
</tr>
<tr>
<td>Conradson carbon residue (10% DR) % wt.</td>
<td>%</td>
<td>- – 0.2</td>
<td>ISO 10370</td>
</tr>
<tr>
<td>Ash content % wt.</td>
<td>%</td>
<td>- – 0.01</td>
<td>ISO 6245</td>
</tr>
<tr>
<td>Water content % wt.</td>
<td>%</td>
<td>- – 0.05</td>
<td>ISO 12837</td>
</tr>
<tr>
<td>Neutralization (strong acid) number mg KOH/л</td>
<td></td>
<td>- – 0.02</td>
<td>ASTM D974-95</td>
</tr>
<tr>
<td>Oxidation stability mg/ml</td>
<td>mg/ml</td>
<td>- – 0.025</td>
<td>ISO 12205</td>
</tr>
</tbody>
</table>

* sulfur limit of 50 mg/kg effective 2005 (Euro 4)

- a - the actual sulfur content must be reported

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**Designation: D2880 – 03 (Reapproved 2010)**
- **Receiving and settling tanks**
  - Floating Suction
  - Sloping bottom
  - Water / Sediment take off-point / drain
  - Centrifuge, filter, coalescer fitted to minimise impact of water and particulate matter

- **Settling / Day Tank (if used)**
  - Design as for main tank, including all best practice features
  - “Polishing” system comprising aspects such as centrifuge, filter
  - Polishing applied regularly to ensure water/particulate kept to minimum acceptable level
## Fuel Contamination Issues

<table>
<thead>
<tr>
<th>Operational concern</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Solids in gas fuel</strong></td>
<td>➢ Wear of fuel system component</td>
</tr>
<tr>
<td>➢ Scale, rust, sand, dirt, weld splatter, grit blast</td>
<td>➢ Valve failure to seat increased leakage</td>
</tr>
<tr>
<td>➢ From old poorly maintained pipe system</td>
<td>➢ Corrosion and wear of fuel injector</td>
</tr>
<tr>
<td>➢ From new or modified fuel system</td>
<td>➢ Erosion of fuel/combustion components</td>
</tr>
<tr>
<td></td>
<td>➢ Build up of debris in gas passageways - impaired operation</td>
</tr>
<tr>
<td><strong>Heavy Hydrocarbons as liquids</strong></td>
<td>➢ Can drop out in fuel system, resulting in poor fuel control</td>
</tr>
<tr>
<td>➢ Incorrect process control</td>
<td>➢ Carried in combustion resulting in uncontrolled combustion - explosions, flashback</td>
</tr>
<tr>
<td>➢ Not present in pipeline quality gases</td>
<td>➢ Abnormal distribution and localised hot gas path component damage</td>
</tr>
<tr>
<td>➢ Incorrect temperature for fuel dew point</td>
<td>➢ Coking of fuel burner passages and mal distribution</td>
</tr>
<tr>
<td>➢ Over fuelling (uncontrolled)</td>
<td>➢ Abnormal temperature spread, as seen in exhaust / interduct thermocouples</td>
</tr>
<tr>
<td></td>
<td>➢ Adverse impact on performance and emission targets</td>
</tr>
<tr>
<td><strong>Water in gas fuel</strong></td>
<td>➢ Ice &amp; Hydrates can cause valve failure</td>
</tr>
<tr>
<td>➢ Affinity of other contaminant - eg sodium, calcium etc</td>
<td>➢ Corrosion of pipe system and valve</td>
</tr>
<tr>
<td>➢ Acid formation</td>
<td>➢ Corrosion of hot turbine components</td>
</tr>
<tr>
<td>➢ Formation of Hydrates</td>
<td>➢ Poor combustion operation, including loss of flame</td>
</tr>
<tr>
<td>➢ At low temperature can freeze resulting in pipe blockage and reduced gas flow</td>
<td>➢ Unstable operation</td>
</tr>
<tr>
<td>➢ ingestion of liquids into combustion with consequential damage</td>
<td></td>
</tr>
<tr>
<td>Operational concern</td>
<td>Effect</td>
</tr>
<tr>
<td>--------------------</td>
<td>--------</td>
</tr>
</tbody>
</table>
| **Gas Fuels containing Hydrogen Sulphide, H2S** | ➢ Harmful to personnel  
➢ Can result in hot gas component erosion  
➢ Sulphidation attack on some materials  
➢ Increased component attack in the presence of other contaminants, such as Sodium |
| ➢ Poisonous even in small quantities  
➢ Flammable  
➢ Acidic when water present  
➢ Corrosive | |
| **Gas Fuels containing Carbon Dioxide, CO2** | ➢ Reduced output for same volume input (lower heating value)  
➢ Increased supply pressure  
➢ Combustor passage size increase |
| ➢ Acidic when water present  
➢ Lowers effective heating value of fuel | |
| **Gas fuels containing Hydrogen, H2** | ➢ Leakage of pipe work - consider regulations - eg Group 2C approval  
➢ Explosive  
➢ System design - flange joints and seals - embrittlement |
| ➢ Increased flammability  
➢ Explosive | |
| **Gas fuels containing Carbon Monoxide, CO** | ➢ Harmful to personnel  
➢ Flashback results in damage to combustion components |
| ➢ Poisonous  
➢ Exacerbates flame velocity, especially if H2 present  
➢ Flash back | |
Summary / Key Take Aways

- Take a holistic view when understanding the use of gas turbines
- Understand all sources likely to influence GT operation
- Maximise reliability and availability by working closely with customers
- Understand customers need
- Provide help and advice as early as possible

Gas Turbine OEM’s are there to help