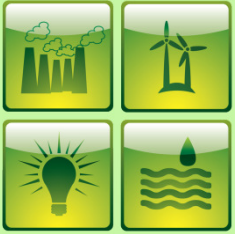




Land Based Gas Turbines Emissions Regulations and Measurement Methods

Hydrocarbons

Laura Platt
University of Sheffield
E-Futures DTC
Email: dtp09lcp@sheffield.ac.uk



E-Futures

Overview

- **Gas Turbines**
- **Atmospheric Hydrocarbon Pollutants**
 - Speciation
 - Health Implications
 - Environmental Impacts
- **Legislation and Control**
 - Gas Turbine Emissions
 - Ambient Air Quality
- **Emissions Measurement**
 - Instrumentation
 - Limits of Detection
 - Suitability for Gas Turbines
- **Use of Alternative Fuels**

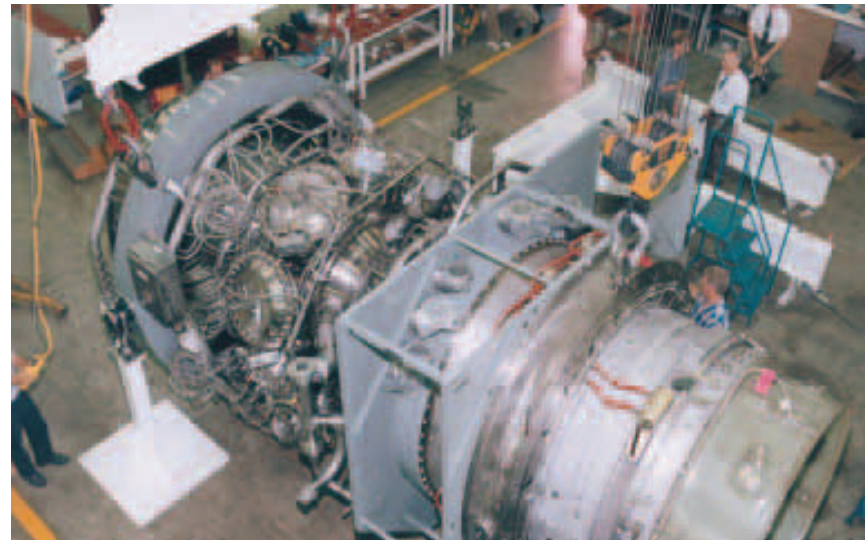


Fig 1. Rolls Royce Trent 60 Gas Turbine.

Source: http://www.rolls-royce.com/Images/trent60_brochure_tcm92-10920.pdf

Gas Turbines

- Stationary Gas Turbines are used for power generation. Gas Turbines are also used in aircraft and ships.
- Gas Turbines are used at Combined Cycle Power Stations.

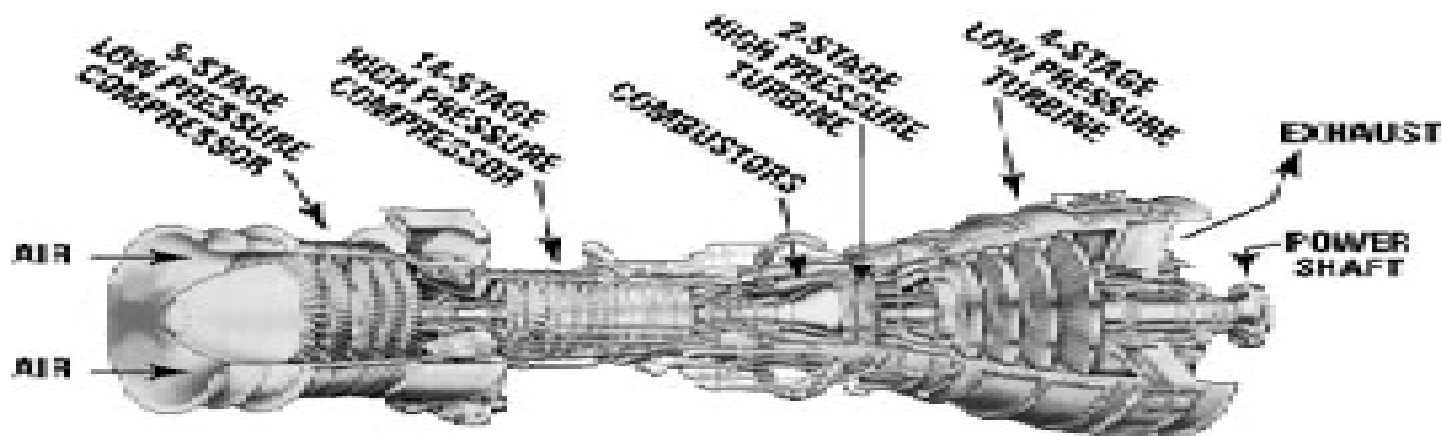


Fig 2. Gas Turbine. Source: <http://files.asme.org/IGTI/101/13001.pdf>



Hydrocarbons

- Anthropogenic and Biogenic Sources.
- Volatile Organic Compounds.
- Polycyclic Aromatic Hydrocarbons.
 - Benzo[a]pyrene.
 - Benzo[a]anthracene.
- Carbonyl Compounds.
 - Formaldehyde.
- Contribution to Ozone Formation.

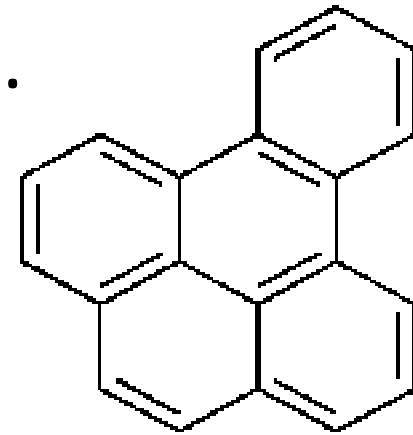
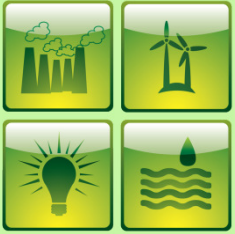


Fig 3. Benzo[a]pyrene. Source: <http://www.pnas.org/content/101/6/1433/F1.large.jpg>



Health and Environment

- Some hydrocarbon compounds are known carcinogens and mutagens, for example:
 - Benzene.
 - Benzo[a]pyrene.
 - Formaldehyde.
 - 1,3 Butadiene.
- The detrimental effects of certain hydrocarbon compounds has been widely investigated.
- Hydrocarbon compounds in the troposphere can undergo photochemistry to create ozone, which is a controlled atmospheric pollutant.
- Excess hydrocarbons in the environment can be detrimental to ecosystems and be toxic to marine life and terrestrial habitats.



E-Futures

Legislation

- Legislation for Stationary Gas Turbines mainly covers:
 - NO_x
 - SO_2
 - Particulates, PM_{10}
- Many hydrocarbon compounds referred to as Hazardous Air Pollutants (USA) or Air Toxics (UK), known carcinogens.
- Currently, anthropogenic hydrocarbon emissions are mostly dealt with as part of ambient air quality directives and as part of industrial processes emissions limitations, for example manufacturing and solvent use.
- United Nations (1979) Convention on Transboundary Air Pollutants.
- Industrial best practice and Maximum Achievable Control Technology (MACT) indications of acceptable emissions levels.



Exhaust Gas Measurement

- Requirements for a suitable technique:
 - minimal interference from other exhaust gases.
 - Complex mixture of gaseous and particulate species.
 - suitable for high temperature testing $\geq 500^{\circ}\text{C}$.
 - Reliable at low limits of detection, ppm and ppb.
 - Response Time.
 - Cost.
 - Speciation.
- On line and collection sampling methods:
 - Exhaust probes.
 - Absorbent collection for later analysis.
 - Laser analysis of exhaust gases.



Volatile Organic Compounds

- Gas Chromatography.
- High Performance Liquid Chromatography.
- Proton Transfer Reaction Mass Spectroscopy.
- Fourier Transform Infrared Spectroscopy.
- Resonance Enhanced Multiphoton Ionization – Time of Flight Mass Spectrometry.
- Differential Optical Absorption Spectroscopy.



Fig 4. Portable BTEX analyser. Source: <http://www.photovac.com/PetroPRO.aspx>



Carbonyl Compounds

- Absorbent methods analysed with HPLC.
 - EPA method TO-11A, Formaldehyde.
- Chemiluminescence.
- Tunable Diode Laser Absorption Spectroscopy.
- Flow Injection Analysis using a Chromatomembrane Cell, Spectrophotometer/Fluorometer.
- Biosensors.
- Gas Chromatography.
- Fourier Transform Infrared Spectroscopy.

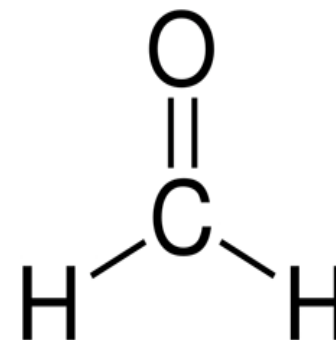


Fig 5. Formaldehyde. Source: http://www.edinformatics.com/interactive_molecules/3D/formaldehyde_molecule.htm



Alternative Fuels

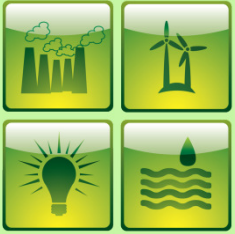
- Alternative fuels including bioethanol, biodiesel and synthetic fuel have become the focus of much interest due to the finite nature of fossil fuels.
- Any change in fuel stream may have an impact on the hydrocarbon species present in exhaust gases.
- Ballesteros *et al* (2008) observed that carbonyl emissions are higher in engines fuelled with biodiesel. See also, He *et al* (2009).



Fig 6. Jatropha Crop. Source: <http://www.agricultureinformation.com/mag/wp-content/uploads/2009/01/jatropha-cultivation.gif>



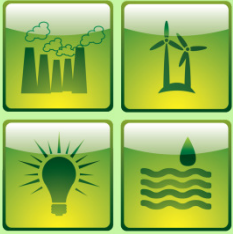
Fig 7. Virgin Atlantic Flight fuelled in part by Coconut and Brazilian Babassu. Source: <http://news.bbc.co.uk/1/hi/uk/7261214.stm>



E-Futures

Conclusions

- There are numerous measurement techniques to analyse the concentration of hydrocarbon compounds within exhaust plumes and ambient air. The work detailed here is not exhaustive.
- The reliability, cost and suitable limits of detection need to be considered when choosing an appropriate technique.
- Techniques which can determine multiple species may be more cost effective long term.
- Legislation regarding stationary gas turbines may undergo change in the coming years, possibly making hydrocarbon emissions limits more stringent.
- Alternative fuels for use in stationary gas turbines may become attractive, the species of hydrocarbons in exhaust emissions may change, requiring changes in exhaust emission measurement technique, turbine components and legislation.



References

- Arrigone, G.M., Hilton, M. (2005) **Theory and Practice in using Fourier Transform Infrared Spectroscopy to Detect Hydrocarbons in Emissions from Gas Turbine Engines.** Fuel. 84, pg 1052-1058.
- Axelsson, H., Eilard, A., Emanuelsson, A., Galle, B., Edner, H., Ragnarson, P., Kloo, H. (1995) **Measurement of Aromatic Hydrocarbons with the DOAS Technique.** Applied Spectroscopy. 49(9), pg 1254-1260.
- Ballesteros, R., Hernandez, J.J., Lyons, L.L., Cabanas, B., Tapia, A (2008) **Speciation of the Semivolatile Hydrocarbon Engine Emissions from Sunflower Biodiesel.** Fuel. 87, pg 1835-1843.
- Correa, S.M., Arbilla, G. (2006) **Aromatic Hydrocarbons Emissions in Diesel and Biodiesel Exhaust.** Atmospheric Environment. 40, pg 6821-6826.
- Environmental Protection Agency [online] **EPA Method TO-11A Determination of Formaldehyde in Ambient Air Using Adsorbent Cartridge Followed by High Performance Liquid Chromatography (HPLC) [Active Sampling Methodology]** Available From: <<http://www.epa.gov/ttnamti1/airtox.html>>
- Gullet, B., Touati, A., Oudejans, L. (2008) **Use of REMPI-TOFMS for Real Time Measurement of Trace Gas Aromatics during Operation of Aircraft Ground Equipment.** Atmospheric Environment. 42, pg 2117-2128.
- He, C., Ge, Y., Tan, J., You, K., Han, X., Wang, J., You, Q., Shah, A.N. (2009) **Comparison of Carbonyl Compounds Emissions from Diesel Engine Fuelled with Biodiesel and Diesel.** Atmospheric Environment. 43, pg 3657-3661.
- Slawinska, D., and Slawinski, J (1975) **Chemiluminescent Flow Method for Determination of Formaldehyde.** Analytical Chemistry. 47(13), pg 2101-2109.
- United Nations (1979) **Convention on Long Range Transboundary Air Pollution.**