Alternative Aviation Fuels – Aromatics & Thermal Stability

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Aviation Fuel

- Aviation kerosene is a multi-component fuel of carbon chains of C8-C16.
- The most common two commercial fuels are Jet A and Jet A-1 which are produced to a standardized international specification.
- Generally contains[1]:
  - 70% – 85% normal/iso/cyclic alkanes.
  - 8% – 25% aromatic species.
  - Heteroatomic species at parts between a thousand and a million.
    - Oxygen containing compounds such as phenols, hydroperoxides.
    - Sulphur containing compounds such as thiols, sulphides, disulphides, benzothiophenes and dibenzothiophenes.
    - Nitrogen containing compounds such as anilines, pyridines, indoles, amines and carbozoles.

Why Alternatives?

- Current aviation emissions are 2-3% of the total anthropogenic emissions.[2]

- The industry is projected to grow at around 3-4% per year. [3]

- Although emissions aren't as high as other sectors there is particular concern due to the CO_2 being released high in the atmosphere.

- Concern about the security of supply – oil prices increased fivefold from 2003-2008 and there are concerns about stability in oil rich countries as well as peak oil.

Gas-to-liquid Fuels

- Synthetic fuel derived from syngas using the Fischer-Tropsch process.

$$nCO + \left(n + \frac{m}{2}\right) H_2 \rightarrow C_n H_m + nH_2O$$

- Current GTL comes from natural gas sources but has potential to provide a carbon neutral biomass-to-liquid fuel.

Gas-to-liquid Fuels

- GTL fuel is almost 100% normal/iso alkanes with zero aromatic content.

- Nitrile o-rings swell in the presence of aromatic compounds within the fuel.[4]
- Significant concern that without this swelling the ageing seals would fail.

- If GTL is to be used as ‘drop-in’ fuel we require an aromatic additive; but how would affect the thermal stability...

Thermal Stability

- The thermal stability of a fuel is the ability of a fuel to act as a heat sink without the creation of insoluble deposits.

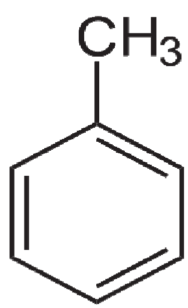
- In a jet engine, before combustion, the fuel is heated through various heat exchangers to remove heat from aircraft subsystems.

- This heat leads to the formation of insoluble deposits which can plug the narrow passageways found in fuel systems and in extreme cases, lead to component failure.

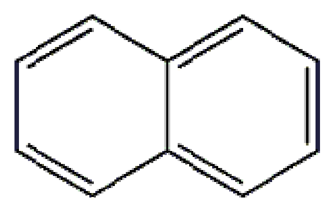
- The exact mechanisms that leads to the creation of deposits is unknown but it widely attributed to the aromatic and heteroatomic species within the fuel.

Aromatic Additives

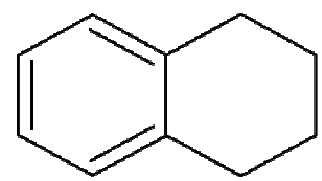
- Selected aromatic molecules to provide a baseline against future studies.



Toluene



Naphthalene



Tetralin

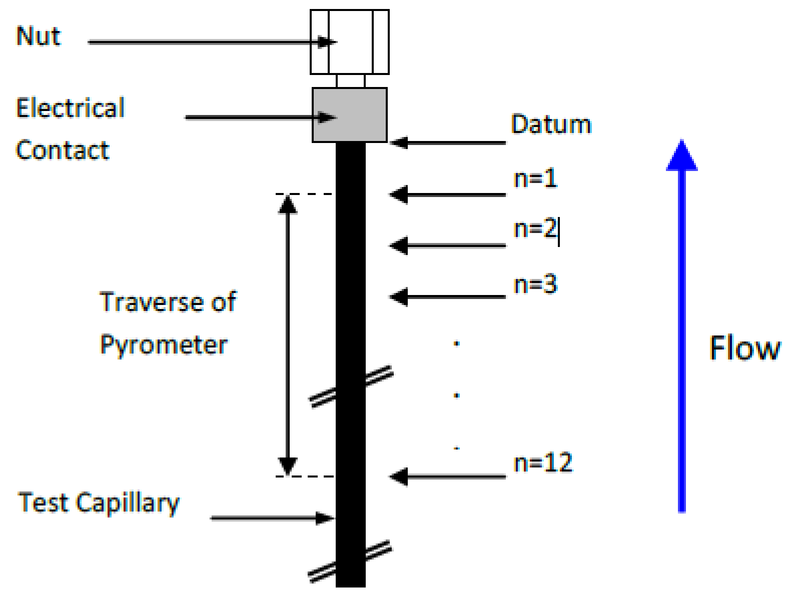
- These aromatic additives were added to a GTL provided by Shell and their thermal stability tested using the HiReTS method.

HiReTS Method

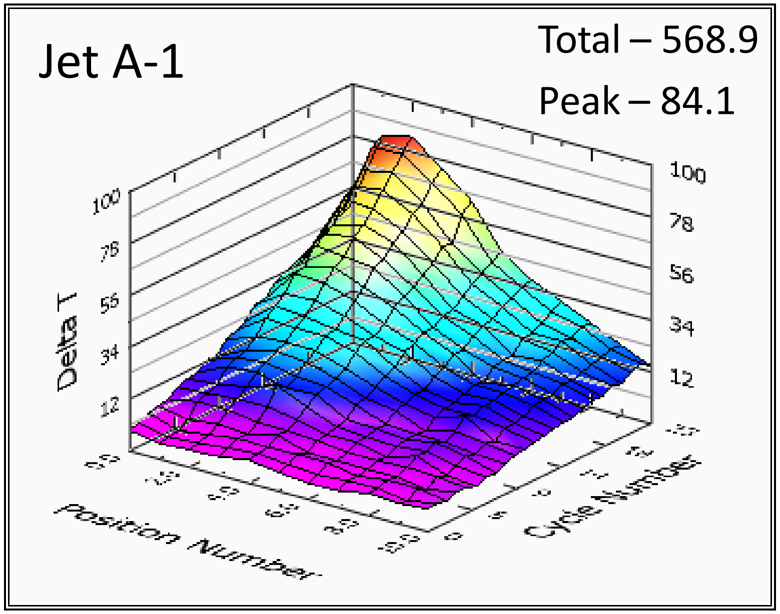
- The High Reynolds Number Thermal Stability (HiReTS) test provides a quantitative analysis of the thermal stability of aviation fuel under turbulent conditions.

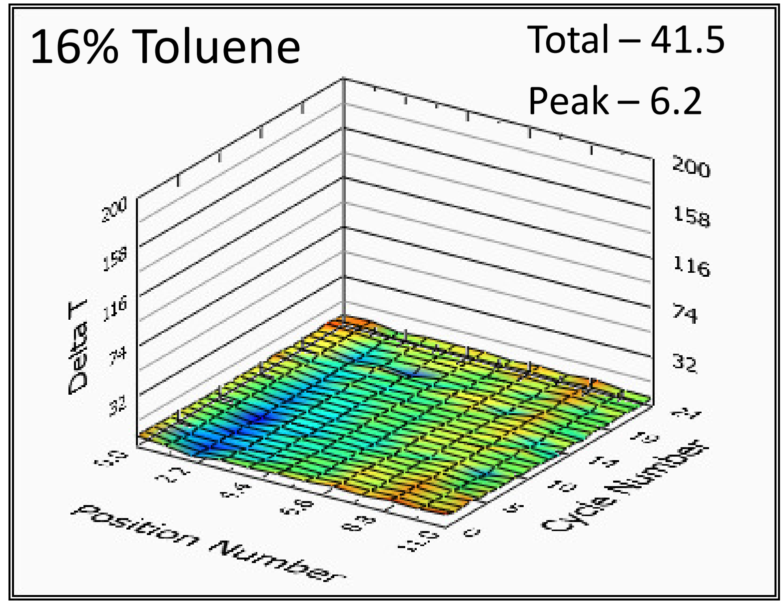
$$\text{HiReTS Total Number} = \sum_{n=1}^{n=12} \Delta T_{FINAL} - \Delta T_{MIN}$$

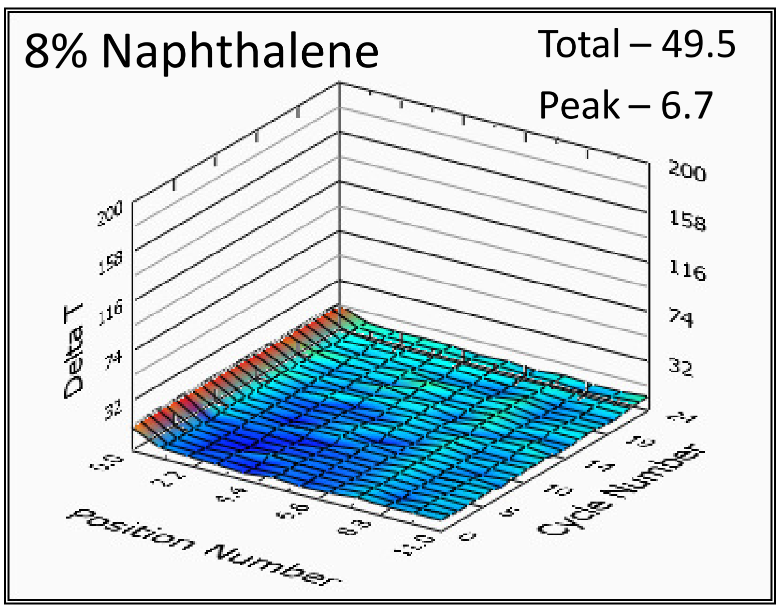
$$\text{HiReTS Peak Number} = (\Delta T_{FINAL} - \Delta T_{MIN})_{n=\max \Delta T}$$

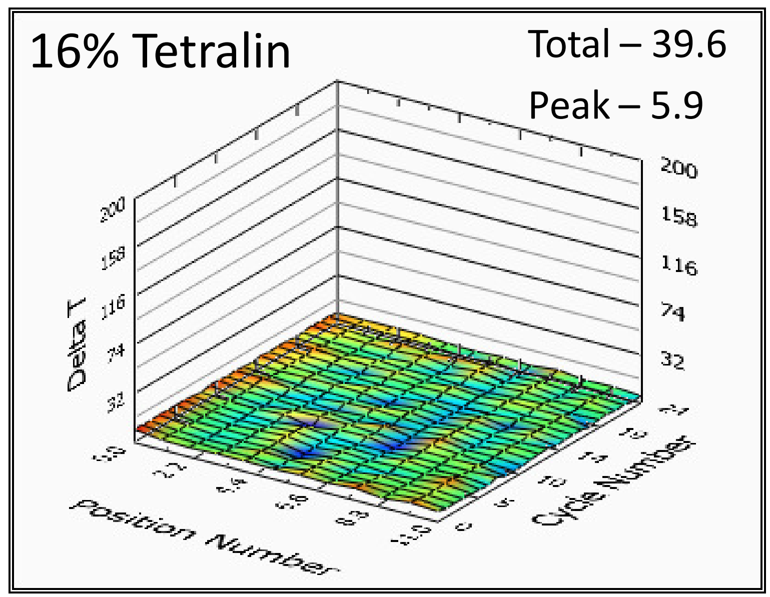


HiReTS Results









Conclusions and Further Work

- Lack of insoluble deposits shows that it is not simply the aromatics that lead to poor thermal stability.

- For potential use as an aromatic additive this is advantageous as thermal stability is unaffected.

- The next step is to study the role of heteroatomic species such as hydroperoxides and sulphur containing compounds in deposit formation.

References

[1] CRC, Handbook of Aviation Fuels, Society of Automotive Engineers 2004

[2] J. Penner, D. Lister, D. Griggs, D. Dokken, M. McFarland (Eds.), 1999, *Aviation and the Global Atmosphere*, Cambridge University Press,

[3] International Civil Aviation Organization, Environmental Report 2010

[4] J. L. Graham et al., 2006, 'Swelling of Nitrile Rubber by Selected Aromatics Blended in a Synthetic Jet Fuel', *Energy Fuels*, 20:2 p759-765