Lube 2018

ISSN 1744-5418

THE EUROPEAN LUBRICANTS INDUSTRY MAGAZINE ISSUE No. 143 February 2018

The official journal of UEIL

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Lube Magazine's 30th Anniversary

Aviation derived ester technology for the industry

How performance esters for industrial lubrication have taken advantage of the development of aviation lubricants

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The challenges of jet engine lubrication

Aircraft gas turbine oils are used in aircraft engines to lubricate and cool the bearings of the compressor and turbine shafts. The main constraint placed upon the oil is the extreme thermal and oxidative stress, due to the fact that the bearings are located in the core of the engine, and are directly exposed to the heat radiated by the flow of hot compressed air (in the compressor section) and the combustion gases (in the turbine section). The temperature of the compressed air typically exceeds 350°C at the outlet of the high pressure compressor, and the turbine inlet temperature exceeds 1200°C. Whilst some thermal insulation and sophisticated cooling techniques (using relatively cool air blanketing) are in place to protect the bearing chambers from such extreme temperatures, the oil temperature in the bearings is continuously in the range of 200 to 230°C. The heat dissipated by friction in the bearings is also a significant contributor to the generated heat.

The thermal stress on the oil can also be greatly increased by inadequate engine shut-down procedures. A sudden shut-down, without any idling period, cuts off the supply of circulating oil and cooling air in the bearing chambers. At this point, the heat accumulated in the hot engine parts (blades, vanes) will sharply increase the temperature of the bearing chamber up to 340°C, leading to a rapid oxidation and, eventually, coking of the residual quantity of oil in the bearing chamber.

Jet Engine - 24,000 h

Standard performance oil (STD)

High temperature oil (HTS)

Formation of coke is therefore a major concern, as coke build-up may eventually block pipes or oil injection nozzles, leading to engine failure and a potentially catastrophic fate for the aircraft. Not surprisingly, the improvement of thermal and oxidative stability has been a constant focus of aviation oil manufacturers over the past decades.

Low temperature viscosity is also an important requirement, because during the certification process, aircraft and engines must demonstrate their ability to start at temperatures as low as -40°C. For this reason, the maximum viscosity at -40°C of aviation oils is limited to 13,000 mm^2/s. Some military aircraft have a more demanding requirement: to operate at -54°C, in which case a lower viscosity oil, complying with MIL-PRF-7808 Gr.3, is used.

Advances in commercial engine technology enable airliners engines to operate for a very long period of time - as much as 40,000 h (more than 10 years) under certain conditions – without any oil drain. In contrast, military engines are operated for a much shorter period of time, but in very high power and temperature conditions.

The advantages of neopolyol esters

In order to comply with such extreme requirements, aviation turbine oils use very carefully selected and manufactured high performance components. They are typically composed of high quality polyol ester base fluid (93 to 95%), and anti-oxidant, anti-wear and corrosion inhibiting additives (5 to 7%).

Earlier generation jet engine oils, especially for military engines, were based on diesters, i.e. esters of diacids. Diesters of sebacic acids, in particular, have been used as base fluids for the MIL-PRF-7808 Grade 3 turbine oils. However, diesters break down through the ß-elimination mechanism to olefins and acids, because of the presence of a hydrogen atom on their alcohol

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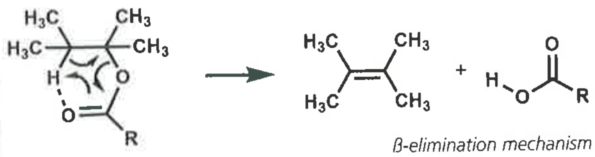
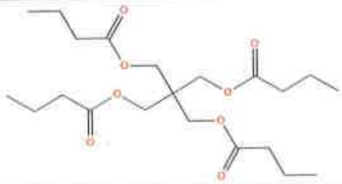
chain, in the beta position. Neopolyol esters do not have any ß-hydrogen in their molecules, so they decompose at a much higher temperature (320 to 340°C), while diesters decompose at about 280°C. Due to their poorer thermal stability, diesters have been dropped and replaced by neopolyol esters. Neopolyol esters are the only base fluids that deliver the thermal and oxidative stability, lubricity, cleanliness and low temperature behavior required for jet engine lubrication.



ß-elimination mechanism



Neopolyol ester

Four neopolyols are commonly used to produce such esters: neopentyl glycol (NPG), trimethylol propane (TMP), monopentaerythritol (MPE), and dipentaerythritol (DPE). They are all synthetic polyols made from methanol, ethylene and propylene. The possible use of several polyols and acids blends during esterification allows chemists to design in a very flexible way the structure showing the desired properties in terms of rheology, volatility, lubricity, thermo-oxidative stability, cleanliness... The most commonly used acids have 5 to 10 carbon atoms.

Optimising and controlling the performance of neopolyol esters

Neopolyol esters components may be selected from a variety of neopolyols and acids (short chains, long chains, linear, branched) that will greatly impact rheology, volatility, thermo-oxidative stability, cleanliness, lubricity and elastomer compatibility – sometimes in a conflicting manner. Optimising performance and reaching the best compromise requires careful engineering work to design the chemical structure that will meet technical requirements.

However, not all esters are alike even though they may display chemically identical structures. In particular, carefully selecting raw materials is essential to warrant performance as they may contain traces of impurities, either organic or inorganic, that may affect thermo-oxidative stability and deposit formation, as well as hydrolytic stability, amongst other properties.

Similarly, the manufacturing process is key to neopolyol ester performance. There are different ways of producing, purifying, neutralising and filtering esters. The process, when suitably engineered, should lead to a fully esterified compound, and will remove impurities possibly brought by raw materials or generated by the reaction that is carried out at high temperature (oxidation and thermal degradation by-products).

Aviation lubrication requirements have indeed been met by designing optimised chemical structures, strictly selecting raw materials, following tight production specifications, working out the best process, and using the right additive systems – all in the most cost-effective way.

Aromatic amines are the best type of anti-oxidants for the usual operating temperatures reached by aircraft turbine oils (alkylated diphenylamines, phenyl-alpha-naphthylamines). Oligomers of aromatic amines have also gained popularity for the latest generation of aviation turbine oils: their main benefit lies in the increased stability of the turbine oil at high temperatures (above 200°C) by reducing the amount of carbonaceous deposit and varnish on the bearings and gears of the hot section of the engines. This new generation of anti-oxidant systems appeared in the '80s with the MIL-PRF-7808 Grade 4 and the MIL-PRF-23699 Grade HTS performance standard. Anti-wear additives are generally necessary to fortify the load carrying capability of turbine oils. They are generally made of a phosphorus containing component (almost exclusively tricresylphosphate), that will also passivate iron to keep it from catalyzing oxidation and elimination reactions. Copper corrosion inhibitors (benzotriazole and its derivatives) are widely used to protect yellow metal parts, as well as to passivate copper against catalytic promotion of oxidation and elimination reactions.

Verifying performance is another essential aspect of the production of turbine oils. Such products must be evaluated and compliance verified with a sequence of tests including:

- Evaporation test at 204°C
- Oxidation and corrosion tests at 175°C, 204°C, 218°C and 274°C
- Dynamic coking test at 375°C
- Gear load carrying ability on gear test rigs
- Bearing deposits on bearing test rig (260°C)

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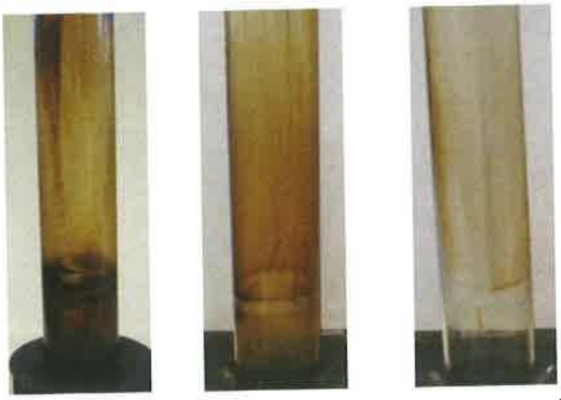
The oil must then be tested in a full-scale turboshaft engine to evaluate its serviceability and to ensure that engine components are compatible with the lubricating oil. The post-test condition of the engine shall not indicate excessive or unusual deposits, wear or corrosion which are attributed to the test oil.

ASTM D4636: oxidation and corrosion test, 204°C – 72 h



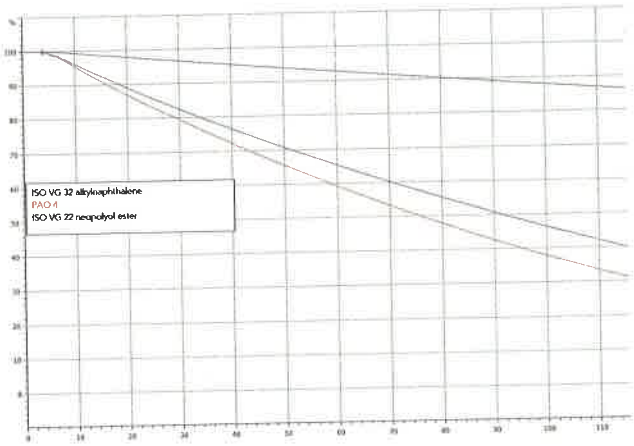
PAO 4 | *Nycobase® Diester ISO VG 15* | *Nycobase® Neopolyol Ester ISO VG 22*

Extension to high performance industrial applications

Aviation is not the only area of lubrication showing such severe requirements. In industrial lubrication too, equipment may operate in extreme conditions, some of which are close to those found in jet engines. Consequently, it is possible to utilise the acquired know-how and technologies developed for the design, production and formulation of neopolyol esters to demanding industrial applications. The most obvious illustration of that is the use of jet engine oils in ground turbines for power generation, especially those that are aero-derivated.

High temperature chains and conveyors are typically found in furnaces, ovens or dryers used in the production of construction materials like glass fibers or cement, laminated particle boards and flooring, plastics, ceramics, stretch film, and even baked products, where temperatures exceeding 300°C may be found. Lubricants showing insufficient resistance to heat may evaporate, causing lack of lubrication, or decompose, leaving sticky residues leading to mechanical failures, fire outbreaks, potential production downtime or increased maintenance costs. Neopolyol esters, especially when combined with oligomer anti-oxidants developed for aviation lubrication, deliver reduced volatility and excellent deposit control, resulting in cleaner operation, reduced downtime, less consumption, and added fire safety. In high compression rate air compressors, temperatures of up to 160°C, or even more in the valves of the discharge section, especially in case of failure. The generation of carbonaceous deposits has been a matter of concern as it may lead to dangerous auto-ignition or valve sticking phenomena. Esters may be used to deliver added durability and ensure cleanliness. In addition, their low volatility will contribute to the production of cleaner compressed air.

Thermogravimetry – Nitrogen, 250°C



Finally, in some passenger car engines, turbochargers may submit the engine oil to extreme temperatures too. The TEOST 33C oil tests evaluate the ability of the oil to resist such temperatures in the turbocharger area of the engine, while generating minimal deposits, through oxidation cycle using temperatures ranging from 200 to 480°C. High performance esters, in addition to their contribution to reduced volatility and friction, are able to improve engine cleanliness.

However, the one aspect of neopolyol esters that has not been taken advantage of in the aviation industry is their excellent environmental profile, combining biodegradability, renewability and non-toxicity features; such specific properties are being increasingly exploited in low environmental impact, high performance industrial products.

Will we see, in the future, equipment manufacturers of the aviation industry willing to make the most of neopolyol esters and their unique technical performance/environmental profile combination?

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