Alternative Fuels from the Engine Lubrication Point of View

The use of biogenic fuels such as biodiesel or vegetable oil fuels leads to specific engine lubrication issues which result in shorter oil change intervals. This paper will attempt to explain the correlations and discuss possible counter-measures.

1 Introduction

The drastic increase in crude oil prices in recent years and the discussions concerning future oil supplies as well as increasing awareness regarding the ecological effects of fossil fuels have encouraged mainstream political parties around the world to promote the use of alternative fuels based on harvestable raw materials.

With the 2003/30/EC directive concerning the promotion and use of biofuels, the EU Commission has created the basis for increasing the sales of such fuels. This should have increased to 2 % by the year 2005 and increase to 5.75 % by 2010. In the case of diesel fuels, this is mainly being realized at present by the addition of 5 % biodiesel to normal diesel fuel (B5) or the use of pure biodiesel (B100); in addition pure vegetable oil fuels are also used, above all rapeseed oil and all of these fuels will be used until BtL (Biomass-to-Liquid) fuels are available on the market. Quality standards have already been set for biodiesel and vegetable oil fuels or are available as pre-standards.

This paper should look at the challenges which the use of biodiesel according to DIN EN 14214 and vegetable oil according to pre-norm DIN-V 51 605 pose to engine lubrication. Biogenic gasoline engine fuels such as ethanol in the form of E-5 or E-85 mixtures will not be examined.

2 Biodiesel

As a result of its popularity and widespread use, the diesel engine is of particular significance with regard to the optimum use of fossil fuels. Even though carbon dioxide emissions can best be reduced by lowering fuel consumption, the question whether alternative fuels could offer CO_2 benefits always arises. For about 15 years now and motivated by the relative free availability and compatibility with normal diesel fuels, vegetable oils in a re-estered form are being increasingly used mainly because their chemical structure and resulting characteristics are very similar to diesel fuels. In chemical terms, biodiesel is Fatty Acid Methyl Ester (=FAME), standardized by EN DIN 14214. Creating this standard was a valuable step because setting a quality standard for alternative fuels is of decisive importance.

In central Europe, rapeseed oil is largely used for re-estering. But sunflower oil, soya oil, palm oil (imports) and used cooking oils are also used, to some

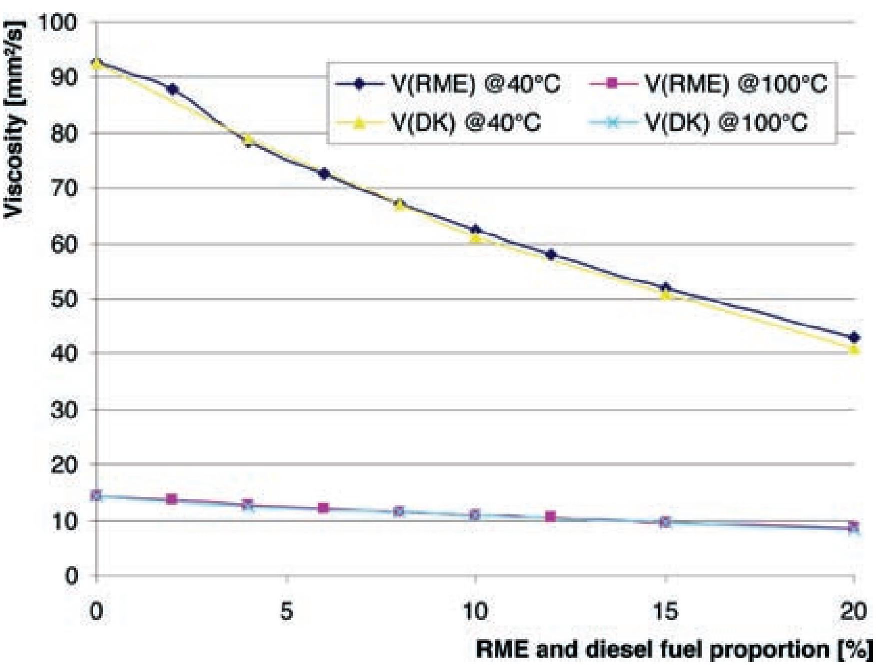

Figure 1: Viscosity of a 10W-40 engine oil with diesel fuel or RME

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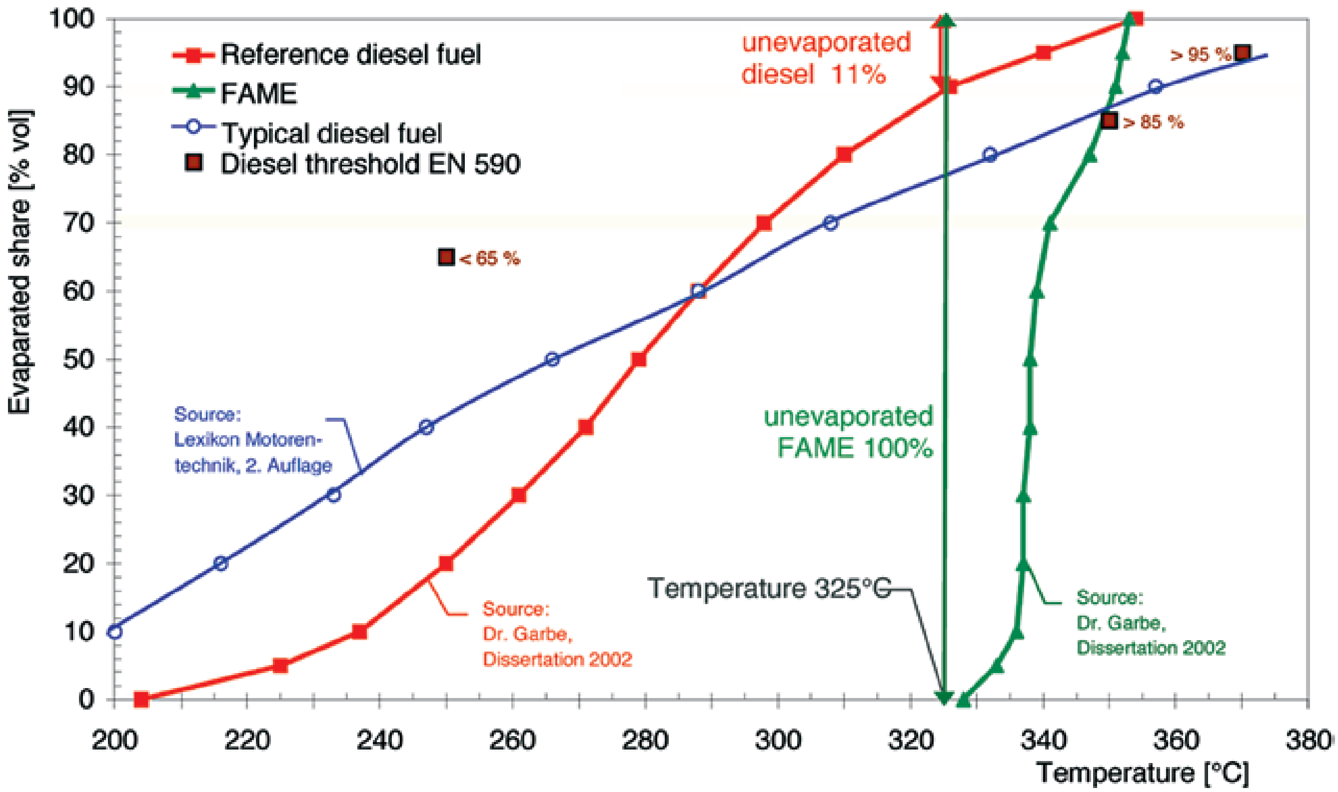

Figure 2: Boiling characteristics of various diesel fuels

extent as mixtures to comply with norm thresholds.

Biodiesel complying with DIN EN 14214 is used as a pure "B100" fuel and as a blend component "Bxx%" (today about B5) for DIN EN 590 diesel fuel. Important: FAME as a blend component must also comply with this standard.

2.1 Oil Dilution

Oil dilution caused by dragged-in fuel is also a factor in diesel fuel operation. **Figure 1** shows the viscosity of an engine oil with fuel – there is almost no difference between diesel and FAME. The specific FAME problem is the accumulation of fuel which does not evaporate, i.e. the long-term dilution of the engine oil.

There are three primary causes for this:

- Compared to equiviscous hydrocarbons, ester oils have powerful penetrating properties. This leads to the greater drag-in of unburnt FAME into the engine oil.
- Today's diesel engines with particle filters (DPF) often use a filter regeneration system which involves the periodic injection of a small quantity of fuel which burns. This increases the exhaust temperature to a point at which the carbon "burns-off". This procedure however, leads to the increased drag-in of unburnt fuel in the engine oil.
- Due to the higher boiling points of FAME compared to diesel fuel, the FAME in engine oil remains in the oil and leads to long-term dilution. **Figure 2** presents the boiling characteristics of various diesel fuels. The diagram shows that, for example, one litre of B10 at 325 °C yields an unevaporated residue of 100 ml FAME and 99 ml diesel fuel – a B50 blend is virtually in the engine oil.

A number of tests have shown that at the end of a conventional oil change interval, up to 20 % FAME can be found in the engine oil but normally between 5 and 10 %. This figure is also dependent on the condition of the engine. The result of oil dilution is a drop in viscosity with the accompanying danger of increased wear. Another effect to which little attention is paid is the dilution of the engine oil additives and the detrimental effect on their function.

2.2 Oil Ageing

During its use, the engine oil is subject to a number of stresses such as high temperatures, shearing as well as dragged-in blow-by gases and fuel. In the case of vegetable oil-based fuels and their lower long-term stability, the latter significantly accelerates oil ageing. The result can be an increase in viscosity and the formation of fluid and solid reaction by-products. A differentiation is made between:

- Oxidative ageing, i.e. reactions with oxygen in the air which can form organic, oil-soluble, often short-chained and thus relatively strong acids and
- Thermal ageing, which through the formation of high-molecular structures can lead to significant viscosity increases and even resination (polymerization).

In practice, both processes occur. The oxidation of oils can be avoided or reduced by the inclusion of anti-oxidants but dragged-in FAME fuels are particularly susceptible to oxidative, thermal and hydrolytic ageing.

Polymerization begins with oxidation reactions, an initially slow process because there are only few radicals and

Table: Change in engine oil viscosity during operation

Engine oil viscosity change due to:	Increase ↑ Decrease ↓
Shearing	↓
Structural viscosity	↓
Soot, contaminants	↑
Evaporation losses	↑
Base oil oxidation	↑
Polymerization	↑
Fuel (diesel, biodiesel)	↓

plenty of inhibitors in the oil. This mechanism attacks, above all, double-bonds and this is why unsaturated fatty acids play an important role. There is therefore a direct connection between oil ageing and FAME content.

Solid reaction by-products resulting from thermo-oxidative reactions or combustion soot are held in suspension in the oil by dispersants to avoid sedimentation when the engine is not running. Detergents are used to combat the formation of residues consisting of high-molecular, organic, low-hydrogen and oil-insoluble compounds.

Measures to counter the acidification of engine oils are the Total Base Number (TBN) and socalled TBN carriers. This describes the buffer capacity of an oil. In addition, the effects of acidification are countered by the inclusion of corrosion inhibitors.

During the course of oil ageing, reaction hot-spots increase while inhibitor concentration falls so that oil ageing gradually speeds-up. In addition, some oxidation by-products have an auto-catalytic effect and accelerate polymerization. One of the results can be the formation of sludge, i.e. the combination of oil components and ageing by-products with solid contaminants, water and acids which sometimes occur in phases as thin and thick components.

2.3 Oil Change Intervals

Unfortunately the described effects, "oil dilution by FAME" and "oil thickening as a result of ageing" do not cancel each other out. The **Table** qualitatively evaluates operational influences on the viscosity of an engine oil.

In the case of biodiesel blends, such as the presently favoured B5 to B20 blends, these problems occur only proportionally. Tests on B5 fuels have shown that no serious lubricant changes occurred even under critical driving modes. In the case of future B10 or B20 blends, the selective enrichment of biodiesel in engine oil has still to be examined.

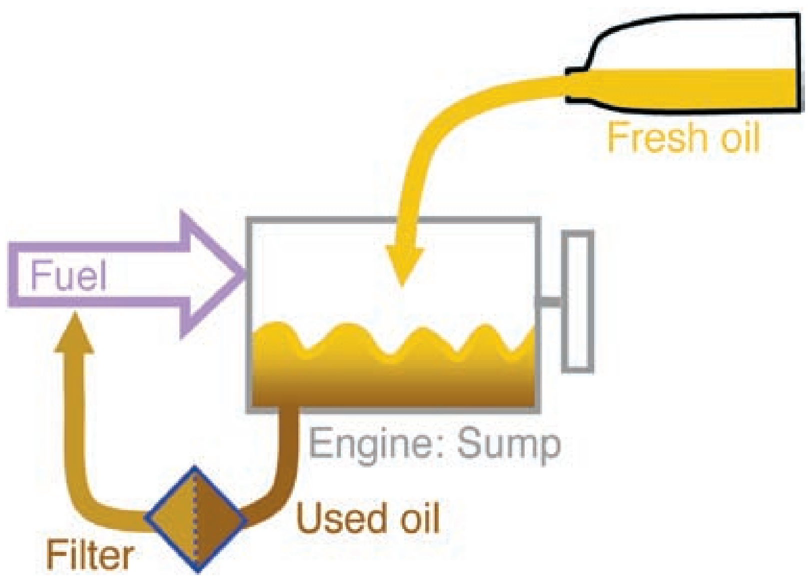

Figure 3: Schematic of the Plantotronic oil refreshment method: metering circuit

The influences on engine oil described here put restrictions on oil change intervals, at least for pure FAME set-ups. To avoid a critical drop in viscosity, the recommended oil change intervals in vehicle applications are often simply halved. In some cases, the normal oil change interval can be used for biodiesel operation. However, the decision to deviate from the recommended oil change interval should be based on a laboratory test of the used oil. In normal cases, i.e. without laboratory testing, manufacturers will continue to recommend shorter oil change intervals if B100 is used. In some cases, an oil change is already recommended then the FAME content exceeds 6 %.

An alternative which often gets discussed is whether ester-based engine oils are more "compatible" with biogenic fuels, following the alchemy maxim "like dissolves like". There are in fact indications of such better solubility but this only applies to corresponding additive environments. There are without doubt engine oils which are well and less well compatible with biodiesel. However, the first prerequisite for compatibility is compliance with the biodiesel standard.

3 Vegetable Oils as Fuels

At present, pure vegetable oils as fuels must be regarded as a niche with 2006 sales in Germany of about 176,000 tonnes compared to about 2.5 million tonnes of biodiesel. As a result of the efforts by the Technology and Support Centre in Bavaria (Dr. Remmele, Straubing[2]), a large step towards the greater acceptance of this alternative was made in 2006 by the creation of the pre-standard "Fuels for Vegetable Oil-Fuelled Engines – Rapeseed

Oil Fuels – Requirements and Testing Procedures (DIN V-51 605).

3.1 Lubrication Circuits

The fuel-related ageing mechanisms of vegetable oil fuels are similar to those of bio-diesel but the dilution effect hardly occurs (FAME viscosity ca. 4 mm²/s, rapeseed oil ca. 36 mm²/s at 40 °C).

Typical operational problems[4] always reoccur when vegetable oils are used in suitable engines. The triglyceride structure results in an ageing mechanism which causes a relatively pronounced, spontaneous thickening of the contaminated engine oil (polymerization). This happens during normal operation when the engine is hot but more often when the engine is cooling down after being stopped. Oil thickening often blocks the oil circuit; serious engine damage such as seizures or bearing failure then follow.

The oil thickening in vegetable oil-fuelled engines is preceded by some of the fuel being dragged-into the oil. This can be caused by poor combustion, sticking piston rings, leaking valves or defects in engine oil-lubricated injector pumps. Cold starts and partialload operation further increase the amount of dragged-in fuel. Reallife applications of vegetable oil fuels show engine oil thickening occurs more often in direct injection engines than in swirl- and prechamber engines. Engine oil additives have no active role in oil thickening but naturally influence the service life of the engine oil.

Although field trials have shown that relative long oil change intervals can be achieved with vegetable oil fuels if laboratory condition checks are performed, the danger of engine seizures should not be underestimated. Monitoring equipment such as oil level and oil pressure sensors designed for diesel fuel operation usually react too slowly to give sufficient warning of oil thickening.

In certain conditions, some engine oils display advantages over others with regard to ageing but if the conditions change, these can become disadvantages with the same oil. This means that the risks of lubricating oil problems occurring with vegetable oil fuels can only be minimized by a specific combination of measures. These include:

- Engineering measures to the engine such as
  - Improved changeover systems which reduce fuel drag-in
  - Improved sealing between the combustion chamber and crankcase (reducing blow-by)
  - Increasing sump volume
  - Integrating a continuous oil refreshment system such as Plantotronic (see below)
- More favourable operating conditions such as
  - Avoidance of partial-load operation and cold starts
  - Avoidance of very high temperatures (with high engine loads)
- Careful adherence to service plans such as
  - Adherence to prescribed oil change intervals
  - Regular visual checking of the engine oil condition and oil level together with used oil analyses
  - Heeding automatic warnings on oil pressure, oil level, etc.
- Using oils with highly-effective additives to
  - Slow-down ageing reactions and neutralizing acid ageing by-products
- The integration of a reliable oil monitoring system into vegetable oil-fuelled engines such as sensors which continuously monitor oil quality (in development).

Absolutely essential, also for the engine oil, is the use of fuel which meets the quality standard DIN-V 51 605. If this is not given, no serious recommendation can be made regarding oil change intervals.

The pre-standard DIN-V 51 605 exclusively defines the use of rapeseed oil as a fuel. Previous tests already showed the crucial influence of the type of vegetable oil used. As long ago as 1937, Gaupp[3] examined the influence of various vegetable oil fuels (palm oil, peanut oil, sesame oil, soya oil) on engine lubricants. The results indicated that vegetable oil fuels with many double-bonds (e.g. soya oil) generated more pronounced ageing processes than vegetable oils with fewer double-bonds (e.g. palm oil).

3.2 Oil Refreshment to Combat Contamination

A new concept to avoid the problems associated with using vegetable oil fuels is being pursued by the lubricant manufacturer Fuchs with a specially-developed engine lubrication method[5,6]. This is

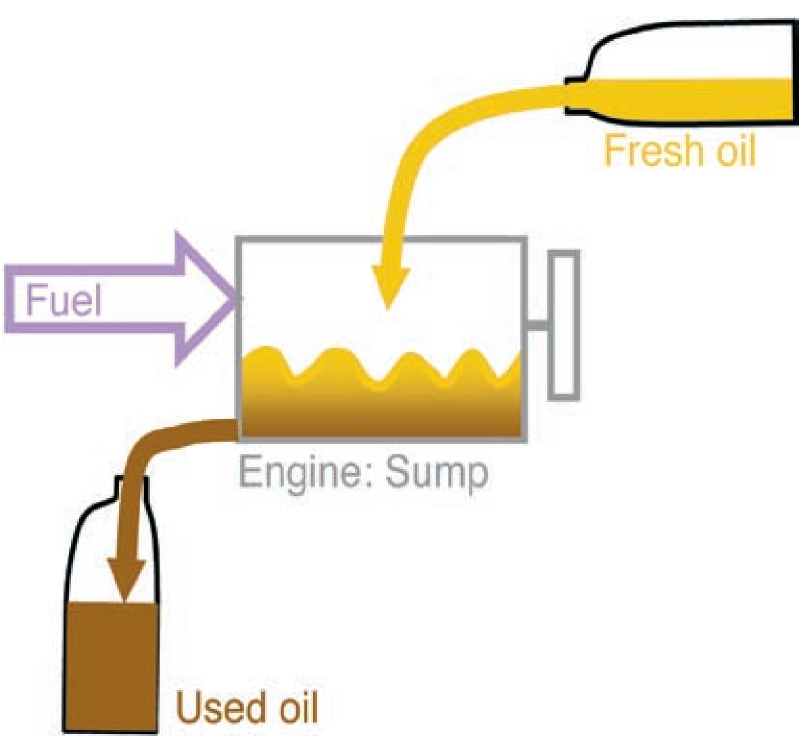

Figure 4: Schematic of the Plantotronic oil refreshment method: used oil tank

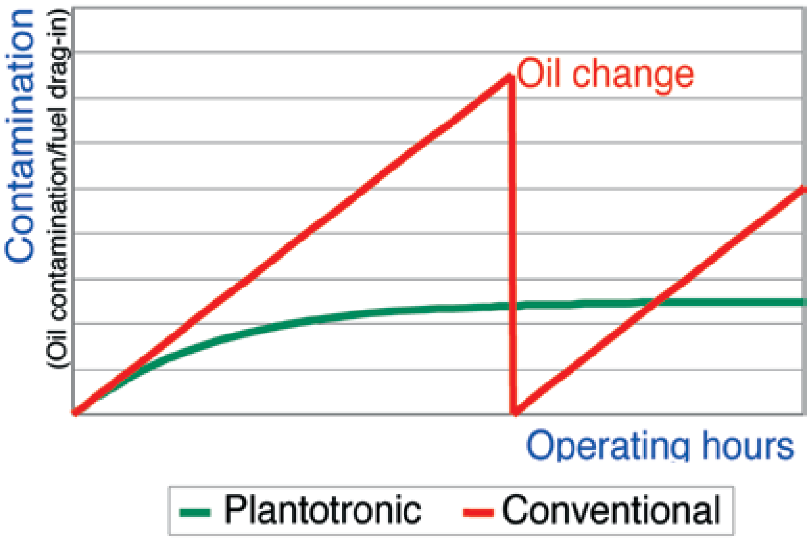

Figure 5: Oil refreshment can combat fuel drag-in

based in the idea that oil should not be changed according to a fixed schedule but continuously refreshed. This significantly reduces the negative influences of FAME or pure vegetable oil fuels on the engine lubricant.

Technically, this socalled Plantotronic system draws used oil out of the sump and replaces it with fresh oil in proportion to the fuel consumption. In its original form, which was developed for power stations, a special engine oil based on rapeseed oil (PLANTOPUR 5W-30) was drawn off through a filter and then burnt together with the fuel. Out of the necessity caused by poor ageing stability, a virtue was made of the low reduction in oil quality due to the relatively high refreshment rate (about 2 % of fuel consumption). As the process specifically utilized energetic use, i.e. the burning of the engine oil, no conventional engine oil could be used. Detailed trials over many thousands of operating hours in two power stations showed that this process and the use of a special engine oil hardly effected emissions which did not exceed emission threshold values, **Figure 3**.

The development of direct injection diesel engines with increasing injection pressures as well as increasingly stringent emission thresholds appears to make the burning of lubricants, even low-additive formulations, problematic. **Figure 4** therefore illustrates another version of the oil refreshment system in which the drawn-off oil is collected in a tank. This system can, of course, use conventional engine oils as well as significantly lowering the refreshment rate (to under 0.5 %).

From a user's point of view, oil refreshment systems avoid a number of subsequent problems when using alternative fuels. Possible contamination caused by biodiesel fuel is proportionally removed, **Figure 5**. Moreover, it offers the advantage of eliminating the routine manual oil change and the associated costs. The cost and complexity of adapting engines is relatively small and only affects engine peripherals.

Apart from a pumping system, an additional reservoir for the fresh oil and possibly one for the used oil is necessary. In principle, the system could be used for a large number of diesel engines but is only specifically recommended for stationary engines which benefit most from such automatic oil changing

4 Outlook

For a number of reasons, the dragging-in biogenic fuels into lubricating oils often leads to a shortening of recommended oil change intervals. The large number of overlapping influencing factors, of which dilution and polymerization are re-emphasized, make it difficult to find a uniform solution to prevent failures in the various applications.

A particularly promising step appears to be the development of oil condition sensors which record the specific stresses on the engine oil during use, pass important information on the condition of the oil to the operator and give advanced warning of impending threshold violations, the most important of which is viscosity. Oil change intervals could thus be scheduled in line with necessity.

Finally, it should be said that the vast majority of reported lubricant problems which occur with the use of biogenic fuels can be traced back to fuel quality and this underlines the particular importance which needs to be attached to the (further) standardization of such "new" fuels.

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