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# Lubricating oil properties – effect of using high acidity fuel

*Abstract: This paper presents results of an investigation focusing on the effect of high acidity fuel (high TAN) on the properties of lubricating oil. The capability of the upgraded lubricating oil (increased TBN) to withstand an operation of the engine when fuelled with animal fat was checked. Two lubricating oils were compared. A Thermo gravimetric method is proposed for characterisation of deposits formed in the lubricating oil centrifuge.*

Keywords: *animal fat, tallow, lubricating oil, total acid number TAN, total base number TBN, thermo-gravimetric analysis TGA, engine deposits*

## 1. Introduction

Growing interest is being shown in alternative fuels for electricity production. Researchers investigated the possibility of using SVO (straight vegetable oil) as fuel for internal combustion engines [1]. This paper presents the consequences of using neat animal fat in a medium speed, four stroke diesel engine. As high acidity of fuel was detected it was decided to verify the capability of the standard and upgraded the lubricating oil to withstand an operation of the engine when fuelled with animal fat. Two lubricating oils were compared.

## 2. Lubricating oil

Lubricating oils used in generating sets are subject to a number of requirements for properties that are needed to assist in various oil duties.

Oil is necessary in the following processes:

- Separation of moving surfaces with oil film
- Engine cooling by dissipation of combustion and friction heat
- Combustion chamber sealing
- Cleaning the engine from deposits.

Juoperi [2] listed the demands for medium-speed diesel engine lubricating oils as:

- Excellent thermal stability
- Excellent oxidation stability
- Effective capability to neutralize acid compounds entering the lube oil
- Slow viscosity increase rate (influence of insoluble matter and oxidation)
- Excellent water shedding properties (removal of water also from used lube oil)
- Excellent compatibility with fuels preventing:
  - deposit formation into piston cooling gallery
  - deposit formation on piston ring groove area
  - black sludge / deposit formation on cold engine component surfaces
  - sticking of fuel injection pumps

## 3. Acidity

Acidity is expressed as Acid Number (AN) [or Total Acid Number (TAN)] and measured in mg KOH/g or given as Free Fatty Acid content (%). FFA results may be expressed in terms of acid value by multiplying the FFA percent by 1.99 [3]. Monitoring of this parameter is important due to the corrosive impact of high acidity fuels on the fuel injection systems [3, 4].

*Acid number (AN)* – the quantity of base, expressed in milligrams of potassium hydroxide per gram of sample, required to titrate a sample in the solvent from its initial meter reading to a meter reading corresponding to a freshly prepared non-aqueous basic buffer solution, or a well defined inflection point, as specified in the test method [5].

*Strong acid number (SAN)* – the quantity of base, expressed as milligrams of potassium hydroxide per gram of sample, required to titrate a sample in the solvent from its initial meter reading to a meter reading corresponding to a freshly prepared non-aqueous acidic buffer solution, or a well defined inflection point, as specified in the test method [5].

## 3. Testing programme

A Ruston 6AR (technical data given in Table 1) has been used for the research described in this paper. Modifications included installation of a new heated fuel supply system, installation of an electronic control unit enabling engine speed control, operational parameters monitoring and also synchronising with the grid. The engine has been equipped with cylinder pressure sensors, a shaft encoder and an emissions' monitoring system. Two types of lubricating oils were used in the research plant. The oil properties are given in Table 2. The main purpose of this part of the research was to verify what kind of impact on oil properties is caused by the usage of animal fat as a fuel. The first oil, Fuchs Titan 30 – SAE 30 grade, complies with the engine manufacturer's recommendations. After 1000 hours of operation the oil grade was altered to Fuchs Titan Marine 30, which can be characterised by higher TBN and increased detergency. The oil type was chosen after the fuel properties' testing, which showed a very high TAN of tallow, reaching even 70 mg KOH/g fuel.

The oil was sampled directly from the sump by a vacuum sampling pump and then tested against a set of criteria, including viscosity, soot content and chemical composition. The testing interval was set to be 100 hours or 1 month. The engine lubricating system, shown in Figure 1, has been modified to avoid the possibility of oil contamination with fuel that may leak from the fuel pumps' supply lines. The oil lubricating rocker gear, delivered by pipe No. 22 and returning via pipe No. 21 was originally going back to the sump through the drip tray. In the modified arrangement this oil was diverted to the waste oil tank.

Centrifuge deposits obtained during operation at standard oil grade were tested by a Pyris 1 thermo gravimeter supplied by PerkinElmer. A combined method has been used, including low ramp (3 $^{o}$C per minute) heating up to 850 $^{o}$C in inert atmosphere, cooling to 400 $^{o}$C, and then oxidation in air again up to 850 $^{o}$C. This method allows assessment of the deposits' composition.

## 4. Results

Data collected during the trials are given in Table 3. The table is accompanied by two graphs showing changes in oil viscosity (Figure 2) and iron concentration (Figure 3). Increasing viscosity can indicate fuel contamination; high iron content may be caused by excessive engine wear.

It can be seen that oil viscosity increased for both types of tested oils. During the trials the oil centrifuge had to be cleaned more frequently than for standard fuel operation due to fast deposit formation. The maintenance schedule was altered. Oil contamination with fuel can be caused by increased spray penetration due to different physical properties of fuel; hence droplets may hit liner walls and penetrate to the sump. Excessive wear has not been detected for both types of lubricating oil as concentrations of bearing materials (Cu, Pb, Sn) remained below warning limits.

Figure 4 presents results of the devolatisation process realised at the furnace of the TGA – in the presence of nitrogen up to a temperature of 850 $^{o}$C. Observation of the calculated derivative (green curve) confirms expected weight loss at a temperature of 300 $^{o}$C which may correspond with a fraction of the lubricating oil but also animal fat. Heavier components elute at very high temperatures. Results show that approximately 50% of the centrifuge deposit is a volatile material. The residual material was oxidised in the presence of air (Figure 5); again two stages of the process can be seen, first at a temperature in the region of 400-500 $^{o}$C when the weight loss is the most significant, and the second stage with slow oxidation up to a temperature of 650 $^{o}$C. Approximately 40% of the sample mass was ash – it proves that modern high quality oils can suspend ashes originating from fuels such as animal fat. A comparison with similar deposits taken from the piston crown shows a significant difference in ash content – in the case of the piston deposit this value oscillates at around 30%.

## 5. Conclusions

Engine tests lasted for 2000 hours. More than 1 GWh of electricity has been generated and approximately 285 tonnes of animal fat have been utilised. This research has shown that appropriately filtered animal fat can be used as fuel for large, stationary engines.

Usage of animal fat as fuel for an internal combustion engine requires modification of its maintenance schedule and may lead to injection system failures. The conducted tests proved that it is possible to operate a compressed ignition engine fuelled with tallow without a major alteration of the lubricating system. Standard lubricating oil (SAE 30 grade) withstood a 1000 hours' change interval. The application of marine oil did not result in a significant difference in oil contamination with various wear products. It has to be noted that due to piston failure, the engine oil (Marine) had to be replaced before reaching the planned 1000 hours. The capacity of the oil centrifuge should be increased to improve removal of fat from the lubricating oil. Another modification that improved operation on animal fat was increasing the diameter of the pipe feeding the centrifuge and the introduction of trace heating. It resulted in an improved flow of oil to the centrifuge and ensured that contaminated oil will not solidify in the narrow parts of the lubricating system.

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**Table 1. Engine technical data**

| | | |
|---|---|---|
| No. of cylinders | 6 | - |
| Nominal speed | 600 | rpm |
| Power | 809 | kW |
| Bore | 260.5 | mm |
| Stroke | 368 | mm |
| BMEP | 1.4 | MPa |
| Compression ratio | 12.3:1 | - |
| Injection pressure | 20 | MPa |
| Injection commences | 22 | ºBTDC |

**Table 2. Lubricating oil properties [6, 7]**

| Characteristics | Unit | Test Method | Titan TXE 30 Oil | Titan Marine 30 Oil |
|---|---|---|---|---|
| SAE designation | - | - | 30 | 30 |
| Kinematic viscosity | | | | |
| @100ºC | $mm^2/s$ | IP 71 | 11.2 | 12.3 |
| @40ºC | | | 96 | 107 |
| Viscosity index | | | 102 | 106 |
| Flash point | ºC | IP34 | 220 | 210 |
| TBN | mg KOH/g | - | | 14 |
| Sulphated ash | %wt. | - | | 1.7 |
| Density at 20ºC | $kg/dm^3$ | IP160 | 0.893 | 0.890 |
| Pour point | ºC | IP15 | -20 | -15 |

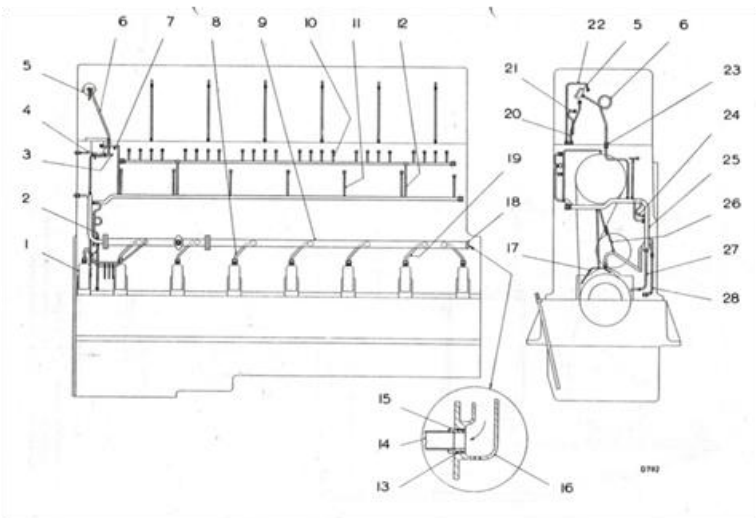


**Figure 1. Ruston 6AR lubricating system [8]**

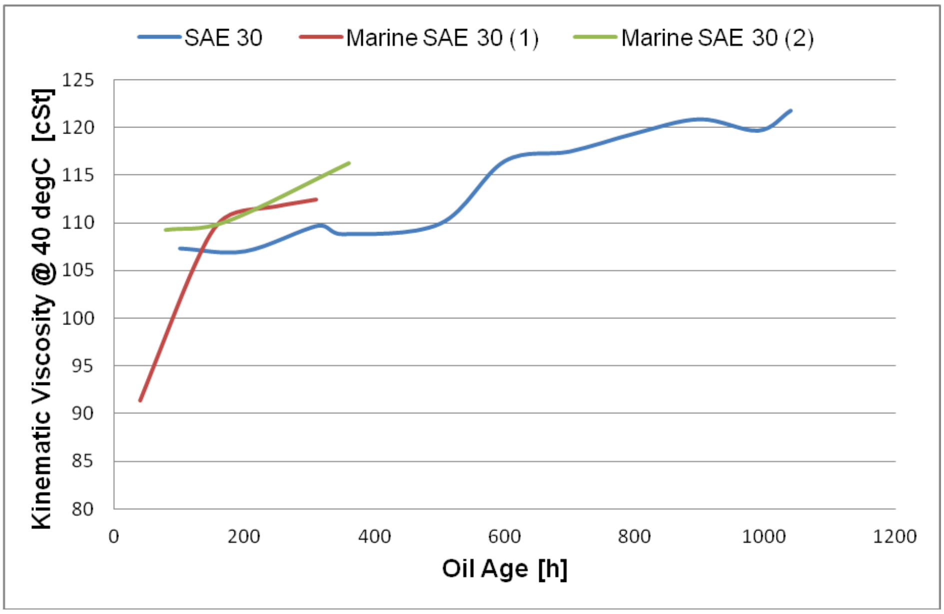


**Figure 2. Long term effect of animal fat usage on lubricating oil viscosity**

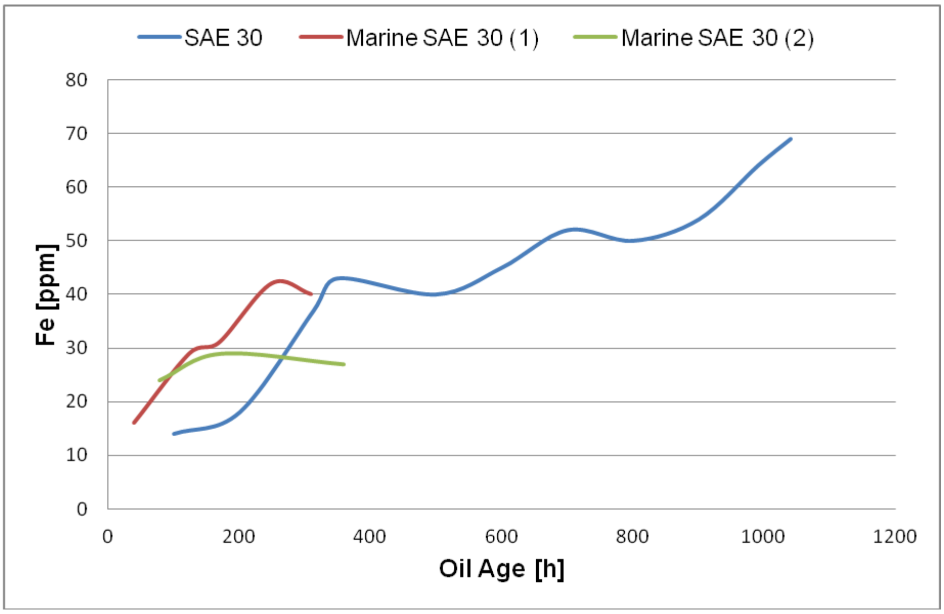


**Figure 3. Long term effect of animal fat usage on engine wear - iron concentration**

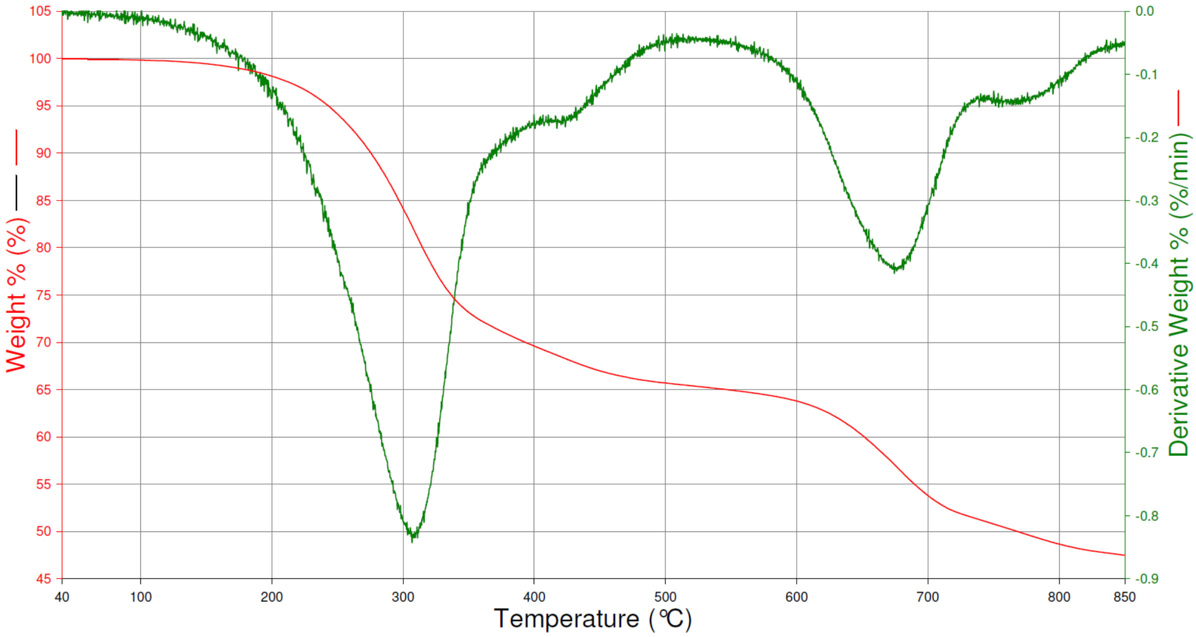


**Figure 4. Oil centrifuge deposit - thermal analysis - devolatisation phase in the presence of nitrogen**

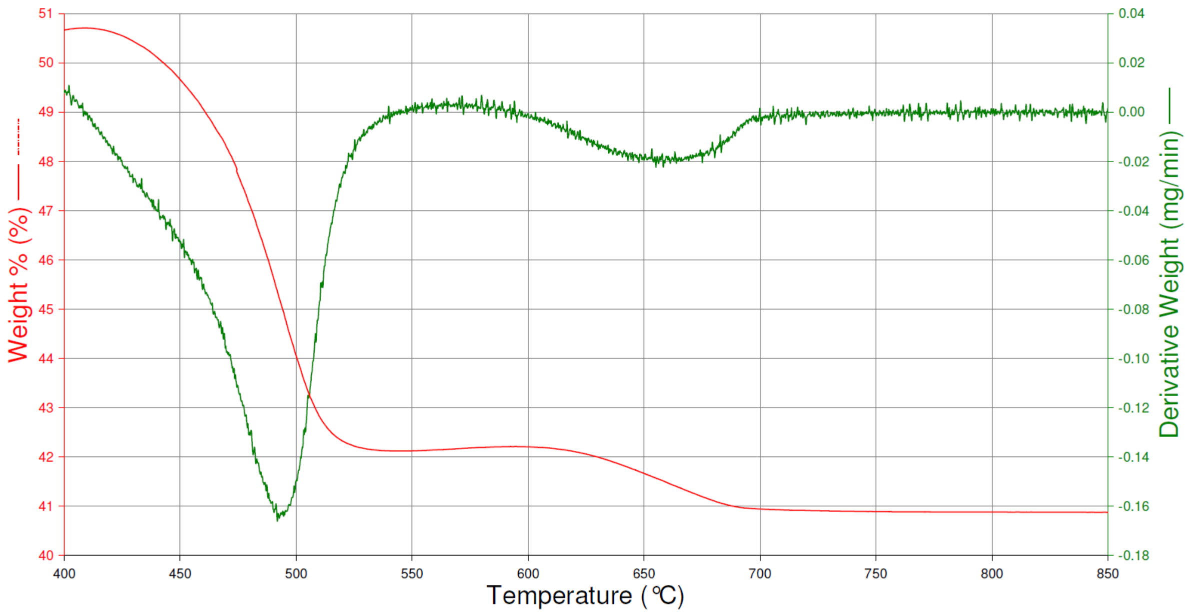


**Figure 5. Oil centrifuge deposit - thermal analysis - residue oxidation in the presence of air**

## Table 3. Effect of ageing during operation on animal fat on various types of lubricating oil

| Oil Type | SAE 30 | | | | | | | | | | | Marine SAE 30 (1) | | | | | Marine SAE 30 (2) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hours of operation | 100 | 200 | 313 | 350 | 500 | 600 | 700 | 800 | 900 | 990 | 1040 | 40 | 125 | 170 | 250 | 310 | 78 | 172 | 360 |
| KV [$mm^2/s$] | 107.3 | 107 | 109.7 | 108.8 | 109.9 | 116.5 | 117.5 | 119.4 | 120.9 | 119.7 | 121.8 | 91.4 | 105.8 | 110.6 | 111.8 | 112.5 | 109.3 | 110.2 | 116.3 |
| Soot | 0.4 | 0.5 | 1.3 | 1.4 | 1.7 | 1.9 | 2.2 | 2.2 | 2.2 | 2.5 | 2.5 | 0.2 | 0 | 0.5 | 0 | 0.6 | 0.3 | 0.3 | 0.6 |
| Concentration [ppm] | | | | | | | | | | | | | | | | | | | |
| Iron (Fe) | 14 | 18 | 37 | 43 | 40 | 45 | 52 | 50 | 54 | 64 | 69 | 16 | 29 | 31 | 42 | 40 | 24 | 29 | 27 |
| Copper (Cu) | 1 | 1 | 4 | 5 | 4 | 5 | 4 | 3 | 3 | 3 | 4 | 1 | 1 | 1 | 2 | 5 | 1 | 1 | 1 |
| Silicon (Si) | 2 | 6 | 6 | 7 | 5 | 8 | 7 | 6 | 7 | 5 | 9 | 3 | 7 | 10 | 6 | 10 | 17 | 15 | 10 |
| Aluminium (Al) | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 0 | 1 | 2 | 1 | 4 | 0 | 2 | 1 |
| Chromium (Cr) | 0 | 0 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 |
| Nickel (Ni) | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 2 | 0 |
| Molybdenum (Mo) | 47 | 48 | 50 | 50 | 49 | 52 | 59 | 54 | 58 | 62 | 67 | 37 | 21 | 16 | 8 | 7 | 2 | 1 | 1 |
| Manganese (Mn) | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 2 | 1 | 2 | 2 | 2 | 2 | 1 | 1 | 1 |
| Lead (Pb) | 2 | 1 | 2 | 3 | 3 | 4 | 5 | 3 | 5 | 6 | 7 | 6 | 3 | 3 | 1 | 7 | 1 | 8 | 11 |
| Tin (Sn) | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 0 | 0 | 2 | 2 | 1 | 0 | 0 | 0 |
| Lithium (Li) | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| Titanium (Ti) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Vanadium (V) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Silver (Ag) | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Boron (B) | 6 | 3 | 4 | 5 | 4 | 3 | 2 | 2 | 2 | 4 | 7 | 12 | 9 | 9 | 7 | 6 | 1 | 8 | 4 |
| Sodium (Na) | 7 | 9 | 16 | 18 | 17 | 26 | 36 | 31 | 32 | 45 | 50 | 10 | 24 | 34 | 61 | 63 | 63 | 119 | 83 |
| Barium (Ba) | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 2 | 0 |
| Calcium (Ca) | 1682 | 1740 | 1931 | 1861 | 1651 | 1887 | 1993 | 1794 | 1869 | 1862 | 2114 | 2884 | 4214 | 5027 | 5244 | 5113 | 4764 | 5610 | 5677 |
| Magnesium (Mg) | 9 | 9 | 12 | 15 | 9 | 12 | 12 | 10 | 10 | 11 | 12 | 13 | 19 | 18 | 19 | 18 | 14 | 17 | 16 |
| Phosphorus (P) | 689 | 740 | 803 | 790 | 718 | 799 | 858 | 774 | 824 | 860 | 888 | 715 | 665 | 641 | 595 | 549 | 502 | 566 | 567 |
| Zinc (Zn) | 74 | 810 | 865 | 887 | 768 | 883 | 988 | 842 | 893 | 946 | 950 | 825 | 771 | 764 | 726 | 695 | 593 | 657 | 643 |
| Where: KV – Kinematic Viscosity | | | | | | | | | | | | | | | | | | | |

## Nomenclature/*Skróty i oznaczenia*

FFA Free Fatty Acids
KV Kinematic Viscosity
SVO Straight Vegetable Oil
TAN Total Acid Number
SAN Strong Acid Number
TBN Total Base Number
TGA Thermo Gravimetric Analysis

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