Correlation between electrical, mechanical and chemical properties of fresh and used aircraft engine oils

Juliusz B. Gajewski1, Marek J. Głogowski1, Maciej Paszkowski2, Bogusława Czarnik-Matusewicz3

1 Wrocław University of Technology, Institute of Heat Engineering and Fluid Mechanics, Wybrzeże Wyspiańskiego 27, 50-370 Wrocław, Poland
2 Wrocław University of Technology, Institute of Machine Design and Operation, ul. Łukasiewicza 5, 50-371 Wrocław, Poland
3 University of Wrocław, Faculty of Chemistry, Joliot-Curie 14, 50-383 Wrocław, Poland

Email: juliusz.b.gajewski@pwr.wroc.pl

Abstract. In this paper the results are presented of measurements of electrical, mechanical and chemical properties of fresh and used aircraft engine oils. Oils were used in a four-stroke aircraft engine and their samples were taken after the 50-hour work of the engine. The resistivity, permittivity and viscosity of oils were measured as a function of temperature. Additionally, some measurements of the absorbance spectra and size of particles contained in the oils were carried out. The significant reduction in the resistivity of the used Total oil was observed. The relative permittivity of both used oils was slightly increased. The oil’s relative viscosity depends on temperature of oil and given time that elapsed from the very first moment when the shear force was applied in a rheometer. The results obtained allowed one to identify more precisely the chemical and physico-chemical interactions occurring in the tested samples, as compared with a typical infrared spectroscopy.

1. Introduction
Lubricating oil protects engines from the effects of pressure, corrosion, heat, and oxidation. The oil creates a separating film between moving parts, reduces friction and wear, and cleans the interior of an engine by removing particle as a product of wear, carbon deposit and combustion contaminations. The rate of deterioration depends on operating conditions and loads of an engine. Aircraft engines are made of lightweight alloys, and operate over a wider temperature range than normal automotive engines which causes the rapid ageing of oil. In order to avoid any engine failure, the oil must be changed before it looses its protective properties. Changes in these properties can be seen as variations in the resistivity, the relative permittivity and the viscosity [1, 2, 3].

2. Experimental system
The measurements of the oil’s resistivity \( \rho \) and relative permittivity \( \varepsilon \) were made for the steady and stable temperature. The temperatures \( T \) were changed from 20 to 100°C every 10°C. The resistivity and permittivity were measured using a capacitor KP-4 which was made according to the Polish technical standard PN-EN 60247 [4]. The measurements of the permittivity were performed with the use of a precision LCR meter 7600 Plus made by QuadTech, while a meter MIC-2500 made by Sonel was
used to measure the resistivity. The measurements were repeated five times during each experimental session to get a certain statistics.

The rheological properties of the engine oil were measured with an Anton Paar Physica MCR-101 rotational rheometer which worked in the Couette system. The measuring system was equipped with a computer software RheoPlus for the data acquisition. The temperatures of the oil’s samples were kept constant in a thermostat by the Peltier module at a given level. The temperatures ranged from 0 to 100°C every 20°C. The dynamic viscosity measurements were performed as a function of time.

The size of different particles contained in both the fresh oils and the used oils was measured with ZetaSizer Nano ZS made by Malvern Instrument. The aim of these experiments was an assessment of percentage of particles of different sizes in the volume of the oil being tested.

The FTIR-ATR spectra were recorded using a FT-IR Nexus-Nicolet spectrophotometer with a resolution of 1 cm\(^{-1}\) with 128 scans per spectrum in a frequency range of 4000–400 cm\(^{-1}\) at 25ºC. The spectrometer was equipped with the DTGS detector. The transmission measurements were carried out in a 208 µm-KBr cell, while the ATR spectra were collected on the ATR system supplied with a diamond crystal (face angle: 45º, 1 reflection) (Graseby, Specac, UK).

3. Materials tested
The experiments were conducted for two aircraft piston engine oils: mineral Total Aero D 100 and synthetic AeroShell 15W50 whose kinematic viscosities were 182.0 and 19.0 mm\(^2\)·s\(^{-1}\) as well as 146 and 19.9 mm\(^2\)·s\(^{-1}\) at 40 and 100°C, respectively. Their viscosity indexes were 118 and 175, respectively. The oils were used in an air-cooled, carburetted, four-stroke gasoline aircraft engines, and the samples of the used oils were taken after the 50-hour work of an engine. AeroShell oil was used in a Lycoming O-360 engine while Total Aero oil was used in an AI-14RA engine whose powers were 135 and 191 kW, respectively. For the sake of simplicity both oils will henceforth be termed Shell and Total.

4. Experimental results and discussion
4.1. Resistivity and relative permittivity
The resistivity \(\rho\) and the relative permittivity \(\varepsilon\) as a function of the temperature \(T\) are shown in figure 1 for two aircraft oils.

The decrease in the resistivity with the increasing temperature is due to the higher mobility of all charged particles and molecules in the oil. A higher value of the resistivity of Total reflects the lower content of additives in the oil. The larger resistivity decrease of used Total may be caused by an increase in the contamination and acidity of the oil. The minimal change in the resistivity of used Shell may result from the ZnDTP content in oil, which protects moving metal parts of engines.

![Figure 1](image_url)

**Figure 1.** Resistivity (a) and relative permittivity (b) vs. temperature for oils: Total — ○ – fresh oil and ● – used oil, and Shell — □ – fresh oil and ■ – used oil.
The relationships between the relative permittivities and the temperatures of both oils tested are shown in figure 1b. It may be noticed that for the used oils values of the permittivity to increase. This may indicate the increase of water content in the oil tested; the water can be produced by, for example, the condensation of water vapour.

4.2. Dynamic viscosity

In figure 2 the sample graphs show the trends of the relative dimensionless value of the viscosity $\Delta \eta$ as a function of the temperature of both oils for the shear rate $D = 500 \text{ s}^{-1}$. The relative viscosity $\Delta \eta$ means the ratio of the viscosity of used oil to the viscosity of fresh oil.

The relative viscosity was determined for the measurement results obtained after a given time elapsed from the very first moment when the shear force was exerted in a rheometer. These times were: 1st, 60th, 120th, and 180th second from the start of a shaft’s rotation and of the measurements. In figure 2 these times are marked with the following symbols: $\bigcirc$, $\diamond$, $\triangle$, and $\square$, respectively.

The highest values of the viscosity for the used oils were observed at temperatures of 0°C and above 40°C. The values of the viscosity measured depend on the duration of measurements. An increase in the duration of measurement causes the relative viscosity to tend to the constant value.

![Figure 2](image.png)

**Figure 2.** The sample plots of the relative dynamic viscosity vs. temperature of Shell (a) and Total (b).

Used oils seem to be more complex rheological liquids because they contain much more contaminations than fresh oils. All the oils tested also showed pseudo-plastic behaviour.

4.3. Absorbance spectra measurements

According to the figure 3a for the Shell oil in the spectrum of its used sample the concentration of aromatic components decreases. It can be caused by presence of such an additive as Irgalube 211 that is not present in the Total samples. In the Shell samples some component is present that contains an acid group and the concentration of the component is not changed in the sample of the used Shell oil. The Total samples are free of acid components. For both kinds of oils the concentration of components that contain the ester group increases.

For the spectra shown in figure 3b there are distinct changes in the two samples of the Shell oils in the range of two peaks which can be attributed to the ZnDTP content in the oils – ZnDTP is an antioxidant and antiwear extreme pressure additive. For the Total samples, free from this additive, the differences between different peaks are negligible. Only one effect can be observed that is the elevated absorbance for the sample of used Total. It was probably caused by a higher content of soot in the sample.
4.4. Granulometry measurement
Additionally, some granulometric experiments and analysis have been carried out. Their results permitted one to know the particle size distribution in both samples of the used oils.

In the Shell sample the largest fraction of particles (7.7%) were particles of 412.5 nm in diameter. The smallest recorded size of the particles was 21.9 nm. This sample did not contain particles larger than 1152 nm within an optical range of 0.4–4000 nm for ZetaSizer Nano ZS.

In the Total sample the largest fraction of particles (10.6%) were 2780 nm diameter particles. The size of the Total particles ranged from 39.4 to 3728 nm. It should be noted that in both cases there were probably the particles larger than 4000 nm as well. These particles were outside the measuring range of the instrument used.

5. Concluding remarks
The research results presented here show the relationships between the electrical, mechanical and chemical properties of investigated oils. A decrease in the resistivity for the used oils depends on an increase in the metal particles produced by wear (wear debris) and in the amount of soot from a combustion processes – these particles and soot were getting into the oils during their normal, regular use in the aircraft engines. The used Total oil had more soot than a Shell one. The lowest value of the resistivity of Shell’s oils was a result of the higher content of different additives.

An increase in the relative permittivity of the used oils was the result of increasing ester and acid groups in the volume of all the oils tested.

The increase observed in the viscosity of the used oils tested results mainly from soot particles that were introduced to the oil as the products of oil and fuel combustion as contaminants, as supposed.

References
[1] Gajewski JB, Głogowski MJ and Paszkowski M 2010 Electrical and tribological properties of engine oil during its operating time in the aspect of tribocharging SFE 2010: Proc. of 7th Conference of the French Society of Electrostatics (Montpellier, France, 30 August–1 September 2010) pp 341–344
[2] Olszewski W 2001 Możliwości oceny stanu jakości oleju silnikowego podczas eksploatacji za pomocą pomiaru własności dielektrycznych (The possibility of estimate quality state of using motor oil by measuring dielectrical properties) J. of Kones. Combustion Engines 8 (3–4) pp 84–90
[3] George S, Balla S, Gautam V and Gautam M 2007 Effect of diesel soot on lubricant oil viscosity Tribol. Int. 40 p 809
[4] Polish standard PN-EN 60247:2004