IMPROVING ENERGY EFFICIENCY THROUGH USING MODERN HYDRAULIC OIL

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The service life of hydraulic oil is significantly influenced by operating conditions as well as by its composition. Manufacturers have access to different groups of base oils for the production of hydraulic fluids. Due to the varying properties of these groups, the service life of the final product also varies. This article discusses hydraulic oils according to different groups of base oils, their basic characteristics, and the differences between them. Furthermore, it introduces the new series of Energolubric hydraulic oils, focusing on extended service life compared to conventional mineral-based hydraulic oils. Results of comparative testing on oxidation stability of various oils will be presented. The article will also address the aspect of energy efficiency in hydraulic system operation, which is also influenced by the choice of hydraulic oil.

Keywords:
hydraulic oil,
base oils,
oxidation stability,
energy efficiency

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1 Introduction

Base oils are the fundamental component of lubricants and hydraulic fluids and are classified into five major groups according to production method and physicochemical properties:

– Group I: Mineral base oils obtained through conventional refining techniques such as solvent extraction and distillation. They exhibit lower oxidation stability and higher levels of impurities compared to higher groups.
– Group II: More refined mineral oils produced by hydrocracking, offering improved properties such as greater oxidation resistance and longer service life.
– Group III: Highly refined mineral oils processed via hydrocracking and isomerization, which closely approach the performance of synthetic oils.
– Group IV: Synthetic oils based on polyalphaolefins (PAOs), characterized by excellent oxidation stability, low volatility, and a wide temperature operating range.
– Group V: All other base oils not included in Groups I–IV (e.g., esters), typically used in specialized applications due to exceptional lubricity and thermal stability.

Each base oil group has its own advantages and limitations, which directly affect the performance characteristics of the final hydraulic fluid. Choosing the appropriate base oil is essential for achieving optimal performance and extended service life in hydraulic systems [1] to [4].

The extension of service life for mineral-based hydraulic oils is closely related to their oxidation stability. Oxidation leads to the formation of acids, varnish, and other degradation products that can negatively affect system performance. The use of highly refined mineral oils or synthetic alternatives with advanced antioxidant formulations can significantly slow down this process, resulting in longer oil change intervals and reduced maintenance costs [2], [4].

In addition, hydraulic oil plays a crucial role in the energy efficiency of hydraulic systems. Its formulation and viscosity influence frictional losses, energy dissipation, and system temperature. Fluids with lower viscosity at low temperatures and stable viscosity-temperature characteristics at high operating temperatures contribute to reduced energy consumption and improved system efficiency.

Consequently, the industry is increasingly adopting hydraulic oils based on higher-group base oils and containing advanced additive technologies that enhance oxidation stability and energy efficiency. A relevant application example is the plastic injection moulding industry.

Plastic injection moulding machines are energy-intensive, requiring heating of the material, operation of hydraulic drives, and cooling. Monitoring energy consumption allows [5]:

- Real-time consumption tracking – identifying peak energy use during start-up, operation, standby, or shutdown phases.
- Injection cycle analysis – comparing consumption across different moulds or products to assess process efficiency.
- Cost-per-part evaluation – calculating energy use per production cycle to support cost analysis and pricing strategies.
- Detection of anomalies – sudden increases in energy consumption may indicate mechanical failures, inadequate maintenance, or operational changes.
- Optimization opportunities – for example, identifying high idle-time consumption may justify implementing automatic energy-saving modes or reducing system pressure during standby.

2 Oxidation stability – a key performance parameter for long-life hydraulic oils

Oxidation stability is a critical property of hydraulic fluids, especially in demanding industrial applications where long service life, system reliability, and cost-efficiency are of paramount importance. Oxidation refers to the chemical reaction between the oil and atmospheric oxygen, which is accelerated at elevated temperatures, in the presence of catalytic metal contaminants (e.g., copper, iron), or in systems where moisture ingress occurs.

This degradation leads to the formation of a variety of harmful by-products, including organic acids, sludge, varnish, and insoluble compounds. These products can cause filter plugging, valve sticking, increased wear, and changes in oil viscosity–ultimately reducing the efficiency and reliability of the hydraulic system. In severe cases, oxidation-induced deposits may result in unplanned downtime, expensive repairs, and reduced equipment life.

The oxidation stability of a hydraulic oil is strongly influenced by the type and quality of the base oil used, as well as by the formulation and performance of the antioxidant additive system. Oils formulated with highly refined Group II or Group III base stocks–or with fully synthetic Group IV (PAO) base oils–exhibit superior oxidation resistance due to their low content of unsaturated hydrocarbons and impurities. Synthetic base oils also provide enhanced thermal stability and volatility characteristics.

To further inhibit the oxidation process, carefully selected antioxidants are incorporated into the formulation. Over time, however, antioxidant levels deplete, which is why oxidation stability is also a key indicator of oil life. These improvements extend service intervals, reduce oil change frequency and waste oil generation, and lower maintenance and filter replacement costs. At the same time, system reliability increases and the risk of unplanned downtime decreases. In summary, proper oil selection and an understanding of oxidation stability have a direct impact on the efficiency, safety, and cost-effectiveness of hydraulic system operation.

The oxidation stability of various ISO VG 46 hydraulic oils was evaluated using the RapidOxy 100 instrument (Figure 1).

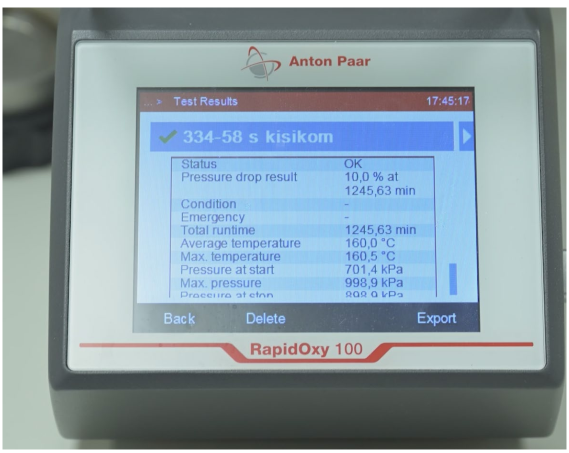

Figure 1: RapidOxy 100 instrument for measuring oxidation stability of oils.
Source: own

RapidOxy 100 is a modern laboratory instrument designed for fast and reproducible determination of the oxidation stability of lubricants, fuels, and other organic materials. It is based on the accelerated aging method under elevated pressure and temperature, in which the pressure drop of oxygen (or synthetic air) in a sealed chamber containing the sample is continuously monitored.

Compliant with ASTM D8206 and DIN 51466 standards, the instrument measures the oxidation induction time (OIT)—defined as the time it takes for the pressure in the chamber to drop by a defined percentage (typically 10 %) from its initial value. This parameter is a reliable indicator of oxidation resistance and, by extension, the expected service life of the oil. The measurement procedure includes the following steps:

- A small sample (approximately 5 mL) is carefully measured and placed into the steel pressure chamber of the instrument.
- The chamber is sealed and pressurized with pure oxygen or synthetic air to about 700 kPa.
- The sample is heated to a defined temperature (most commonly 140 °C), while the instrument continuously monitors the pressure drop.
- The test ends when the pressure has decreased by 10%; the elapsed time is recorded as the test result (OIT in minutes).

Advantages of the RapidOxy method include:

- Speed: the complete test is significantly faster than traditional methods (e.g., RPVOT, TFOUT), typically requiring only 1 hour to 3 hours.
- Low sample volume: suitable for R&D and high-value products where sample availability may be limited.
- Versatility: applicable to various types of oils (hydraulic, engine, compressor) and additive formulations.
- Excellent reproducibility and sensitivity: allows for reliable comparison of different formulations or production batches.

Due to its efficiency and robustness, RapidOxy 100 has become an essential tool in the development and quality control of high-performance lubricants intended for demanding industrial applications, where extended service intervals and high oxidation resistance are critical performance requirements.

The measurement results are presented in Table 1. It is evident that the oxidation stability of the Energolubric oils is significantly higher than that of all other tested oils. In some cases, the stability is more than twice as high. Given this, it is not surprising that these oils demonstrate substantially longer service life under comparable operating conditions.

Table 1: Oxidation stability of different oils

Oil name	Method	Value [min]
Energolubric 3046 ZF	ASTM D8206	1310
Energolubric 2046 ZF	ASTM D8206	1300
Energolubric 4046 ZF	ASTM D8206	1220
Energolubric 2046	ASTM D8206	1067
Hydrolubric VG 46	ASTM D8206	664
Hydrolubric HD 46	ASTM D8206	570
Hydrolubric HLP 46	ASTM D8206	529
Hydrolubric VGS 46	ASTM D8206	672
Hydrolubric HVLP 46	ASTM D8206	787
Hydrolubric VG 46 D	ASTM D8206	536

Source: www.olma.si

This improved performance directly translates into lower overall operational costs, despite the slightly higher purchase price of these oils. Extended oil change intervals, reduced maintenance frequency, and less waste oil generation all contribute to improved cost-efficiency and system reliability.

3 The impact of hydraulic oil on energy efficiency

We conducted energy consumption measurements on several plastic injection moulding machines: Krauss Maffei 1100 MX, Krauss Maffei 1150 MX, and Krauss Maffei KM 1000. On the first machine, the initial test was carried out using standard hydraulic oil (Hydrolubric VG 46), which was later replaced with the high-performance, energy-efficient oil Energolubric 2046 for a repeated test. Similarly, on the second machine, measurements were made first with Hydrolubric VG 46 HC and then with Energolubric 2046.

In both cases, energy consumption was recorded at the main power supply input to the machine, which includes all major electrical loads — most notably the hydraulic pump motor and the plasticizing heaters.

Data acquisition was conducted using Beckhoff hardware and software (Figure 2), employing the EL3443 power measurement module in combination with SCT6421 – 500 A current transformers (accuracy class 0.5). This system enables high-frequency recording (every 20 ms) of key electrical parameters, such as voltage, current, active power, and energy.

Figure 2: Beckhoff data acquisition system.

To verify consistency and ensure reliability, three separate test runs were performed for each oil type on each machine. However, analysis of the results revealed a significant limitation: measuring at the main power inlet was not the most effective or meaningful approach. The repeatability of machine operation from cycle to cycle proved to be very difficult to maintain due to several internal control loops — such as those regulating plastic temperature — where heating elements switch on and off at varying times and intensities.

This limitation is clearly illustrated in Figure 3 which shows the active energy consumption of the KM 1100 MX machine using Energolubric 2046 over three consecutive cycles, each lasting 63.0 seconds. As shown, the energy usage varies considerably from one cycle to the next. This variation makes it nearly impossible to achieve reliable, repeatable measurements with this method alone.

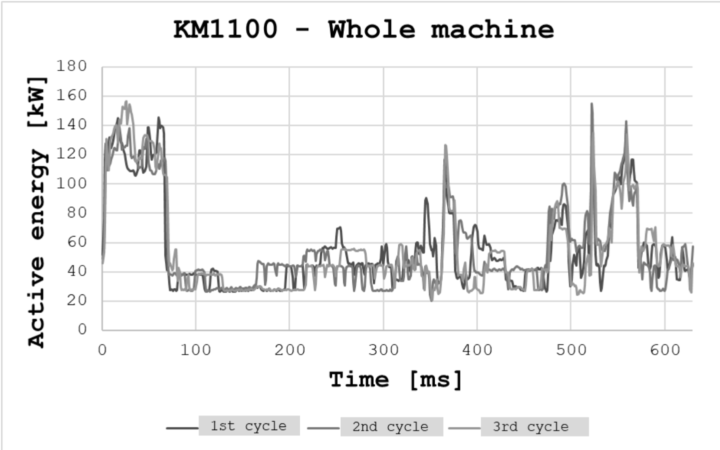

Figure 3: Comparison of three consecutive cycles measured at the main power input.

Although a detailed analysis of the active energy in individual cycles, when measuring on the main power supply, shows a strong non-repeatability of the heaters switching on, we nevertheless performed a numerical analysis of the average active electrical energy in the half-hour interval of the machine's operation. In this case, the influence of the heaters' operation is to some extent removed, since such a measurement contains their average consumption in the aforementioned half-hour interval. Table 2 shows the average active energy during operation of the KM 1100 MX machine in a 30-minute interval when using the classic hydraulic oil Hydrolubric VG 46 and the energy-saving hydraulic oil Energolubric 2046.

Although we are aware that such a measurement of consumption on the main power supply to the machine itself is not completely authoritative, the first analyses of the electricity consumption when using the energy-saving hydraulic oil Energolubric 2046 indicate certain savings of 4.3 %.

Table 2: Comparison of average active energy

KM MX 1100 (30 min interval)	Average active energy [kW]	
Hydrolubric VG 46 – 1st measurement	53.3	53.35
Hydrolubric VG 46 – 2nd measurement	53.4	
Energolubric 2046 – 1st measurement	50.7	51.05
Energolubric 2046 – 2nd measurement	51.4	

Since the measurements performed on the first two machines show promising results, we are now continuing with measurements on the hydraulic pump's drive electric motor itself, which will eliminate the effects of other energy consumers, such as heaters and others. These measurements are performed on the third KM 1000 machine, where it is planned to replace the currently used classic hydraulic oil Hydrolubric VG 46 with the energy-saving oil Energolubric 2046. The measurements are not yet complete. However, we can present the first analysis of the measurements with Hydrolubric VG 46, which confirm that the measurement results of three consecutive cycles are now much more repeatable and comparable, as shown in Figure 4.

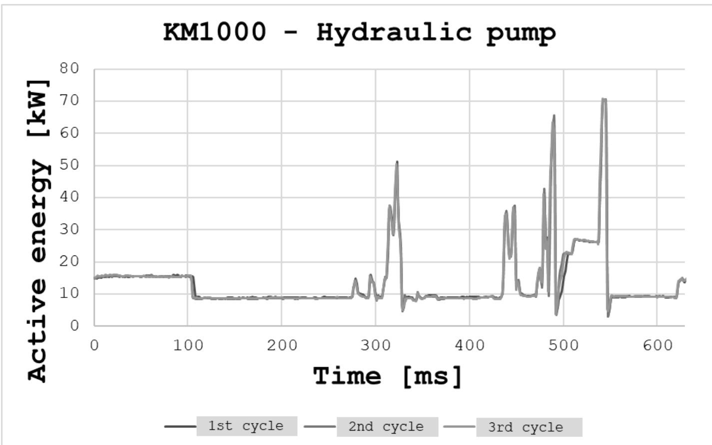

Figure 4: Comparison of three consecutive cycles measured on the drive electric motor.

We decided to perform 6 readings of electricity consumption within each measurement, namely in two consecutive cycles at the beginning of the measurement, in two consecutive cycles after 30 minutes and in two consecutive cycles after 60 minutes. The second measurement on the same machine and during the production of the same product was performed in the afternoon shift, and the third the next day in the morning shift, to determine repeatability or possible deviations between individual measurements. After the machine was used to produce another product in the following days, the fourth and fifth measurements were taken on this machine again a week later on the same product as the week before. The fourth measurement was performed in the morning shift and the fifth in the afternoon shift. The results of the first set of measurements are shown in

Table 3 and Figure 5. We can see that the differences in active power between two consecutive cycles and over a period of 30 minutes or 60 minutes are not large.

Table 3: Comparison of active energy readings of first measurement

Cycles	Avgerage active Power [kW]	Difference to previous cycle [%]	Difference to before 30 min [%]
Start_1	27.865		
Start_2	28.004	0.50	
Middle_1	27.800		
Middle_2	28.143	1.23	0.13
End_1	28.085		
End_2	28.060	-0.09	0.36
1-hour run average	**27.890**		

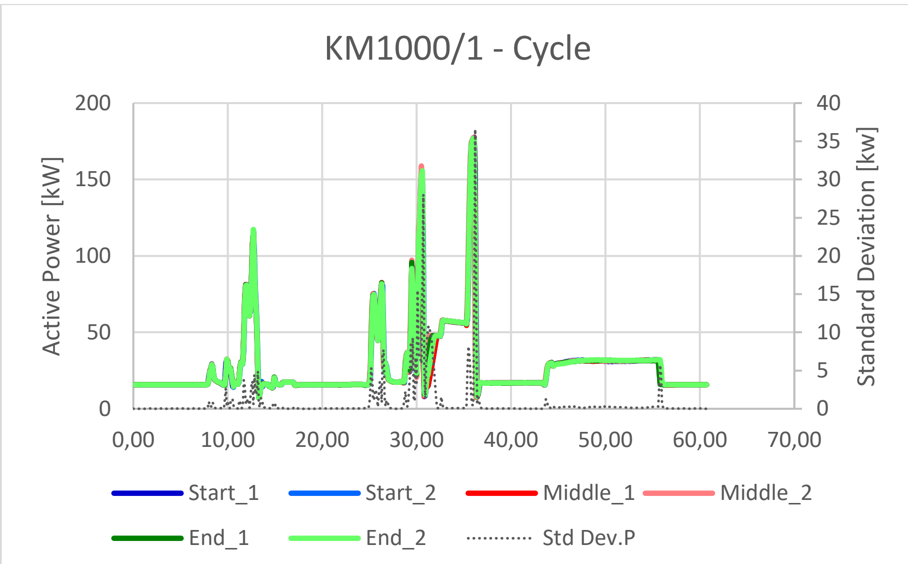

Figure 5: Comparison of active energy consumption during first measurement.

We were able to find a similar result in measurements two, three, four and five. The average active power consumption [kW] in two adjacent cycles and in cycles over a period of 30 min and 60 min is accurate or repeatable to approximately ± 1 %.

A comparison of the average active power consumption [kW] in a 1-hour interval (Table 4) demonstrates that the average active power consumption [kW] in a 1-hour interval is accurate or repeatable to approximately ± 0.4 %, i.e. under 1 % in total.

This will allow us to realistically assess whether the new oil will actually bring savings and what kind.

Table 4: Comparison of average active energy consumption of all five measurements

	1-hour run Average Active Power [kW]	Difference to average [%]
Measurement 1	27.890	-0.52
Measurement 2	28.112	0,28
Measurement 3	27.976	-0.21
Measurement 4	28.064	0.10
Measurement 5	28.134	0.35
Average (1-hour run)	**28.035**	

4 Summary

This paper explores the impact of modern hydraulic oils on the operational efficiency and energy consumption of hydraulic systems. It begins by examining the role of different base oil groups in determining oil performance and service life. The study emphasizes the significance of oxidation stability as a key property influencing oil degradation and system reliability. A new line of Energolubric hydraulic oils was introduced, demonstrating superior oxidation resistance compared to conventional mineral oils.

Oxidation stability tests using the RapidOxy 100 instrument confirmed that Energolubric oils significantly outperform traditional oils, resulting in extended service intervals and lower maintenance costs. Furthermore, energy consumption measurements conducted on plastic injection moulding machines revealed measurable energy savings, up to 4.3 %, when using energy-efficient hydraulic oils. Subsequent, more targeted tests on the hydraulic pump motor confirmed improved measurement repeatability and consistency, with deviations in average power consumption remaining within ±1 %. These measurements were performed using conventional hydraulic oil Hydrolubric VG. The next step will be to repeat the measurements using the modern energy-saving oil Energolubric 2046. These measurements should confirm that this oil actually saves energy and also allow for an accurate assessment of these savings.

The findings suggest that selecting high-quality, oxidation-resistant hydraulic oils can contribute not only to extended oil life and enhanced system reliability but also to measurable improvements in energy efficiency and overall cost-effectiveness.

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