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Rating Hydraulic Fluids for Performance and Sustainability: Bosch Rexroth's Approach

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Abstract

The increasing power density of hydraulic systems and growing demands for environmental compatibility, resource conservation, and energy efficiency are putting traditional mineral oil-based hydraulic fluids under increasing pressure. This encourages the development of new fluid types such as zinc- and ash-free formulations, biodegradable and bio-based hydraulic fluids, and re-refined base oils (RRBO). In view of this development, Bosch Rexroth has expanded its "Fluid Rating 90235" [1], established in 2015, which originally focused on wear behaviour and component lifespan. Since 2026, the rating includes a practical oil aging test for precise evaluation of fluid lifetime. In the future, the Fluid Rating will be supplemented by a comprehensive sustainability block, integrating criteria such as energy efficiency, environmental compatibility, and aspects of circular economy, including life cycle assessments (LCA) and product carbon footprints (PCF). This expanded assessment approach enables a standardized and transparent evaluation of hydraulic fluids, considering modern technical and regulatory requirements, and supports the transformation towards more sustainable fluid solutions.

Keywords. Fluid Rating, sustainability, energy efficiency, oil aging, performance, regulatory requirements

1. INTRODUCTION

In recent years, the performance of hydraulic systems has once again significantly increased. Consequently, the demands on the hydraulic fluids used are also rising steadily, as they can, for example, decisively influence the wear properties of hydraulic components. Relevant standards only define minimum requirements for hydraulic fluids. They do not reflect technical advancements and do not allow for differentiation between fluids. Bosch Rexroth offers lubricant and additive manufacturers a standardized evaluation procedure based on scientific findings, which takes these aspects into account and tests hydraulic fluids for suitability under realistic operating conditions.

The increasing power density, growing demands for environmental compatibility, resource conservation, energy efficiency, occupational safety, and rising regulatory requirements from countries and authorities pose new challenges for the development of hydraulic fluids. Traditional mineral oil-based fluids, which currently make up the majority of the market, are increasingly under pressure as the mentioned aspects become crucial criteria (Figure 1).

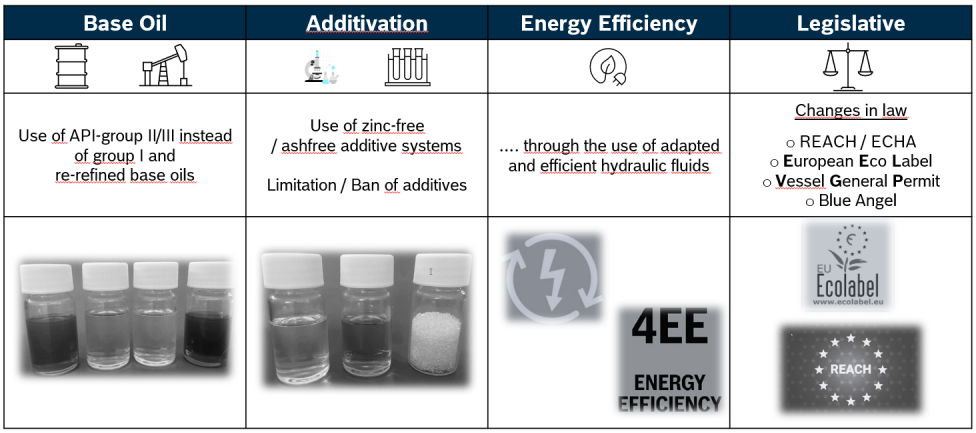


Figure 1: Challenges for future high performance hydraulic fluids

This development promotes the emergence and use of new fluid types, including zinc- and ash-free formulations, biodegradable hydraulic fluids, bio-based products, re-refined base oils (RRBO), and fire-resistant fluids. This change is no longer driven solely by environmental awareness but significantly by stricter regulations, the pursuit of carbon neutrality, and technical innovations. For example, biodegradable lubricants are increasingly used in environmentally sensitive areas such as transport, marine, food processing, and forestry and agriculture.

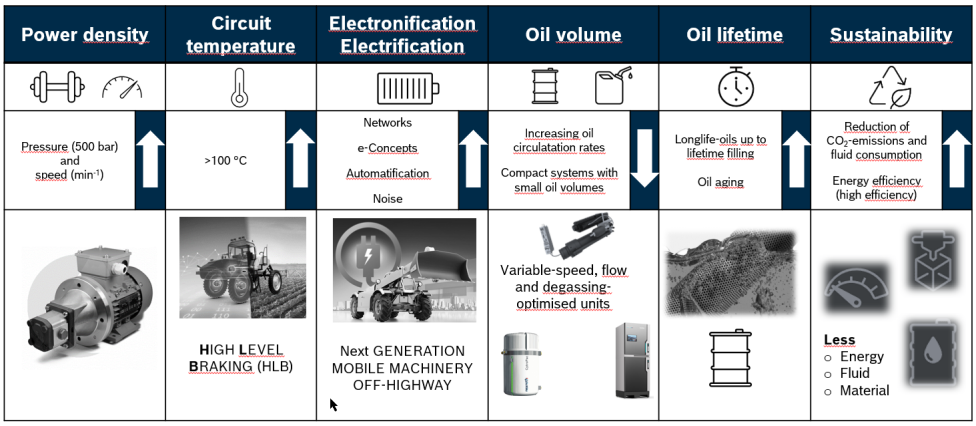


Figure 2: Changes and trends in hydraulic systems and components

At the same time, hydraulic applications are also being further developed through electronification and electrification. The replacement of internal combustion engine-driven systems by electric drives, power-on-demand systems with electrically controlled pumps,

and decentralized hydraulic systems with small oil volumes and high-power density require correspondingly adapted fluid properties (Figure 2).

2. STATE OF THE ART AND TRENDS

Hydraulic fluids based on mineral oils are the most used group, accounting for approximately 85%. About 15% of the market share is accounted for by synthetic base oils, such as esters, polyalphaolefins (PAO), and polyalkylene glycols (PAG). Among mineral oil-based base oils, the trend is moving away from paraffinic API (American Petroleum Institute) Group I towards hydrotreated paraffins of API Group II (hydrotreated) and Group III (hydrocracked) (Figure 3).

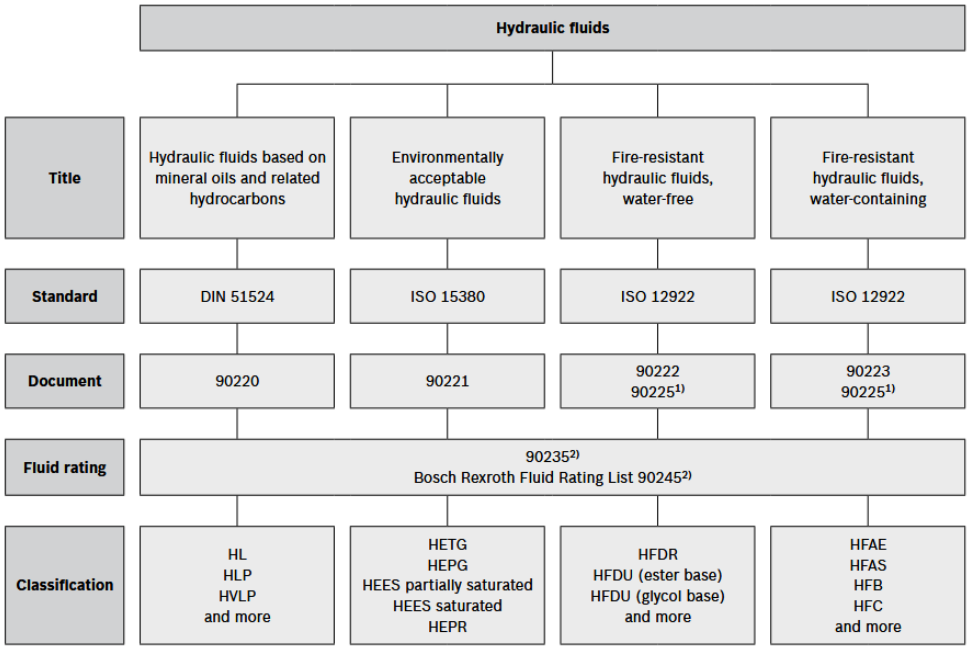


Figure 3: Overview of classification and relevant standards for hydraulic fluids [1]

To address this development, Bosch Rexroth has already established a standardized rating procedure for hydraulic fluids – the Bosch Rexroth Fluid Rating 90235 (Figure 4) [1]. Since then, this has become a recognized industry standard and is used by many fluid and additive manufacturers for the development of fluid formulations and hydraulic fluids. The primary focus has been and continues to be mainly on the wear behaviour and lifetime of hydraulic components.

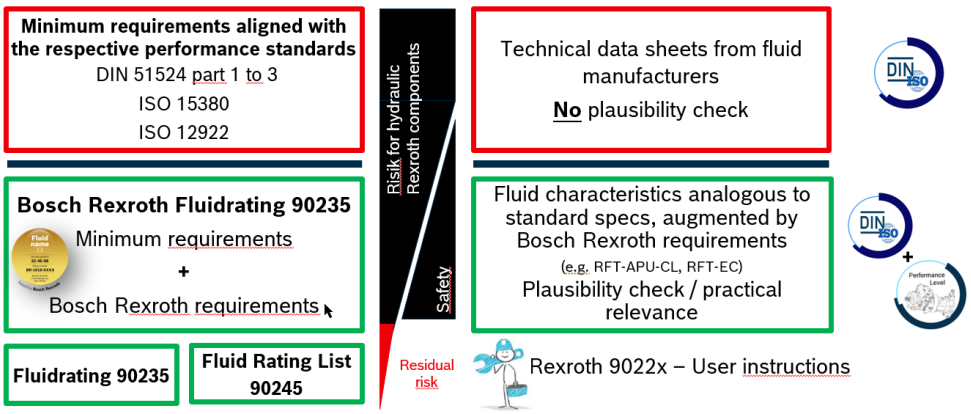


Figure 4: Bosch Rexroth Fluidrating: actual structure

The central part of the Fluid Rating, in addition to stricter requirements based on relevant performance standards and a seal and oil aging test, is a comprehensive fluid test based on the use of hydraulic components such as swash plate axial piston pumps and bent axis axial piston motors (Figure 5).

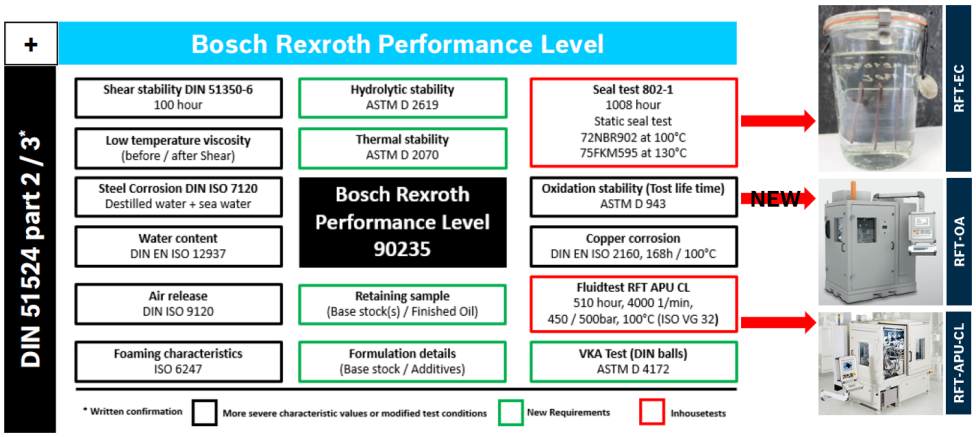
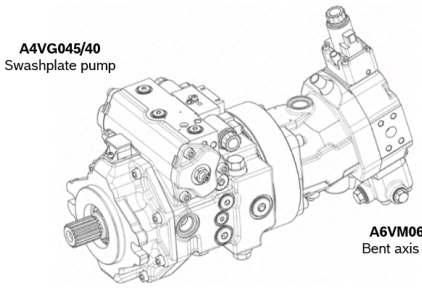


Figure 5: Bosch Rexroth Performance Level for mineral oils H(V)LP

These units simulate a typical hydrostatic drive in a closed circuit and, due to their high-performance parameters (pressure, speed, temperature), also cover the requirements of units in open circuits regarding wear behaviour and material compatibility. The drive components used are subject to strict quality control, are precisely measured and documented to minimize influences from test specimens. Such a fluid test lasts a total of 510 hours and includes phases such as run-in, swivel cycle, and corner power operation (Figure 6). After the test run, a detailed evaluation of the relevant components is carried out.

To reduce resources, the test units for the fluid tests are not completely replaced by new ones but reconditioned, and only relevant components, such as the rotary group and seals, are replaced – already a corresponding contribution to the sustainability claim.



	Cycle	pHD (bar)	Speed (1/min)	$T_{A6\_Leakage\ oil}$ (°C)	Duration (h)
1	Run-in	250	2000	60	10
2	Swivel Cycle	450	4000	100 (110)	300
3	Corner Power	500	4000	100 (110)	200

Figure 6: Bosch Rexroth Fluid Test RFT-APU-CL (Rexroth Fluid Test Axial Piston Unit Closed Loop)

The Fluid Rating currently covers the different fluid categories: mineral oils, environmentally acceptable hydraulic fluids, UTTO oils, and hydraulic fluids based on re-refined base oils (RRBO).

3. OBJECTIVE AND APPROACH

Given the necessity to transparently rate new fluids (e.g., RRBO, biodegradable fluids, fire-resistant fluids) and the associated requirements regarding environmental compatibility, efficiency, and resource conservation, an expansion of the rating to include a comprehensive sustainability block is sought.Criteria such as fluid lifetime, energy efficiency, environmental compatibility in the context of the entire lifespan, and the CO2 footprint are to be integrated into the Fluid Rating in the future (Figure 7).

A first step for this is the recently implemented inclusion of an oil aging test, to assess the lifetime of hydraulic fluids more practically than the TOST TEST (Total Oxidation Stability Test) currently required in standardization. This will be described in more detail in Section 4.1.

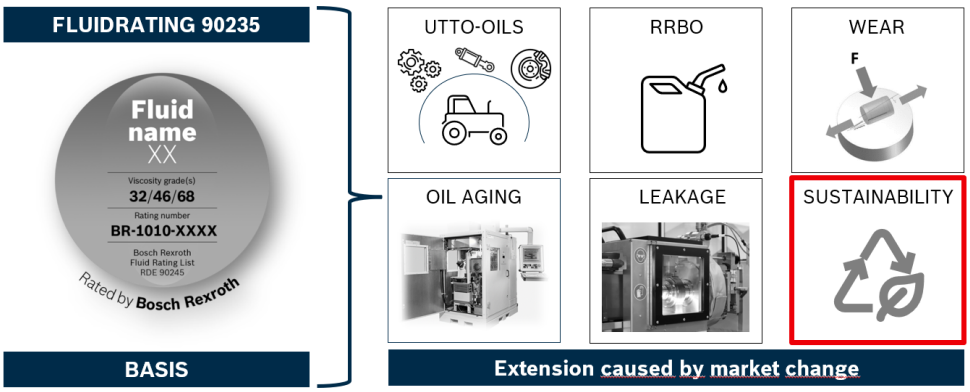


Figure 7: Extension of the fluid rating due to market change

The new requirements, in addition to the lifetime of hydraulic components which serves as the basis, are now to be integrated into the Fluid Rating as follows:
The primary objective is the development of a standardized and transparent evaluation procedure for additional sustainability aspects of hydraulic fluids. This essentially includes the following criteria (Figure 8):

- **Fluid Lifetime:** (Expanded in 2026 by an oil aging test)
- **Energy Efficiency:** Evaluation of the hydraulic fluid's influence on the system's energy consumption.
- **Environmental Compatibility:** Evaluation of ecological impacts, including biodegradability, toxicity, and water hazard class.
- **Circular Economy** (Life Cycle Assessment, LCA) **and CO2 Footprint** (Product Carbon Footprint, PCF): Evaluation of environmental impacts throughout the fluid's entire life cycle, from raw material extraction to disposal/recycling.

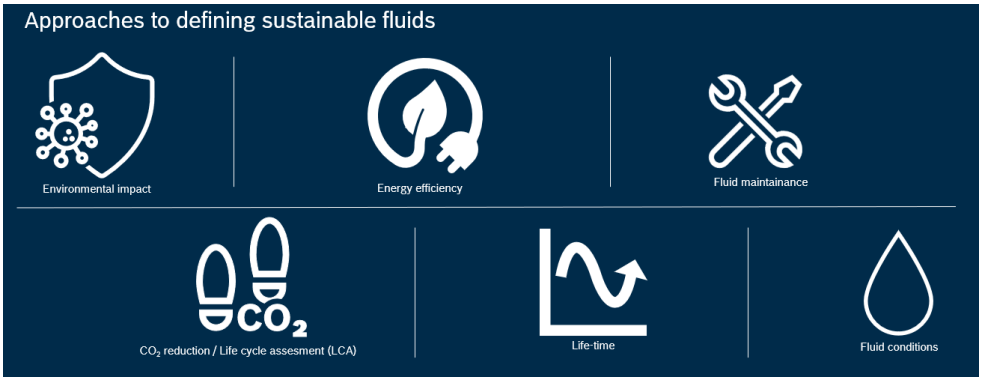


Figure 8: Sustainability aspects for hydraulic fluids

The approach envisages offering this expanded evaluation block successively in several expansion stages as a further module to the existing Fluid Rating. This requires the development of new test methods, the identification of relevant fluid parameters, and the creation of a transparent rating system that enables the comparison and classification of fluids regarding their sustainability performance (Figure 9).

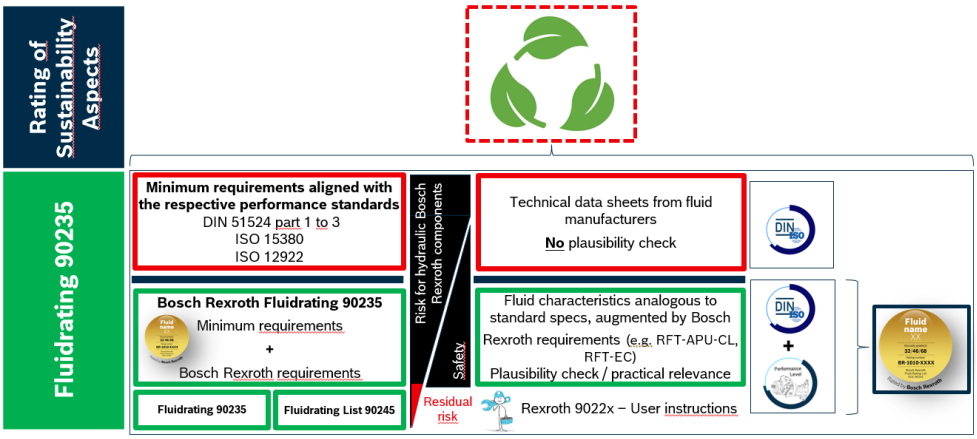


Figure 9: Sustainability aspects as a further rating block on top of the existing Bosch Rexroth Fluidrating

4. CURRENT STATUS AND ACHIEVED RESULTS

The expansion of the Fluid Rating is being carried out through targeted research and development efforts in the following areas:

4.1. Lifetime of Hydraulic Fluids

The determination and evaluation of the hydraulic fluid's lifetime are carried out using a specially developed oil aging test rig.

This fully automated test rig subjects the fluid to accelerated aging for over 300 hours at 90 °C with the addition of a copper catalyst and air. Automatically taken oil samples are regularly analyzed to comprehensively record and evaluate the aging behaviour (Figure 10). This test closes the gap for a practically relevant aging assessment that was not covered by the conventional TOST (Total Oxidation Stability Test).

Figure 10: Bosch Rexroth Oil Aging Test [2]

In preparation for inclusion in the Fluid Rating, tests were carried out with a reference oil (mineral oil HLP containing zinc), and the aging behaviour was determined over time based on NMR analyses (nuclear magnetic resonance analysis) and FTIR spectroscopy (Fourier-Transform Infrared Spectroscopy) and documented under different test parameters (speed, pressure, temperature).

4.2. Energy Efficiency (Development of a Systematic Approach)

The influence of hydraulic fluids on the energy efficiency of hydraulic systems is often underestimated. Currently, a uniform and standardized rating procedure is lacking. Bosch Rexroth plans, in cooperation with industrial partners and institutes, to identify relevant fluid parameters that influence the efficiency of various hydraulic components. Based on experimental data, a systematic approach will be developed and integrated into the Fluid Rating. This will enable a comparison and evaluation of hydraulic fluids regarding their contribution to energy efficiency in different applications. In the long term, this could include the development of a dedicated energy efficiency test rig and a standardized evaluation procedure to validly assess energy efficiency in various applications.

4.3. Environmental Compatibility (Integration of Labels and Criteria)

The environmental compatibility of hydraulic fluids is determined by their chemical composition, their behaviour in case of leaks, and their disposal. The assessment includes biodegradability, toxicity, and water hazard class. Transparent representation is achieved by integrating existing environmental labels and certifications such as the Blue Angel, VGP (Vessel General Permit), or the EU Ecolabel. These labels certify compliance with relevant environmental requirements. Additionally, ISO (International Organization for Standardization) certifications and manufacturer specifications, as well as fluid monitoring concepts, can be used to minimize environmental impact.

4.4. Circular Economy and CO2 Footprint (LCA/PCF Assessment)

For the evaluation of circular economy, the analysis includes the proportion of recycled or bio-based raw materials, the avoidance of scarce or poorly degradable raw materials, environmental impacts during raw material extraction and processing, reprocessability and recyclability, as well as corresponding service concepts and condition monitoring. The assessment of the CO2 footprint considers emissions from raw material extraction and production, behaviour during the use phase (energy efficiency, oil lifetime, leaks), and end-of-life management (emissions and energy consumption during transport, reprocessing, and disposal). For a neutral and comparable assessment, life cycle assessments (LCA) according to recognized standards are used, possibly in cooperation with independent institutions.

5. SUMMARY AND OUTLOOK

The increasing power density in hydraulic applications and global sustainability goals necessitate a fundamental adaptation of fluid formulations. The Bosch Rexroth Fluid Rating, a proven tool for rating the performance of hydraulic fluids, is being consistently expanded to meet these new requirements. By integrating aspects such as energy efficiency, oil aging, environmental compatibility, and holistic life cycle analyses (LCA/PCF), we are creating a comprehensive rating platform.

Achieved Results:

- Component lifetime is already established.
- The existing Fluid Rating has been supplemented since the beginning of the year by a practical oil aging test, which precisely evaluates the lifetime of fluids.
- The foundations for integrating energy efficiency parameters have been laid to make the influence of fluids on system efficiency measurable.
- A framework for evaluating environmental compatibility based on existing labels and other criteria is being established.
- The need for a comprehensive LCA/PCF assessment has been recognized, and the steps for implementation have been defined.

Outlook:
Bosch Rexroth will continue to actively support the transformation of the fluid industry. In the next steps, the detailed methodology for evaluating energy efficiency, environmental compatibility, and LCA/PCF aspects will be finalized and integrated into the Fluid Rating. This will be carried out gradually in several expansion stages.
Furthermore, we see potential for more intensive cooperation with the fluid industry to jointly develop sustainable hydraulic fluids that meet both the highest performance requirements and strict sustainability criteria. The possibility of offering fluid monitoring concepts in conjunction with the expanded rating criteria will also be evaluated. The goal is to provide users with transparent and reliable information for selecting the optimal fluid for their specific needs while promoting the sustainable development of hydraulic technology.

6. REFERENCES

[1] Bosch Rexroth data sheet ‘Rating of hydraulic fluids for Rexroth hydraulic components (pumps and motors)’, RE 90235/02.2015.
[2] Bosch Rexroth data sheet ‘Rexroth Oil aging test rig RFT-OA’, RE 98145/2025-06-11.

Biographies

Klaus Ellenrieder[1] received the Diplom Ingenieur degree in mechanical engineering 1995 at the Technical University in Munich and the MPhil degree 1996 at the Silsoe College / Cranfield University in UK. He was responsible for the testing department at Bosch Rexroth in Elchingen, Gemany, until end of 2023 and is currently working as the head of the Business Innovation Team Fluids at Bosch Rexroth.

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