Enhancing hydraulic efficiency using Secondary Polyol Ester® technology

***Martin Greaves*, *Zach Hunt*, *Jeff DiMaio*, *Nathan Knotts*, VBASE Oil Company**

One of the principal challenges currently facing lubricant engineers is the development of formulations that deliver improved energy efficiency. In response to this challenge, a new generation of Secondary Polyol Ester® (SPE®) base oils[1] has been developed by VBASE Oil Company through controlled molecular design. In this article the energy-efficiency performance of a synthetic hydraulic fluid formulated using SPE® technology in comparison with a leading factory-fill approved hydraulic fluid is presented. Key aspects of the underlying SPE® chemistry and its contribution to multifunctional performance is highlighted.

Background

Hydraulic systems provide precise control and power transmission in sectors like manufacturing, construction, and transportation. As industries seek improved performance with reduced environmental impact, enhancing hydraulic efficiency has become a priority. Small efficiency improvements can significantly reduce fuel consumption, heat generation, and wear, leading to lower operating costs and enhanced sustainability.

While mechanical design improvements are essential, hydraulic fluid formulation plays a crucial role in system performance. The fluid transmits energy and its physical properties such as viscosity, friction control, shear stability, and air release directly affect energy loss and component life[2]. Advanced formulations reduce internal friction, minimise leakage, and maintain optimal viscosity over a wide temperature range[3].

The use of synthetic hydraulic fluids has become central to efficiency improvements. Traditionally derived from API Group I mineral oils, hydraulic fluids have evolved with the introduction of Group II and III base oils, and later, synthetics such as esters, PAOs and PAGs. Synthetic fluids offer superior high-temperature stability, longer fluid life, and reduced environmental impact, particularly in applications subject to stringent regulations.

Over the past two decades, the adoption of synthetic fluids has accelerated due to several factors including energy efficiency mandates, environmental regulations promoting biodegradable fluids and compact high-pressure systems requiring superior shear stability. Looking forward, they will continue to play a pivotal role as electrification trends demand precise thermal management, sustainability goals push for low-carbon fluids, and OEMs design equipment optimised for high-performance fluids. Energy-efficient fluids enhance the performance and longevity of electrified systems by improving heat management, reducing friction, and lowering power losses, all of which contribute to extended battery life and more efficient power usage. These fluids not only optimise the operation of electric vehicles, machinery, and electronics but also support sustainability goals through reduced maintenance and environmental impact.

Hydraulic efficiency study

The Fluid Power Institute at the Milwaukee School of Engineering (MSOE) (led by Director Paul Michael) conducted a comprehensive hydraulic efficiency evaluation to measure the performance impact of an SPE® formulated EAL (environmentally acceptable lubricant) hydraulic fluid compared to a mineral oil-based reference fluid. The goal was to quantify differences in frictional (torque) and volumetric (flow) losses under realistic operating conditions using a hydraulic dynamometer test stand.

Test stand and equipment

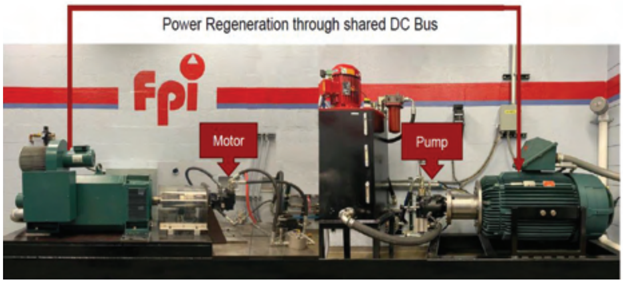

Figure 1: *MSOE Fluid Power Institute hydraulic efficiency test stand showing pump–motor loop and instrumentation setup.*

Testing was conducted using a closed-circuit hydraulic test stand (Figure 1) and consisted of:

- **Pump:** Linde HPR-75 axial piston pump.
- **Motor:** Poclain radial piston motor .
- **Reservoir:** 25-gallon capacity with inline heating and cooling for temperature control .
- **Instrumentation:** High-accuracy torque transducers, flow meters, pressure sensors, and thermocouples to record torque, flow rate, pressure, and temperature.
- **Control:** Proportional relief and load valves to regulate system pressure.

The circuit was designed to simulate typical mobile hydraulic operation with precise control over pressure, flow, and temperature.

Test conditions

- **Temperature:** Maintained at 80 °C ± 1 °C (bulk oil) .
- **System Pressure:** 13.8, 20.7, and 27.6 MPa (2,000, 3,000, and 4,000 psi).
- **Motor Speed:** 400, 600, and 800 rpm.
- **Pump Speed:** Varied to achieve target motor speed (rpm) and system pressure (MPa).

Each test condition was repeated six times for reproducibility. Torque, flow, and temperature data were measured and averaged across steady-state intervals.

Typical physical properties of test fluids

Property	Industrial Hydraulic Fluid	VBASE EAL HF*
Kinematic Viscosity, 40 °C (cSt)	42.0	45.1
Kinematic Viscosity, 100 °C (cSt)	6.7	8.7
Kinematic Viscosity, 0 °C (cSt)	Not listed	402
Viscosity Index	114	174
Pour Point (°C)	-39	-42
Flash Point (°C)	227	>250
Pumping Viscosity, -30 °C (cP)	15,000	< 10,000
Air Release, 50 °C (min)	< 4	0.1
Copper Strip Corrosion	1A	1A
Rust Protection	Pass (A/B)	Pass (B)
Foam Sequence I (ml)	Not listed	0 - 0
Foam Sequence II (ml)	Not listed	0 - 0
Foam Sequence III (ml)	Not listed	0 - 0
Demulsibility (54 °C)	Not listed	40-37-03
Zinc Content (wt.%)	~0.090	0 (ashless)
Phosphorus Content (wt.%)	~0.073	<0.05

Table 1: *Mineral Oil Industrial Hydraulic Reference Fluid compared to VBASE EAL HF (*formulated to meet ISO 15380).*

Two fluids were tested (Table 1 compares typical properties):

1. **Industrial Hydraulic Reference Fluid** is a leading SAE 10W (ISOVG-46) mineral oil hydraulic fluid that is an approved factory fill product.
2. **VBASE EAL Hydraulic Fluid** is a formulated hydraulic fluid using SPE® base oils, (ISOVG-46) and comprises an ashless anti-wear additive package with components that are EU-LuSC listed. The formulation is targeted to meet ISO-15380 (for environmentally acceptable hydraulic fluids).

The mineral oil reference fluid exhibits good low temperature properties but a comparatively low viscosity index. It is speculated it contains no Viscosity Index Improver (VII) due to the risk of shear degradation under high pressure conditions. The product also offers good corrosion inhibition. The presence of zinc and phosphorus suggests it contains a classical zinc dialkyldithiophosphate (ZDDP) antiwear additive.

The novel SPE® EAL hydraulic fluid exhibits a significantly higher VI (and does not contain VI Improvers) and good low temperature properties. Interestingly, it exhibits a remarkably low air release time and low foaming. Smaller equipment reservoirs are being designed, in part, to reduce capital costs incurring even greater stresses to the fluid. Its ability to rapidly release air and avoid issues such as cavitation, will be a key functional requirement of future fluids.

Results and discussion

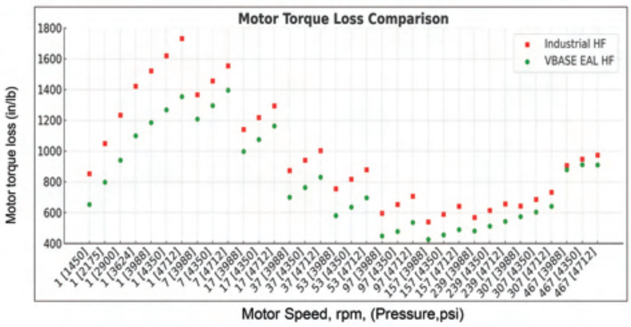

Figure 2: *Motor torque loss comparison between VBASE® EAL hydraulic fluid and reference fluid at multiple speeds and pressures.*

Motor torque loss represents energy loss due to friction and component drag within the hydraulic motor. Lower torque loss indicates reduced internal friction and higher mechanical efficiency. Across all speeds and pressure conditions, the novel SPE® hydraulic fluid consistently exhibited lower torque loss than the reference oil (Figure 2). The difference was most pronounced at high pressure and low speed, conditions where boundary and mixed lubrication regimes dominate, and up to a 25% difference was measured. This improvement is attributed to the low friction coefficients of SPE® base oils under thin-film or mixed lubrication conditions.

System flow loss

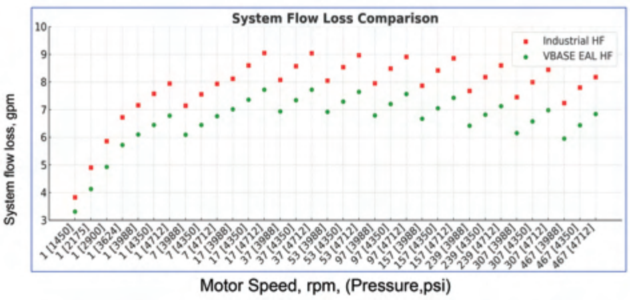

Figure 3: *System flow loss reduction observed with VBASE® EAL fluid versus reference fluid.*

System flow loss encompasses leakage, compression, fluid resistance and shear losses within the pump and system plumbing. The novel SPE® hydraulic fluid demonstrated 10–20% lower flow loss than the reference oil over the entire duty cycle (Figure 3). The advantage remained consistent across all pressures and speeds, suggesting improved sealing efficiency, and reduced fluid leakage under load resulting in improved system responsiveness.

Overall energy efficiency and power ratio

When torque and flow data are combined, they define total hydraulic efficiency. "The Motor Output Power Ratio" divided by "Pump Input Power Ratio" at each point gives the relative efficiency compared to the reference fluid.

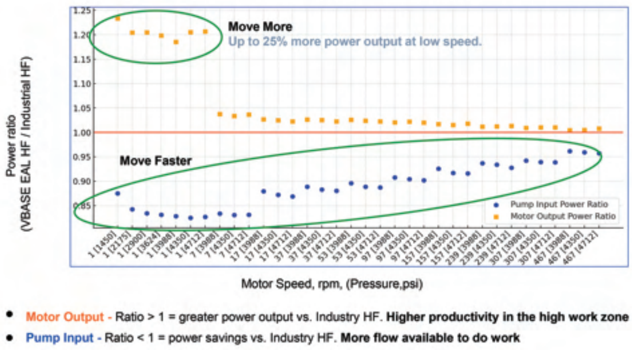

Figure 4: *Power ratio analysis showing higher motor output and lower pump input power with the SPE® formulation.*

Figure 4 illustrates the Power Ratio analysis showing higher motor output and lower pump input power with the SPE® EAL hydraulic fluid normalised against the reference fluid. In the low-speed range, there is up to 25% higher overall efficiency compared to the reference fluid. In the mid- to high-speed range, the efficiency gain is ~ 5–12%. In practical terms, this means more useful work delivered at the actuator per unit of input power at the pump, leading to measurable reductions in fuel or power consumption.

The MSOE results confirm that a hydraulic fluid built on SPE® base oils delivers measurable performance improvements in both mechanical and volumetric efficiency and this has key operational implications such as

- Higher productivity: More effective work delivered at the tool or actuator.
- Lower energy use: Reduced pump power demand, translating into energy savings.

For OEMs and fluid formulators, these results demonstrate the potential of SPE® technology to meet increasingly stringent efficiency and sustainability goals.

Connecting performance with the chemistry behind alkoxylated polyol esters

SPE® base oils are alkoxylated polyol esters. Their structure incorporates highly controlled branching, multiple ester linkages, and oxyalkylene oligomer segments (alkoxy segments) each contributing to specific performance advantages in hydraulic systems. Below is an explanation of how the chemistry of their structural features enable their functional performance.

Friction control
The combination of ester functional groups and alkoxy segments creates low intermolecular shear resistance.

In elastohydrodynamic (EHD) and mixed lubrication regimes, molecular mobility is essential. The flexible alkoxy chains reduce resistance to molecular sliding under high pressure.

In hydraulic systems this reduces internal friction leading to improved mechanical efficiency and lower power consumption.

High VI
The flexible branched alkoxy segments provide controlled free-volume expansion with temperature, resulting in a naturally high viscosity index.

High-VI base oils do not require VII polymers, which are susceptible to shear degradation in high-pressure pumps.

As a result, stable viscosity under load and temperature fluctuations can yield better pump efficiency and reduced energy loss.

Polarity-balanced Structure for elastomer compatibility and wear protection
Alkoxylation allows molecular design engineers to dial in a precise polarity balance by introducing ether segments alongside the ester groups providing good elastomer compatibility.

Balanced polarity and their oxygen-rich structures, strengthens adsorption to metal surfaces, improving boundary lubrication and forming a resilient lubrication film even under low-speed or high-load conditions.

Built-in detergency
Ester functional groups and polar ether segments give naturally higher solvency power compared to non-polar base oils.

This intrinsic solvency can dissolve polar oxidation by-products that can deposit on valve surfaces and reservoirs.

Their ability to keep surfaces clean can minimise varnish, sludge buildup, and sticking of servo valves.

The practical implication is cleaner equipment, lower maintenance, and improved long-term component performance.

Biobased and biodegradable
By choosing oleochemical feedstocks in the esterification process, their renewable carbon content is high and typically greater than 50%.

Ester linkages within their structure are biodegradable through enzymatic and hydrolytic pathways, allowing the fluid to break down naturally in the environment.

These features create environmentally responsible hydraulic fluids meeting modern sustainability and regulatory demands.

Summary
Independent third-party testing at MSOE confirmed that a hydraulic fluid formulated with novel SPE® technology delivers quantifiable improvements in efficiency. By reducing torque and flow losses, hydraulic equipment can transmit more power to the tool while requiring less power at the pump improving total energy utilisation across the hydraulic circuit. This efficiency translates into greater work output per unit of input energy, enabling operators to move more material with less fuel or power consumption. These advantages can drive a measurable reduction in total cost of ownership, achieved through improved machine productivity, extended service life, and lower overall energy consumption.

VBASE® SPE® technology offers new solutions to designing the next generation of hydraulic fluid formulations where OEMs demand both higher performance and efficiency, along with environmental responsibility.

References
[1] M. Greaves, J. DiMaio, M. DiMaio, Z. Hunt, B. Bergmann, Exploring the functionality of SPE® Base oils, Lube Magazine, No. 183, Oct. 2024.
[2] Totten G.E., Handbook of Hydraulic Fluid Technology, Marcel Decker New York 2000.
[3] Alibert, M., & Schimmel, T. (2012). Importance of Viscosity for Hydraulic Fluid Efficiency, Proceedings of the 8th International Fluid Power Conference (IFK 2012), Dresden.

vbaseoil.com