Fundamental Lubricity Protection of Bio-Hydraulic Fluids versus Conventional Petroleum Hydraulic Fluids

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ABSTRACT

The use of vegetable oil as the base fluid for environmentally responsible lubricants has gained popularity over the past three decades, first in Europe during the 1980’s due to various laws placed on petroleum products, then during the 1990’s as many American companies began to develop seed oil based lubricants as well. Beyond environmental advantages, vegetable-based hydraulic fluids have several advantages that should be considered for industrial lubricant performance and usage. They have excellent lubricity, over and above petroleum oil. A literature search shows bio-hydraulic fluids offer enhanced lubricity versus petro-hydraulic fluids. Using ASTM D2670-Falex Pin & Vee Block Test to measure wear, then using prescribed formulary for converting wear data into coefficients of friction, our own experimental measurements showed a 20 to 70% reduction in the coefficient of friction (average of 57%) for canola-based vegetable oils, which correlates to better lubricity protection when the selected bio-hydraulic fluids were compared to the selected conventional petro-hydraulic fluids.

INTRODUCTION

Viscosity is the single most important physical property of a lubricant. It is a measure of a lubricant’s ability at the molecular level to keep moving surfaces separated and easily slipping past each other with a minimum of friction and wear. Basic physics suggests that the higher the fluids operating temperature, the lower the viscosity of the fluid becomes, so a given fluids coefficient of friction performance over a temperature band would correlate to fundamental lubricity protection differences.

Viscosity Index then is a number that indicates the lubricants resistance to viscosity loss with increasing temperature. Vegetable-based bio oils have a very high Viscosity Index, >200 as opposed to 95-100 for most petroleum oils. Vegetable oils can have double the resistance to high temperature viscosity thinning over petroleum based lubricants. When comparing lubricity protection this is a double-negative for petro-hydraulic fluids when contrasted to bio-hydraulic fluids:

1. Petro-hydraulic fluids can run hotter due to friction than bio-hydraulic fluids.
2. Due to their low VI petro-hydraulic fluids will have:
   - ‘Thinner’ viscosity at high temperatures versus the advantageous heavier viscometric protection offered by high VI bio-hydraulic fluids.
   - ‘Thicker’ viscosity at low temperatures versus the advantageous lighter viscometric protection offered by high VI bio-hydraulic fluids.

Another important property of vegetable oils is their high flash/fire points; 610°F/670°F for canola oil compared to 400°F/450°F for mineral oils. This makes them suitable for use in fire resistant hydraulic fluid applications.

Most importantly, vegetable oils are not only biodegradable but also renewable. By definition, a renewable raw material is a material of plant, animal, or microbial biomass. In addition, materials from native crops, trees, and agricultural waste can provide many of the same chemical building blocks that petroleum products and other chemical processes cannot provide without depleting these resources so that they are available to future generations. To further differentiate this difference, the USDA administers a *“Bio-preferred”* program for which those materials that are listed must be renewable in order to, *“… spur economic development, create new jobs and provide new markets for farm commodities. The increased development, purchase, and use of bio-based products reduce our nation's reliance on petroleum, increase the use of renewable agricultural resources, and contribute to reducing adverse environmental and health impacts.”* A modified petroleum based lubricant which passes one of the biodegradable test protocols is not renewable and will not be listed on the Bio-preferred web site.

EXPERIMENTAL

Evaluation of frictional properties was performed using The Falex Pin & Vee machine running under ASTM D2670 conditions modified to accommodate hydraulic oils and their lower Extreme Pressure resistance, but higher anti-wear properties.

Summary of Test Method: The test consists of running a rotating steel journal against two stationary steel V-blocks immersed in the lubricant sample. Load is applied to the V-blocks and maintained by a ratchet mechanism. Wear is determined and recorded as the number of teeth of the ratchet mechanism advanced to maintain load constant during the prescribed testing time.
Standard Coined V-Blocks & Standard Test Journals: Per the test standard.
Test Conditions: Place the loading arm on the ratchet wheel and actuate the motor. Allow the motor to run until the load gage indicates a load of 200 lb. A slight take-up on the ratchet wheel is required to hold the load due to the ball sinking into the test coupon. After a 200-lb load is obtained, hold for 1 min for the indentation to form. Turn off the machine and back off the load until the test coupon is free from the jaws. Advance the test coupon approximately 3⁄8 in. (approximately 9.5 mm) (additional indentations should be separated by a minimum distance of 2.5 × the diameter of the initial indentation). Check the alignment of the jaws, and repeat the procedure at prescribed gage loads:

- If a 800-lb gage is used, check at 400, 600, and 800 lb when using an 800-lb gage.
- If a 3000-lb gage is used, check at 800, 1500, and 2500 lb.

The experimental test consisted of running at a Direct Load on the lower end of the scale; otherwise friction and wear measurements cannot be taken before one of the pins break, ending the test. During the time the test is being run, the Time, Torque, Temperature and Teeth wear are being recorded. This data is available for analysis. The torque readings can be converted to Coefficient of Friction using the manufacturer's formula: **2.9726 x Torque/Direct Load**

Tables of data can be set up from which various graphs can be pulled to better understand the results. Table 1 lists the hydraulic fluids examined in this study:

Table 1: Hydraulic Fluids Tested

Petro-based Hydraulic Fluid Label	**Petroleum Based Fluid Description**
Petro AW 46 HD	AW hydraulic oil for moderate loads and temperatures
Petro AW 46 ZDP	AW hydraulic oil for high pressure, high output pumps
Petro AW 46 G[4]	AW hydraulic oil for equipment operating in environmentally sensitive areas
Petro AW 46 C[3]	AW hydraulic oil for high performance industrial applications and environmentally sensitive areas
Bio-based Hydraulic Fluid Label	**Biodegradable Vegetable Oil Based Fluid Description**
Bio AW 46 EAL[1]	AW hydraulic oil suitable for use in ecologically sensitive applications
Bio AW 40 EA[2]	AW enviro-aware hydraulic oil for use in hydraulic and circulation systems operating at moderate conditions
Bio AW 46 BSF	AW biodegradable biosynthetic formula to replace mineral oil based AW hydraulic fluids
Bio AW 46 FR[1]	Fire Resistant AW hydraulic fluid for use in applications requiring a Factory Mutual approved FRHF

(1) This product meets current EPA requirements to be classified as Environmentally Acceptable Lubricants (EALs) as per the EPA's 2013 Vessel General Permit (VGP) mandated legislation which is currently in effect. This means they meet EPA-recognized protocol testing requirements to be classified as Readily Biodegradable, Minimally Toxic and Not Bioaccumulative.
(2) This bio-hydraulic fluid does not meet the viscosity grade requirements to be classified as a true ISO 32 or ISO 46; instead its viscosity is mid-range between an ISO 32 and ISO 46 (i.e. ISO 40). Further, while it utilizes a vegetable base oil for biodegradability characteristics, it cannot be classified as an EAL as per the EPA's 2013 VGP because it passes only 1 of 3 EPA mandated OECD Minimal Toxicity tests *(Note: ISO/DIS 10253 for algae, ISO TC147/SC5/W62 for crustacean, and OSPAR 2005 for fish, may be substituted.)*:

OECD 201 (algae):	**No Pass**
OECD 202 (crustacean):	**No Pass**
OECD 203 (fish):	PASS

(3) Petro AW 46 C is not formulated with natural or synthetic ester base oils thus it does not meet the generalized definition to be classified as a bio-hydraulic fluid (it's inherently biodegradable). However, it does pass 1 of 3 EPA mandated OECD Minimal Toxicity tests:

OECD 201 (algae):	**No Pass**
OECD 202 (crustacean):	**No Pass**
OECD 203 (fish):	PASS

(4) Petro AW 46 G is not formulated with natural or synthetic ester base oils thus it does not meet the generalized definition to be classified as a bio-hydraulic fluid (it's inherently biodegradable). However, it does pass 2 of 3 EPA mandated OECD Minimal Toxicity tests:

- OECD 201 (algae): **No Pass**
- OECD 202 (crustacean): PASS
- OECD 203 (fish): PASS

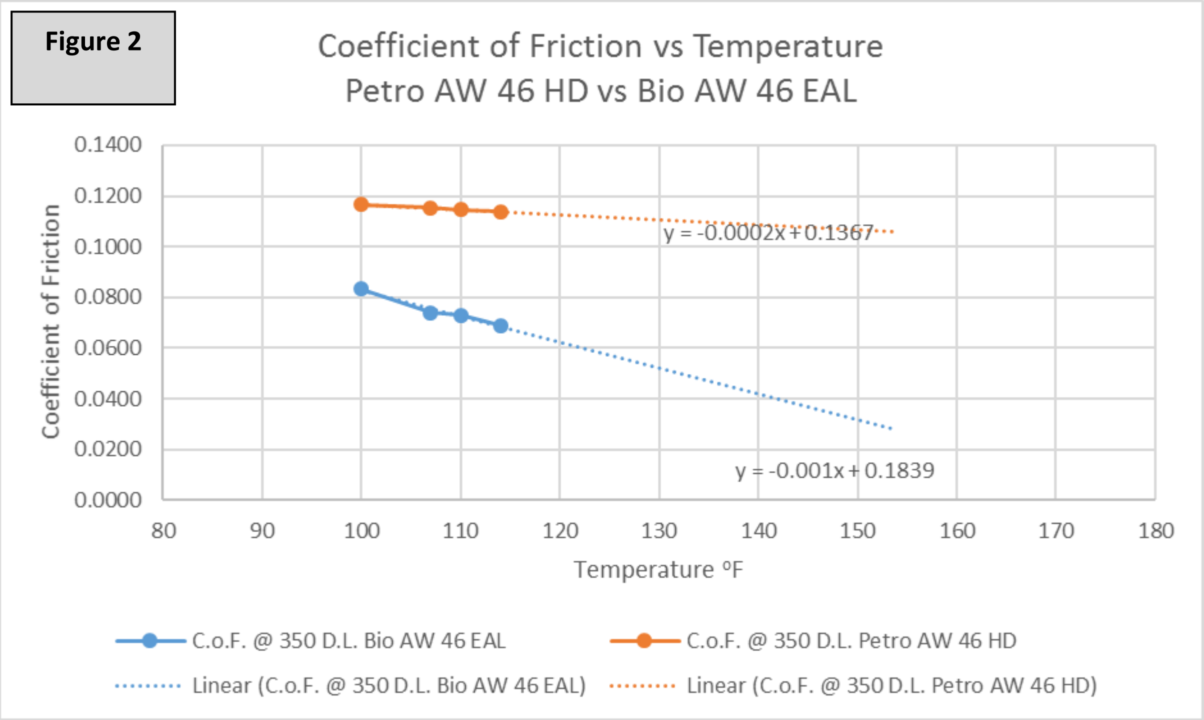
The Pins and Vee Blocks, even after the excess oil is wiped clean, still maintain traces of hydraulic oil deep in the crevices of the metal. When the Falex pin is pressed against the FTIR cell window, traces of the hydraulic oil can be seen on the spectrogram. There is even visual evidence if one looks closely at the Pins and Vee blocks pictured in Figure 1.


Figure 1

In Figures 2 through 5, a graph of Coefficient of Friction vs. Temperature is taken for one each of the Petroleum and Vegetable Oil based Hydraulic fluids. A linear trend line is drawn and extended out 40°F and the equation is noted in the form of ***Y = m*X + b*** where:

- ***m*** is the slope
- ***b*** is the "Y" axis intercept
- ***X*** is the temperature

Figure 2



<u>Key</u>:
C.o.F. = Coefficient of Friction
D.L. = Direct Load (i.e. Outer Scale is the direct load, meaning the load the jaws are applying to the rotating journal pin)
Experimental Test Condition = 350 lb. jaw load (direct load scale)

Figure 3

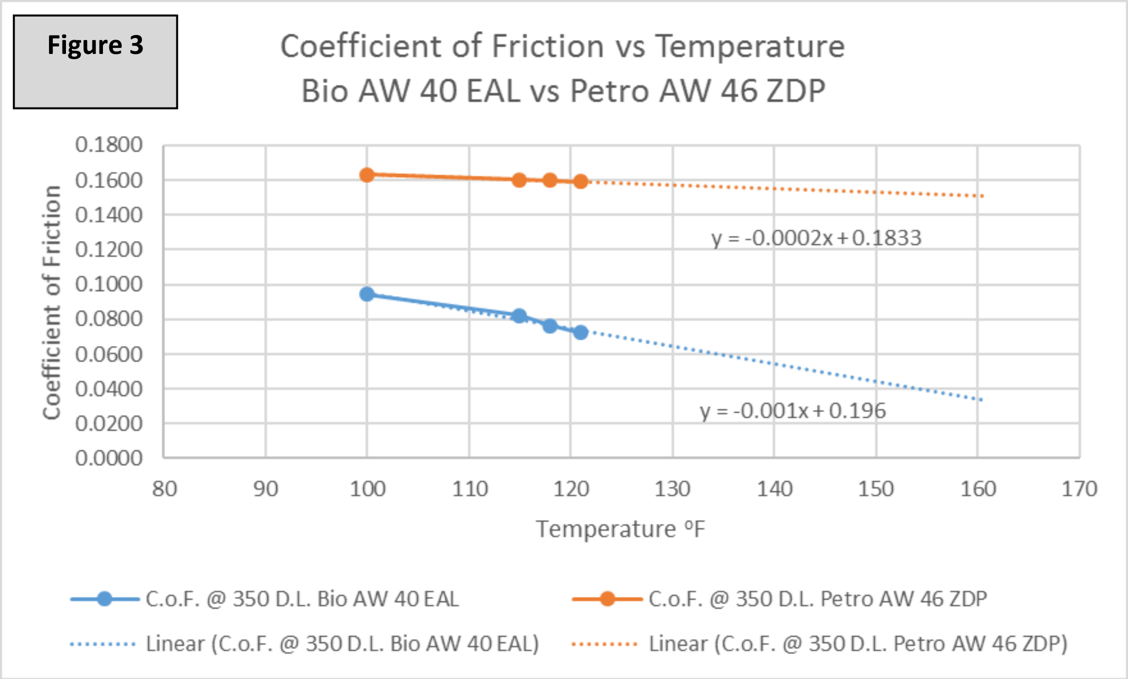


Figure 4

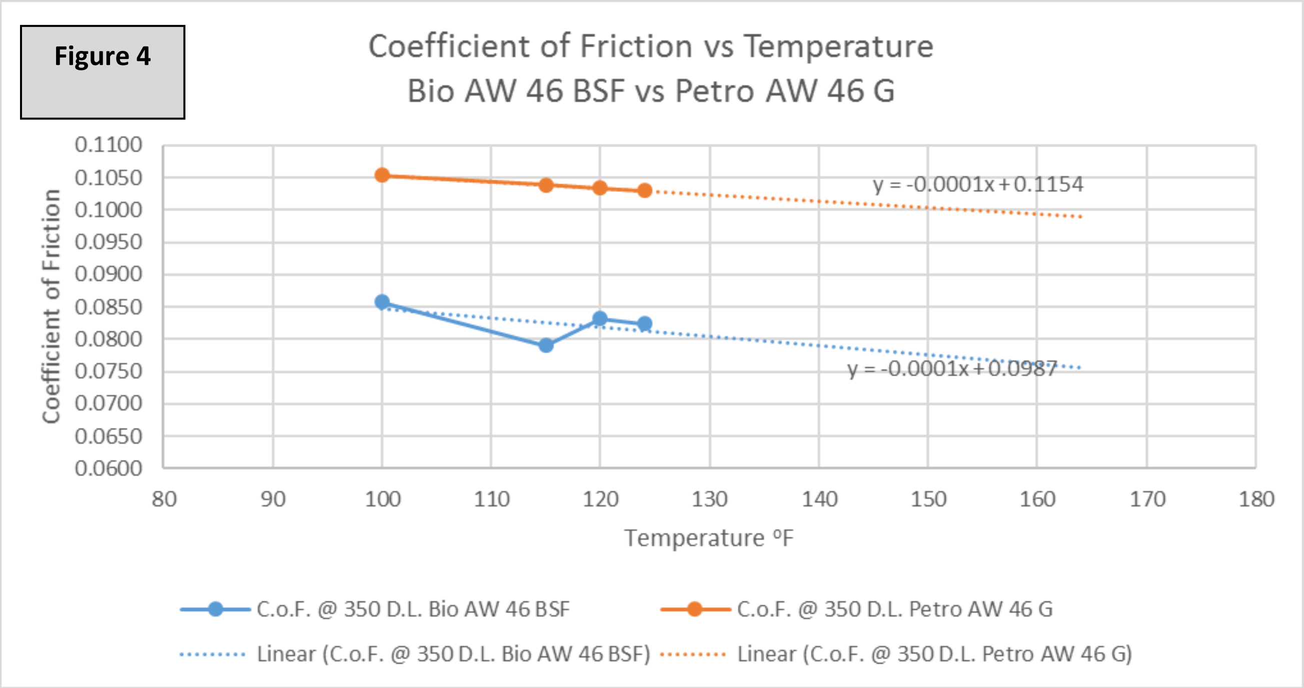
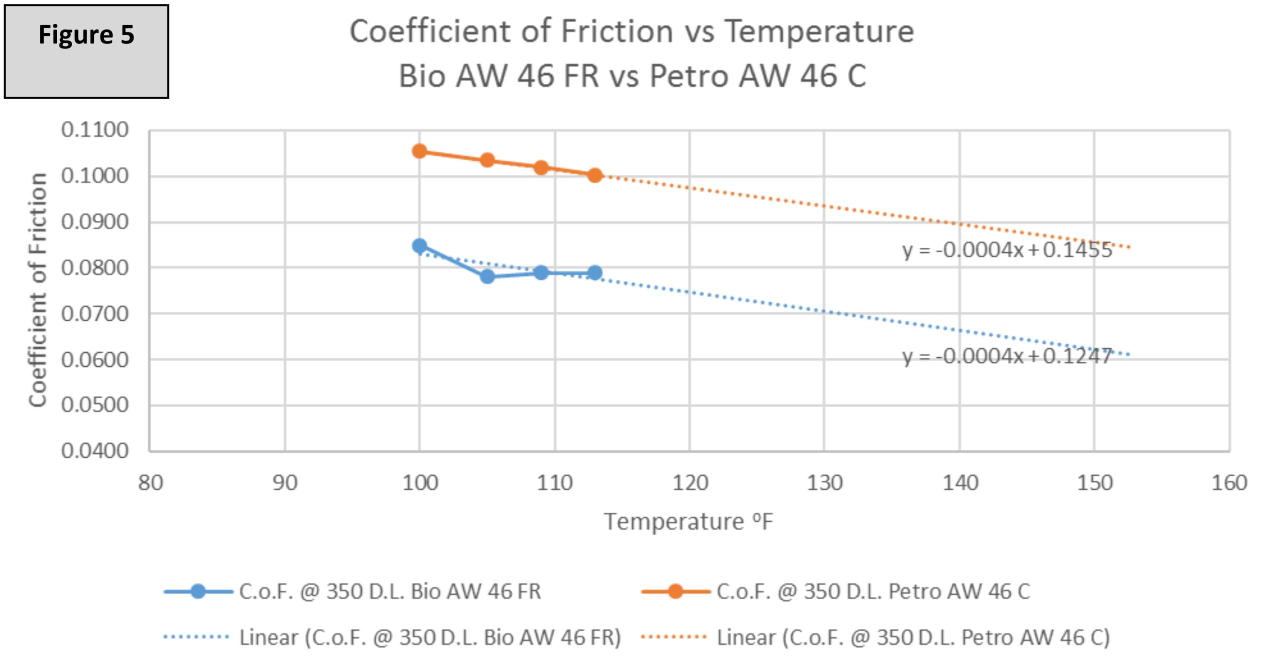


Figure 5



RESULTS AND CONCLUSIONS

Hydraulic systems are typically engineered for a maximum hydraulic sump temperature of 140°F. Table 2 compares the Linear Coefficient of Friction values at 140°F under the stated test conditions so a relative comparison can be made of experimental coefficient of friction values under anticipated maximum hydraulic system operating temperature conditions.

Table 2: Linear Coefficients of Friction at 140F – Experimental Data						
Experimental Hydraulic Fluid Comparisons			**Linear Coefficient of Friction at 140F**			
Petro-Hydraulic Fluid		**Bio-Hydraulic Fluid**	**C o F**		**C o F**	**Δ Bio %**
Petro AW 46 HD	vs.	Bio AW 46 EAL	0.1647	vs.	0.0439	-73.35%
Petro AW 46 ZDP	vs.	Bio AW 40 EA	0.2113	vs.	0.056	-73.50%
Petro AW 46 G	vs.	Bio AW 46 BSF	0.1294	vs.	0.0847	-34.54%
Petro AW 46 C	vs.	Bio AW 46 FR	0.0895	vs.	0.0687	-23.24%
Average Petro AW 46	vs.	Average Bio AW 46	0.1487	vs.	0.0633	-57.42%

Δ Bio% = ((Petro C.o.F. – Bio C.o.F.) / Petro C.o.F) x 100

In the illustrated comparisons the coefficients of friction for the bio-hydraulic based fluids are 20 to 70% lower than those for the petro-hydraulic based fluids. Therefore the data suggests that if you were to convert from the experimental petro-hydraulic fluid to the experimental bio-hydraulic fluid, the hydraulic system components would benefit from using a fluid with a reduced coefficient of friction, meaning the bio-hydraulic fluid would provide a higher degree of lubricity.

The coefficient of friction is the ratio of the tangential force need to start or to maintain uniform relative motion between two contacting surfaces to the perpendicular force holding them in contact, the ratio usually being larger for starting than for moving. Therefore the coefficient of friction helps quantify how readily two surfaces slide in the presence of a lubricant or oil. The importance of fluid lubricity in minimizing component wear in equipment is well documented. The lower coefficient of friction experimental values for the bio-hydraulic fluids support the superior lubricity protection of bio-hydraulic fluids over petro-hydraulic fluids as noted in various literature searches.

In consideration of the lower coefficients of friction seen with bio-hydraulic fluids vs. petro-hydraulic fluids in the experimental data, one can deduce that Viscosity Index (VI) plays a role in bio-hydraulic fluids delivering lower coefficients of friction and superior lubricity since in all cases the VI of the bio-hydraulic fluid was greater than the VI of the petro-hydraulic fluid it was compared against, as illustrated in Table 3.

Table 3. Viscosity Index (VI) of Experimental Products

Petro-Hydraulic Fluid	VI	Bio-Hydraulic Fluid	VI	Bio Gain or Increase	
				Δ	%
Petro AW 46 HD	153	Bio AW 46 EAL	>215	62	+40.52%
Petro AW 46 ZDP	98	Bio AW 40 EA	212	114	+116.30%
Petro AW 46 G	104	Bio AW 46 BSF	199	95	+91.35%
Petro AW 46 C	101	Bio AW 46 FR	>200	99	+98.02%