

Challenging Conventional Wisdom by Utilizing Group II Base Oils in Fuel Efficient Axle Oils

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ABSTRACT

Improving vehicle fuel economy is a major consideration for original equipment manufacturers (OEMs) and their technology suppliers worldwide as government legislation increasingly limits carbon dioxide emissions. At the same time that automotive OEMs have been driving toward lower viscosity axle oils to improve fuel economy, OEMs have worked to improved durability over an extended drain interval. These challenges have driven the use of API group III and/or API group IV base oils in most factory fill axle oils. This paper details the development of a novel lower viscosity SAE 75W-85 axle technology based on group II base oil that rivals the performance of a PAO-based axle oil and challenges the conventional wisdom of not using group II base oils in fuel efficient axle oils. Key to this development was the combination of carefully selected viscosity modifiers (VMs) with base oils to lower the traction coefficients and improve oxidative performance as well as improving lower temperature properties. The performance of this new axle oil technology has been validated in key industry performance tests, including SAE J2360 tests and stressed L-tests, efficiency testing and further field validation is in progress.

CITATION: Hong, H., Engel, C., Filippini, B., Slocum, S. et al., "Challenging Conventional Wisdom by Utilizing Group II Base Oils in Fuel Efficient Axle Oils," *SAE Int. J. Fuels Lubr.* 10(3):2017, doi:10.4271/2017-01-2356.

INTRODUCTION

Because of increasingly strict government legislation around the world to control carbon dioxide emissions, improving fuel economy has become a major consideration in vehicle design. In response, OEMs have started using more efficient, lower viscosity oils in engine, transmission and axle applications. The use of more fuel efficient oils is a pronounced trend globally, particularly in those markets with the most stringent legislation such as Europe and North America.

In both commercial vehicle and passenger vehicle automotive applications, axle oils are a key contributor to overall axle efficiency. A less efficient axle oil will require more power from the engine, and increase fuel consumption for equal power at the wheels. A typical high performance axle oil is an OEM-validated SAE 75W-90 synthetic oil. This type of fluid often contains API group III or group IV base oil and provides excellent hardware protection, oxidative resistance for extended drain interval, and good efficiency to maximize the vehicle's fuel economy. As one might expect, OEMs have almost universally transitioned from high viscosity axle oils to lower viscosity oils such as SAE 75W-85 to improve efficiency.

At the same time as OEMs have successfully worked to improve fuel economy via low viscosity lubricants, they have maintained and even expanded their quest for durability over an extended drain interval.

Combined, these trends have helped drive the lubricant industry to use highly refined API group III and/or group IV base oils in their axle oils.

Although base oils from API groups I, II, III or IV can all be found in commercially available axle oils globally and within the European and North American OEM factory fill markets, many OEM fluids are formulated with API group III or IV base oils and are marketed as synthetic oils. Choice of base oil is contingent on the end-user's durability and efficiency demands. A typical OEM factory fill axle oil will provide hardware protection, oxidative resistance for extended drain interval, and good efficiency to maximize the vehicle's fuel economy. API group I or group II base oils have not been used as the principle base oil in commercial high tier axle fluids that offer high efficiency and extended drain durability. Furthermore, literature references for achieving such performance with API group I or group II base oils, even if not deployed commercially, have not been reported.

One reason many OEMs use API group III or group IV base oils instead of API group II oils is that API group II base oils present potential formulating challenges for intended use in high tier axle oils. One such challenge is that API group II base oils have higher traction coefficients than API group III and API group IV base oils. A fluid's traction properties can impact its ability to efficiently transfer power [1, 2, 3, 4, 5, 6]. Additional technical challenges include thermal and oxidative stability, where API group II oils lag behind higher API group base stocks. Solutions to these traction and oxidative challenges with API group II base oils have not been reported in literature.

Despite these characteristics, API group II base oils can offer some advantages over higher API group base oils. API Group II base oils provide higher film thickness and improved solubilizing properties in comparison to API group III and IV base oils. In addition, security of supply for API group II base oil is often better than API group IV. Therefore, reducing dependence on API group IV base oils could be beneficial to the axle oil market. Finally, API group II base oil is more cost effective driving an improved cost benefit relative to higher group base oils, particularly API group IV base oils.

In this study, a novel SAE 75W-85 axle oil technology was developed with a majority API group II base oil composition. This new axle oil overcame the technical challenges described above to provide a lubricant with efficiency and durability comparable to an API group III or group IV-based synthetic oil. This paper demonstrates that by optimizing the viscosity modifying polymer, performance additive, and the addition of a low level of a traction-reducing co-base oil, the overall performance of the API group II base axle oil can be improved and rival that of a marketed synthetic fluid. Key attributes of this new axle oil were demonstrated in industry performance tests, including SAE J2360 tests, stressed L-tests, and efficiency tests.

EXPERIMENTAL

Traction Coefficient Testing

A commercially available instrument known as a mini traction machine (MTM) was used to study the elastohydrodynamic (EHD) friction or traction characteristics of fluids used in this study. EHD friction or traction is defined as the ratio of force transmitted in the tangential direction in a sliding/rolling contact to the normal force in a highly loaded, lubricated contact;

$$\mu \text{ (Traction Coefficient)} = F \text{ (Tangential)} / N \text{ (Normal)}$$

(1)

A highly loaded contact is simulated by loading a 19-mm diameter highly polished steel ball against a highly polished steel disc. A picture of the simulated highly loaded contact is shown in Figure 1. Normal load, rolling velocity, slide-to-roll ratio (SRR), and fluid temperature are the test parameters that can be controlled or varied for each test. The ball and disc specimen surface speeds (V_b and V_d , respectively) can be independently controlled using servo-motors to produce desired slide/roll motion at the contact. The test specimens and the fluid are contained in an insulated chamber. Temperature is controlled by cartridge heaters embedded in the assembly of the chamber. Once the fluid reaches the desired test temperature, the

contact is loaded to the preset load, and traction is measured as a function of slide-to-roll ratio. The SRR is defined as the difference in sliding speed between the ball and disk divided by the mean rolling speed of the ball and disk.

$$SRR = (v_b - v_d) / [(v_b + v_d) / 2]$$

(2)

In this work, EHD friction of test fluids was measured at a Hertzian pressure of 1.25 GPa, rolling speed of 2.5 m/s and at three discrete temperatures of 40 °C, 100 °C and 120 °C. Testing started with pure rolling motion and SRR was increased in discrete steps from 0 to 50% at each temperature.



Figure 1. MTM test showing highly loaded contact used in this study to measure EHD friction.

Light Duty Axle Efficiency Testing

Axle efficiency testing was completed via the procedure developed by Akucewich et al., a laboratory procedure to estimate the efficiency of axle lubricants [7]. The axle was a commercially available North American light duty axle, with an 8.6-in. (21.8-cm) diameter ring gear and a 3.73 gear ratio. The prime mover was a 200 hp (150 kW) Toshiba electric input motor. Input torque was measured using a HBM T40B-500 Nm torque meter; output torque was measured using a HBM T40B-3,000 Nm torque meter. Torque was controlled at the wheel end using a Midwest Dynamometer 2,000 hp (1500kW) model 3232 eddy current dynamometer. The stand configuration is shown in Figure 2.

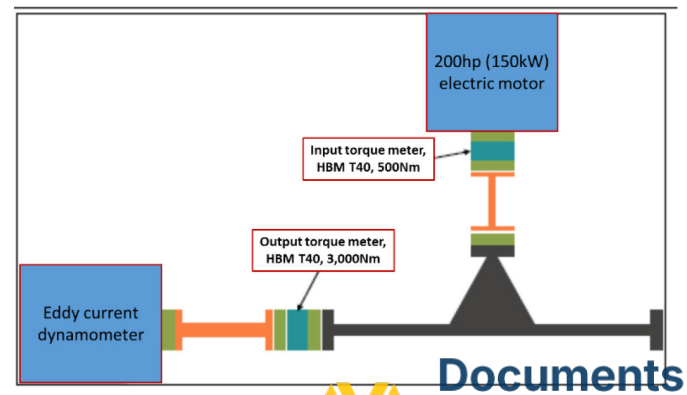


Figure 2. Schematic of axle efficiency test stand

Thermal and Oxidative Stability Testing

Thermal and oxidative stability of fluids were evaluated by ASTM procedure D5704, commonly known as the L-60-1 procedure [8].

Heavy Duty Axle Efficiency Testing

This axle efficiency testing was completed at an OEM's site via a proprietary method.

Experimental Fluids

The experimental fluids of this paper are divided into three categories as shown in [Tables 1, 2, 3](#). [Table 1](#) shows the first four axle fluids of the discussion. [Table 2](#) shows developmental fluids considering viscosity modifier choice and supplemental levels of group IV base oil. All of the fluids in [Table 2](#) use the same experimental additive #1. [Table 3](#) includes fluids for the optimization of the additive.

Table 1. Initial comparative fluids

	KV40 ^a (cSt)	KV100 ^a (cSt)	Viscosity Index (VI) ^b
API Group II base oil, 100N	20.0	4.0	100
Commercial Baseline #1, mineral oil based, 80W-90	129.7	14.1	107
Commercial Baseline #2, synthetic, 75W-90	109.2	15.2	145
Fluid #1, 75W-85	86.3	12.7	146

a – kinematic viscosity at 40°C (KV40) and 100°C (KV100), ASTM D445.

b – ASTM D2270

Table 2. 75W-85 Group II fluids for viscosity modifier and supplemental group IV optimization.

Experimental Fluids	Viscosity Modifier	Added Grp IV (%)	KV40 ^a (cSt)	KV100 ^a (cSt)	VI ^b
Fluid #1	VM1	0	86.3	12.7	146
Fluid #2	VM2	0	77.2	12.5	160
Fluid #3	VM3	0	73.7	12.7	174
Fluid #4	VM4	0	73.8	12.4	166
Fluid #5	VM2	x%	75.4	12.2	160
Fluid #6	VM2	1.5x%	74.4	12.1	160
Fluid #7	VM2	2x%	73.5	12.1	160
Fluid #8	VM2	2.5x%	72.5	12.0	161

a – kinematic viscosity at 40°C (KV40) and 100°C (KV100), ASTM D445.

b – ASTM D2270

VM1 = olefin homopolymer

VM2 = liquid ethylene-propylene copolymer

VM3 = ester-olefin copolymer

VM4 = dispersant polymethacrylate

Table 3. Fluids for oxidative and thermal stability optimization.

Experimental Fluid	API Base Stock	Viscosity Modifier	Added API Grp IV	Additive
Fluid #9	Group II	VM2	x%	Additive #2 (current)
Fluid #10	Group II	VM2	x%	Additive #3
Fluid #11	Group II	VM2	x%	Additive #4
Fluid #12	Group II	VM2	x%	Additive #5

RESULTS AND DISCUSSION

Traction coefficients of the four fluids in [Table 1](#) are shown in [Figure 3](#). The traction curve for the commercial baseline #1 shows that this lubricant has an appreciably higher traction coefficient over a range of slide-to-roll ratios in comparison to commercial baseline #2.

Commercial baseline #2 establishes a traction expectation for a high-tier synthetic axle fluid that will enable axle efficiency. Fluid #1 mirrors the componentry of the commercial baseline #2 (additive and VM) but in an API group II base oil, and its traction is considerably higher than the synthetic commercial baseline #2. For reference, [Figure 3](#) also shows the traction for a 100N API group II base oil without additive or VM. Its traction curve is intermediate between the two commercial fluids and fluid #1. Clearly, this formulating approach will not be satisfactory for developing a group II-based axle fluid that provides the low traction benefits comparable to that of a synthetic fluid.

An effective formulating approach to impact the traction coefficient of a fluid is to introduce a viscosity modifying polymer to the fluid's composition. These polymers increase a fluid's viscosity index, and they also impact other properties of the fluid. Barton et al. have shown that viscosity modifying polymers can also impact the traction properties of API group IV fluids [6]. [Figure 4](#) shows the traction curves for experimental fluids #1 through #4, all API group II-based fluids using various viscosity modifiers (VM1, VM2, VM3, VM4). The addition of VM1 to 100N API group II base oil increases the traction coefficient, showing that all viscosity modifiers that increase the fluid's viscosity index do not necessarily decrease the traction coefficient. The other three viscosity modifiers of this study (VM2, VM3, VM4) impact the traction favorably from SRR = 1-50%. An expansion of SRR = 10-40% for fluids #2 through 4 is shown in [Figure 5](#). The pairing of an appropriate VM with an API group II base oil can achieve similar traction (VM2 or VM4), or even better traction (VM3), in comparison to the synthetic commercial baseline #2.

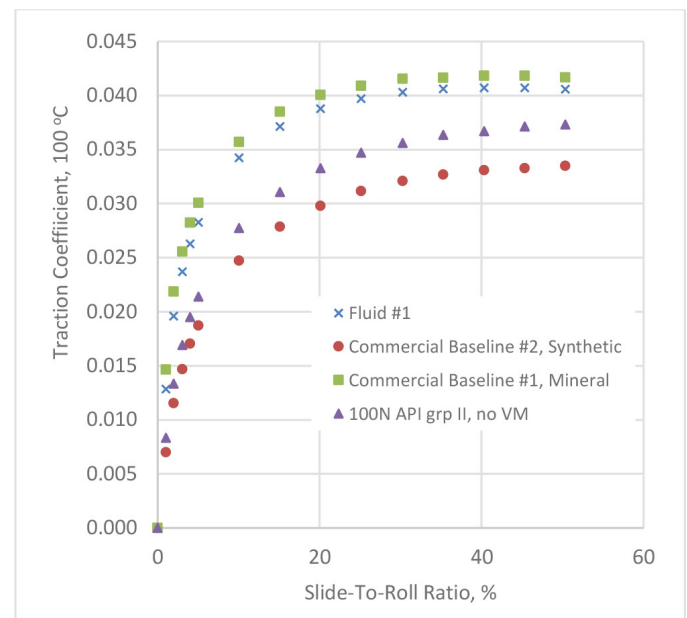


Figure 3. 100 °C Traction coefficient comparisons for fluids from [Table 1](#).