Delivering Synthetic Performance with VHVI Speciality Base Fluids

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Abstract

Historically, the best lubrication performance has been achieved by the use of synthetic fluids, such as polyalphaolefins or esters. Advanced commercial processing techniques for producing base oils through significant molecular change are now available. In many applications, automotive and industrial products formulated with these high-quality API Group III speciality base fluids can achieve the same good performance as that from traditional synthetic fluids.

This paper represents continued work to understand and demonstrate features of very high viscosity index (VHVI) speciality base fluids. Ultimately, the performance of a finished fluid is the key market requirement. Actual field performance can vary dramatically, even among polyalphaolefin-based formulations. Several examples are given to show that equivalent high-level synthetic performance can be delivered through a synergistic balance of VHVI speciality base fluids and additive chemistry.

Keywords

VHVI fluids, API Group III, speciality base fluids, PAO fluids, synthetic lubricants, molecular design

INTRODUCTION

The continuing evolution towards better performing automotive lubricants in Europe and North America has led to significant changes in the quality of the base oils that form the building blocks for these products. Through the use of hydroprocessing, wax isomerisation, and hydrodewaxing technologies, for example, the growth of API Group III fluids has been dramatic and, in many cases, they have been shown to deliver performance previously restricted to polyalphaolefins (PAOs).

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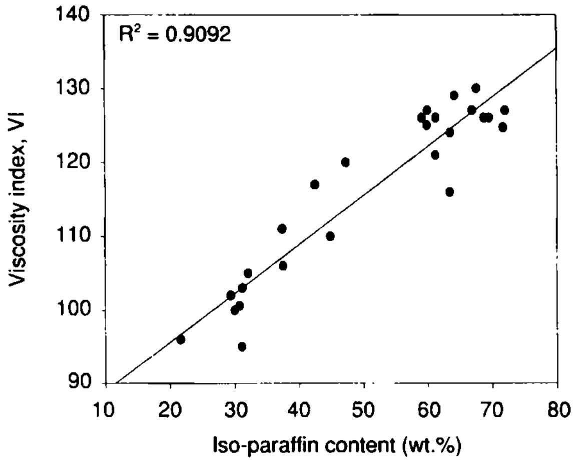
Figure 1 Comparison of VI and iso-paraffin content for base oils of 4 cSt kinematic viscosity at 100°C



The relationship between base-oil composition and performance has been widely studied over the years.[1-5] Lubricant performance is enhanced by balancing high viscosity index (VI) and low-temperature fluidity. This balance is best achieved when base oils are highly iso-paraffinic in structure. With conventional solvent-refined base oils in API Group I[6] as used in automotive lubricants, levels of iso-paraffins are usually low, typically 20–30 wt.%. Severe extraction may increase iso-paraffin levels slightly, but the increase is limited by the nature of the feedstock composition and the efficiency of the separation process.[7]

Hydroprocessing technology, including hydrowaxing, has been essential to the production of high-quality base oils with elevated levels of iso-paraffin structures. These API Group III unconventional base oils (UCBO) or speciality base fluids (SBF) can have iso-paraffin contents above 70 wt.%, depending on the viscosity grade, and provide finished fluid performance equal to, and in some cases superior to, that derived from PAOs.[7-10]

Reactions that occur during the authors' company's hydrocracking, hydroisomerisation, and hydrofinishing process lead for example to the formation of hydrocarbon chains of lengths different to those of the starting feedstock. Changes also occur in the basic arrangement of the atoms in the

Table 1 Considerable variability observed in composition of high quality API Group III speciality base fluids

SBF ID	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*
Kinematic viscosity at 100°C (cSt)	4.1	4.7	4.4	4.2	4.7	4.6	4.2	4.3	4.6
Viscosity index	123	124	120	121	117	127	129	125	126
Composition (mass %)									
Paraffins, *iso* and *n**	63.8	63.5	47.3	61.2	42.5	72.0	64.2	59.9	59.1
Monocycloparaffins	20.5	20.4	28.3	22.8	30.5	18.7	26.4	23.0	22.8
Dicycloparaffins	6.5	7.1	10.8	7.6	12.2	6.3	7.3	8.5	8.3
Tricycloparaffins	1.9	3.2	3.8	3.0	5.1	2.0	1.7	3.8	3.2
Polycycloparaffins	1.3	3.7	3.3	2.7	5.2	0.6	0.4	1.8	4.9
Monoaromatics	0.0	1.5	5.3	2.2	3.7	0.4	0.0	2.8	1.2
Polyaromatics	0.0	0.4	1.2	0.4	0.7	0.0	0.0	0.2	0.5
Paraffins + mono-cycloparaffins	90.3	83.9	75.6	84.0	73.0	90.7	90.6	82.9	81.9
Polycycloparaffins + aromatics	1.3	5.6	9.8	5.3	9.6	1.0	0.4	4.8	6.6

* *n*-paraffin content represents a very small subset of this compositional class (~<3%). This will also vary with the feedstock selection and type of dewaxing process.

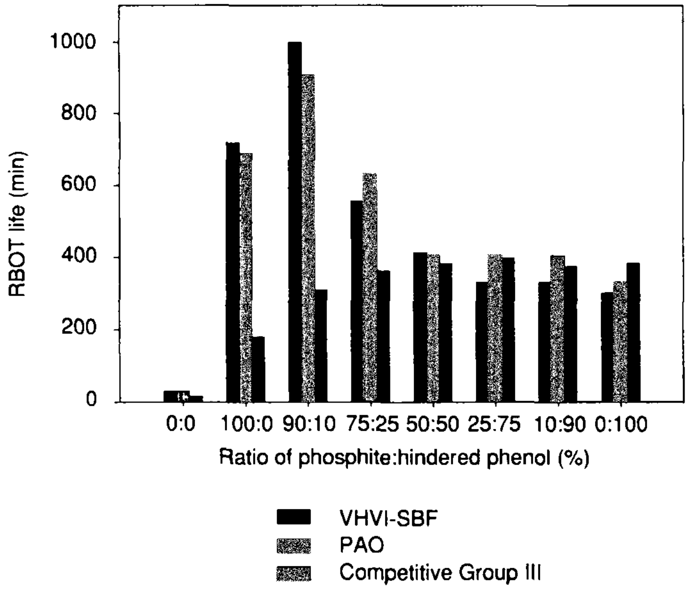
hydrocracking mixture such that it differs chemically from the feedstock components. As a consequence, very high VI (VHVI) SBFs have vastly different chemical and physical properties and, as such, can be considered to be synthetic. This assessment is not limited to the authors' company, and a similar argument and conclusion have been presented elsewhere* with respect to the UCBOs produced by hydrocracking, hydroisomerisation, and hydrofinishing.

Comparing API Group III SBFs

Figure 1 shows the relationship between VI and iso-paraffin content for a series of 100 neutral (i.e., approx. 4 cSt at 100°C) lubricant base oils. These represent API Groups I, II, and III and show the expected VI increase with increasing iso-paraffin content. For API Group III (VI ≥ 120), the iso-paraffin level is typically greater than 55 wt.%. Despite the high iso-paraffin content, however, there is still a significant difference between competitive Group III SBFs as iso-paraffin can reach levels approaching 75 wt.%, while

* by the Chevron Products Company.

Figure 2 Rotary bomb oxidation test for VHVI speciality base fluid, PAO, and competitive Group III SBF
Antioxidant = 0.5 wt.%



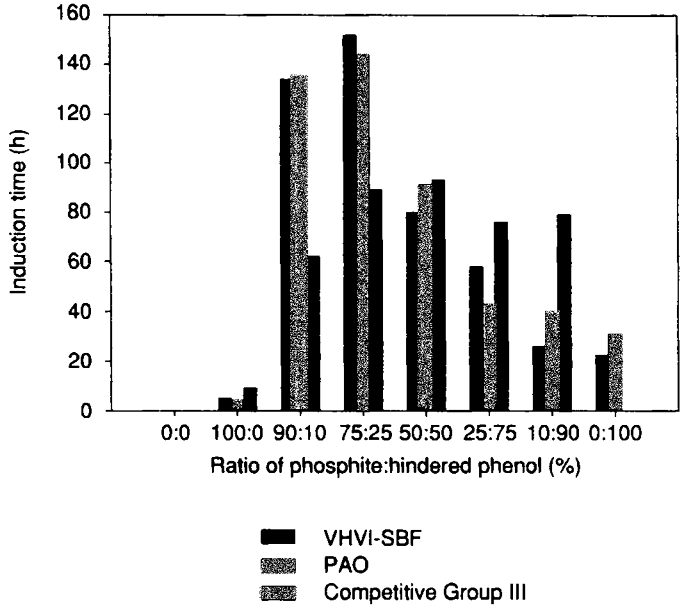
compositional criterion for API Group III is 90 wt.% saturates (**Table 1**). The differences are also evident when monocycloparaffins are included in this comparison. These differences are further enhanced for the heavier viscosity grades and reflect differences in feedstock selection, processing technology, and quality targets that are an integral part of the manufacturing process.

Compositional differences have been used previously to show the similarity and dissimilarity in performance relative to PAO.[2,8,9] **Figures 2** and **3** compare the antioxidant response of two API Group III SBFs with PAOs in the rotary bomb oxidation test (RBOT, ASTM D 2272) and peroxide accumulation as determined by IP 280 at 170°C. The antioxidants used were a commercial phosphite and hindered phenol in various combinations, though overall treat rate was fixed at 0.5 wt.%.

It can be seen from the results that there are different profiles for the two API Group III SBFs over the antioxidant combinations. The VHVI SBF

Figure 3 Peroxide accumulation in VHVI speciality base fluid, PAO, and competitive Group III SBF

Antioxidant = 0.5 wt.%



demonstrates equivalent antioxidant response to PAO, whereas the other Group III fluid does not, because of the higher concentrations of iso-paraffins and monocycloparaffins in the VHVI SBF, which exceeds 90% and is more like PAO.

It is evident that the range of qualities within the API Group III category is wide, as saturate content can vary from 90 to 100 wt.%, and VI from 120 to 140. The question is how to define such a new 'synthetic' base oil category, the compositional properties and performance features of which are consistent with those of PAO. In the authors' opinion, this new API category would be defined by VI, iso-paraffin, perhaps iso-paraffin and monocycloparaffin, and aromatic content, combined with demonstrated engine or field performance equivalent to PAO.

DELIVERING SYNTHETIC PERFORMANCE

In an earlier paper,[7] some results from an extended Sequence III E bench engine programme were presented, in which the performance of two passenger-car motor oil products formulated with VHVI SBFs matched, and in some cases exceeded, the performance of PAO alternatives. The work reported here is presented as further evidence of how the performance of a Group III fluid can equal that of a synthetic lubricant.

VHVI-based 5W–30 PCMO

A development programme was undertaken to create a VHVI-based SAE 5W–30 product meeting the requirements of ILSAC GF-2, API SJ/CF, and GM 4718M (a General Motors specification for high-temperature-resistant engine oil). The key design criteria for the product were that it be formulated with VHVI SBF rather than PAO, and demonstrate engine performance substantially similar to synthetic SAE 5W–30 passenger-car engine oils currently on the market.

The product was formulated on the basis of an existing synthetic product, i.e., with a PAO and synthetic ester base stock, olefin copolymer viscosity modifier, and various performance additives. Data showed that this product qualified as GF-2/SJ/CF and GM-4718M. The approach was to substitute VHVI SBF for PAO in the formulation and then conduct a verification programme to support the SBF performance claims and degree of equivalence to marketed SAE 5W–30 products.

The verification programme consisted of the following steps.

- A complete programme of engine tests conducted according to a protocol set out in the Chemical Manufacturers' Association (CMA) Product Approval Code of Practice[11] to provide supporting data for claims that the product met or exceeded the requirements of ILSAC GF-2, API SJ, API CF, and GM 4718M.
- A vehicle test programme conducted on a road simulator chassis dynamometer under a programmed driving cycle for 50,000 miles (80,000 km). Oil drains were extended in the test to 12,500 miles compared with normal manufacturer recommendations of 7,500 miles. The performance of the new product was compared with that of two existing synthetic 5W–30 products. These products had the same ILSAC, API, and GM performance data to support them.

- A taxi-cab fleet test conducted in San Francisco, California, USA. All three lubricants were compared in this 100,000 mile (160,000 km) test, in which oil drain intervals were extended to 12,500 miles (20,000 km). Taxi-cab testing is considered to be a severe operating environment for passenger-car engine oils due to the nearly continuous operation and high levels of engine idling and stop-and-go driving (data were not available for this paper but will be published at a future date).

Engine test programme The engine test programme was conducted on the VHVI-based formulation according to the CMA protocol, 'Petroleum Additives Product Approval Code of Practice'.[11] The results are summarised in **Table 2** (see pp. 142 and 143). In this table, the VHVI-based formulation (oil L) is compared with two commercial products: oils J and K. Both were formulated with PAO base stock and synthetic ester. Oil L was formulated with the same additive system and synthetic ester used in oil J.

'Pass' results were achieved for the VHVI-based formula (oil L) in terms of the limits for GF-2, SJ, CF, and GM 4718M. Comparison with the data sets available for the two PAO-based products (oils J and K) is somewhat confounded by the fact that the tests run on these oils were not on the SAE 5W–30 viscosity grade with the exception of the Sequence VIA fuel-economy test and the Sequence III E oil oxidation and deposits test. In the case of the fuel-economy test, all three products met the limit for ILSAC GF-2. Equivalent performance was also demonstrated in the Coordinating Research Council (CRC) L-38 test and the Caterpillar 1M-PC tests conducted on oil L and K. Both of these products exhibited better protection against bearing corrosion than did oil K. In the 1M-PC diesel engine test, oil K showed lower weighted piston deposits (WDK) but equivalent piston ring groove fill, within test precision.

In the Sequence VE low-temperature deposit and wear test, oil L showed improvement in average engine sludge, rocker cover sludge, and average engine varnish ratings. Average engine varnish was better for oil L than for oil J but poorer than for oil K. Wear results for oil L were higher than for the other two oils but still well within test limits.

A controlled comparison was available for the Sequence III E runs. This test was used to benchmark the VHVI product and the two commercial oils of the same viscosity grade with the tests conducted in the same laboratory and engine apparatus. By running the tests in the same engine, the effect of stand-to-stand variation was eliminated from the results. The Sequence III E data

Table 2 Engine test data for PAO and VHVI formulated products

Oil code – base stock	*J – PAO/Ester AA*	*K – PAO/Ester BB*
Additive system	*I*	*II*
CRC L-38	Pass (VG)	Pass (VG)
Piston skirt varnish	9.8	9.7
Bearing wt. loss (mg)	18.5	35.1
Sequence IID	Pass (VG)	Pass (VG)
Av. engine rust	8.7	8.6
Lifter sticking	None	None
Sequence IIIE	Pass*	Pass*
Viscosity increase after 64 h at 40°C (cSt)	46	129
Hours to 375%	80.4	70.8
Av. engine sludge	9.63	9.61
Av. piston varnish	9.24	9.23
Oil-ring land varnish	5.64	9.43
Av. cam plus lifter wear (CLWR) (μm)	3.9	5.6
Max. CLWR (μm)	41	10
OR stuck rings	0	0
Oil consumption (l)	2.08	1.46
Sequence VE	Pass (VG)	Pass (VG)
Av. engine sludge	9.29	9.2
Rocker cover sludge	8.74	8.2
Piston skirt varnish	7.18	6.8
Av. engine varnish	5.20	5.8
Av. cam wear (μm)	54.5	35.6
Max cam wear (μm)	91	48.3
Oil screen sludge (%)	1.0	–
HT stuck compression rings	0	0
Sequence VI-A	Pass	Pass
FEI (%)	1.1	1.1
Caterpillar 1M-PC	Pass (VG)	Pass (VG)
TGF (%)	44	52
WDK (CF)	238	188.7
Ring side clearance loss (mm)	0.013	–

Table 2 Engine test data for PAO and VHVI formulated products

Oil code – base stock	*L – VHVI/Ester AA*	*ILSAC GF-2/API CF*
Additive system	*I*	*limits*
CRC L-38	Pass	
Piston skirt varnish	9.8	9.0 min
Bearing wt. loss (mg)	17.6	40 max
Sequence IID	Pass	
Av. engine rust	8.5	8.5 min
Lifter sticking	None	None
Sequence IIIE	Pass*	
Viscosity increase after 64 h at 40°C (cSt)	86	
Hours to 375%	77	64 min
Av. engine sludge	9.54	9.2 min
Av. piston varnish	9.24	8.9 min
Oil-ring land varnish	7.12	3.5 min
Av. CLWR (μm)	1.2	30 max
Max. CLWR (μm)	3	64 max
OR stuck rings	0	None
Oil consumption (l)	1.97	5.1 max
Sequence VE	Pass	
Av. engine sludge	9.35	9.0 min
Rocker cover sludge	8.98	7.0 min
Piston skirt varnish	7.36	6.5 min
Av. engine varnish	5.65	5.0 min
Av. cam wear (μm)	93.1	127 max
Max cam wear (μm)	262.0	380 max
Oil screen sludge (%)	0	20 max
HT stuck compression rings	0	None
Sequence VI-A	Pass	
FEI (%)	1.1	1.1% min vs BC-2
Caterpillar 1M-PC	Pass	
TGF (%)	55	70 max
WDK (CF)	238.8	240 max
Ring side clearance loss (mm)	0	0.013 max

* Source: back-to-back Sequence IIIE test programme. Single calibrated engine stand. All other data on PAO-based products are CMA programme data. VG = viscosity-grade read-across

Table 3 Test conditions of BMW driving profile

Vehicle use	*Engine speed (rpm)*	*Vehicle speed (mph)*	*Dyno load (BHP)*
70% highway	1600	65	24
	1400	55	17
20% suburban	1150	45	11
	N/A	35	7
10% city	N/A	25	4

reported for the two commercial products are for comparative purposes only, and have not been used by the respective suppliers to support their product claims. Worthy of note is that neither competitive product met the requirements of GM 4718M when audited in this test programme, whereas the VHVI formulated product did. Oil K failed to meet the viscosity increase limit of 100% maximum and oil J failed to meet the oil ring land deposit limit of 6.0 minimum. A statistical comparison of the data was conducted for oils J and L. It was concluded that oil L was equivalent to oil J for the parameters of viscosity increase, average engine sludge, average piston varnish, and superior in terms of oil ring land deposits and cam/lifter wear. Oil consumption was also equivalent.

The overall results from this test programme, conducted in calibrated laboratory engines, demonstrated a performance equivalence for these SAE 5W–30 products, formulated with VHVI or with PAO base stocks.

Chassis dynamometer test This test programme was designed to compare oil performance in actual vehicles operated under a tightly controlled and repeatable driving cycle. The vehicles were run by robotic control on chassis dynamometers at the Southwest Research Institute in San Antonio, Texas, USA. The driving cycle selected for this work was the BMW Dyno Profile cycle, a mix of highway, suburban, and city-type operation with a range of speeds and engine loads. The driving cycle breakdown is shown in **Table 3**.

The vehicles used in the test were six 1998 Ford Taurus sedans equipped with 4.6 l V8 engines. Fuel type was unleaded gasoline, sourced locally. Test duration was 50,000 miles. Oil-drain interval was 12,500 miles, an extension of 5000 miles beyond the recommended oil drain interval for this model. Samples were taken for analysis at 7500 miles on oil and at drain. Oil was topped up as required.

Table 4 Chassis dynamometer test history

Unit no.	*Engine miles*	*Oil code*	*Additive*	*Base stock*	*Test duration*
1	50,051	J	I	PAO	1 Jan. – 1 March
2	50,063	J	I	PAO	1 Jan. – 1 March
3	50,059	K	II	PAO	1 Jan. – 1 March
4	50,056	K	II	PAO	1 Jan. – 1 March
5	52,431	L	I	VHVI	1 Aug. – 25 Sept.
6	52,554	L	I	VHVI	1 Aug. – 9 Oct.*

* End of test delayed due to transmission failure and repair.

Table 5 Summary of oil consumption and oil analysis data

Test oil code *Base stock*	*J* *PAO/Ester AA*	*K* *PAO/Ester BB*	*L* *VHVI/Ester AA*	
Av. distance on oil (miles)	12493	12504	13120	
Total oil consumed (qts)	16.63	12.85	2.25	
Oil economy (miles/qt)	3010	3896	23330	
Oil analysis, av. ± standard deviation over drains				*Significant difference?*
Iron	19 ± 5.1	21 ± 3.4	32 ± 12.4	No
Chromium	1 ± 0	1 ± 0.5	2 ± 0.6	No
Aluminium	5 ± 0.8	6 ± 1.9	6 ± 2.8	No
Copper	4 ± 1.5	4 ± 1.7	5 ± 4.9	No
Lead	1 ± 0.6	1 ± 0.6	9 ± 4.1	No
Tin	0 ± 0.5	1 ± 0.6	0 ± 0	No
Silicone	82 ± 59	66 ± 33	106 ± 78.7	No
Viscosity at 100°C (cSt)	10.3 ± 0.2	10.8 ± 0.2	10.9 ± 0.2	N/A
Oxidation	15 ± 1.9	13 ± 1.5	25 ± 14.5	No
Nitration	14 ± 3.6	9 ± 2.2	16 ± 3.9	No
Total base number	4.35 ± 0.5	3.55 ± 0.4	4.33 ± 0.4	Yes

Table 6 Summary of engine ratings

Test oil code	*J*	*K*	*L*
Base stock	*PAO/Ester AA*	*PAO/Ester BB*	*VHVI/Ester AA*
Numerical deposit rating summary			
Average engine varnish	9.97	9.95	9.91
Average engine sludge	9.73	9.72	9.73
Oil-ring land deposits	2.71	1.49	3.63
Intake-valve deposits	6.53	6.79	9.00
Oil-screen clogging (%)	3	5	0
Wear measurement and ratings			
Piston contact, total	21	37	43
Top piston-ring gap (in)	0.012	0.012	0.013
2nd piston-ring gap (in)	0.025	0.025	0.022
Oil-ring groove top (in)	0.020	0.022	0.017
Oil-ring groove 2nd (in)	0.020	0.022	0.020
Cylinder liner wear, av. max (in)	0.0007	0.0007	0.0002
Cam lobe average diameter (µm)	2.153	2.154	2.155

The same three oils as were evaluated in the engine test programme were tested in the vehicle/chassis dyno programme. Details of the test are given in **Table 4.**

Oil consumption and oil analysis results Oil consumption and analysis data are summarised in **Table 5.** Total oil consumed during the 50,000 mile test was considerably lower for oil L than for either of the PAO-based products. Both vehicles operating on the VHVI-based oil showed very low consumption. Although the reasons for this observation are unclear, one possible explanation may be a lower rate of leakage past valve seals. Evidence supporting this theory may be seen in the engine teardown data below (intake-valve deposit ratings).

Analysis of the oil samples taken at oil-drain intervals showed very low rates of engine wear, even though the drain interval was extended well beyond the vehicle manufacturer's recommendations. Statistical analysis of the metal wear data showed no significant difference among the three oils. The level of silicon found in the used oil peaked early in the test and diminished as distance was accumulated; this observation is not unusual during passenger-car field tests. Silicone sealant materials used in form-in-place gaskets can be susceptible to breakdown of materials into the engine oil. This does not cause operational problems but does result in high silicone measurements for the first few oil drains. All three oils showed this tendency.

Engine deposit ratings and wear measurements Following completion of the test, all six engines were disassembled and their parts were rated according to standard procedures established by the CRC. A summary of the numerical ratings, averaged by test oil, is given in **Table 6**.

Average engine varnish and sludge ratings were essentially equivalent for all three oils and are indicative of very clean engines. Oil-ring land deposits, absence of which is an indication of resistance to high-temperature deposits in the critical piston-ring zone, were best for the VHVI-based product. Also of interest was the significantly higher intake-valve deposit rating for the VHVI oil. This may be a secondary effect of lower oil consumption for the VHVI product. Leakage of oil past valve-stem seals can create higher deposit on intake valves as is the case with these PAO formulated oils. Oil-screen clogging did not occur on the VHVI product, whereas minor clogging did occur with the other two oils.

The results for the engine-wear measurements were equally encouraging. Although piston-contact area measured for oil L was higher than for the other two oils, this was the only wear-related parameter that showed a difference. Piston-ring gap, a measure of piston-ring wear, was essentially the same for all three oils. Piston-ring groove measurements were also better for oil L. Cam lobe diameter was also equivalent. One parameter that seemed to favour oil L was cylinder liner wear. This measurement was approximately 25% of the wear exhibited with the other two oils.

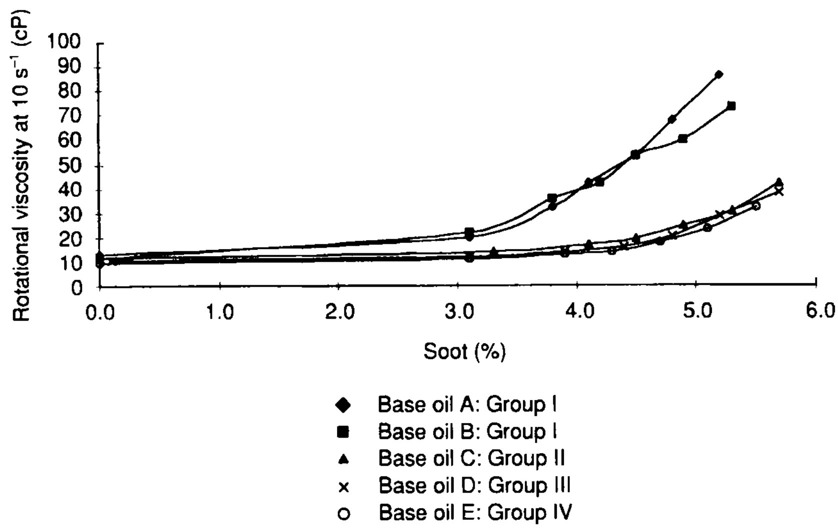
The results of this vehicle test, conducted under controlled conditions, showed that an engine oil formulated with VHVI SBF can give equivalent performance with respect to deposit control and wear to engine oils formulated with PAO.

VHVI-based heavy-duty engine oils

It is well known that conventional mineral base oils can be used for formulation of 15W–40 grade heavy-duty engine oils meeting the API CH-4/SJ performance levels. What is less well understood is whether this level fully meets customer needs.

The 1999 agreement between the US Environmental Protection Agency (EPA) and the diesel engine builders requires retrofitting of existing engines to improve emission control as well as ensure that all new engines have lower emissions. This means that the engine oil will receive higher soot loads caused by retarded injection timing for highway as well as transient conditions and

Figure 4 Base oil effects in T8 screen test (from ref. 13, and reproduced with the permission of Lubrizol*)



* Note that the base oil identification does not coincide with that used by the present authors.

CH-4 oils will require shorter drain intervals for low emission engines than CG-4 oils in the higher emission designs.

Cummins and Mack have introduced their EO-M Plus and CES 20076 specifications, respectively, which go beyond CH-4, and require drain intervals to be kept at pre-1999 levels.

Soot control and advanced base oils In a joint publication,[12] the Cummins and Chevron companies demonstrated in extended M-11 tests that high-quality heavy-duty engine oils using advanced base oils had a dramatically superior ability to disperse soot. This also resulted in less wear of critical engine components.

In a modified Mack engine, the Lubrizol company showed that base oil has a profound impact on ability to disperse soot.[13] Using the same additive package, API Groups II, III, and IV base oils all dispersed engine soot much more effectively than the same additive package in an API Group I base oil

Table 7 Formulating 10W–40 HDEO with Group II/III speciality base fluids

Test	*Result*	*Requirement*
Kinematic viscosity at 100°C (cSt)	14.6	12.5 – 16.3
Kinematic viscosity at 100°C after shear (cSt)	12.9	12.5 min (stay in grade)
Flash point, COC (°C)	229	215 min
Pour point (°C)	–39	none
CCS at –20°C (cP)	2992	3500 max
MRV TP-1 at –30°C (cP)	16400	60000 max
GCD, at 371°C (%)	3	15 max
Noack (wt.%)	9	18 max
HTHS at 150°C (cP)	4.1	3.7 min, 15W–40 2.9 min, 10W–40
Performance	CH-4/SJ Mack EO-M Plus Cummins CES 20076 TMC/SAE Fuel Economy	

CCS = cold crank simulator
MRV = mini-rotary viscometer
GCD = gas chromatographic distillation
HTHS = high-temperature, high-shear

(**Figure 4**). This fundamental difference appears to be linked to dielectric effects derived from the highly saturated base oils.

Benefits of VHVI base fluids The SAE 15W–40 grade is the most used viscosity grade for commercial engine oils and it is possible to meet physical property requirements as well as CH-4 and vehicle performance specifications with most, but not all, conventional base oils (CBOs); although higher additive contents may be required. The benefit of API Group III SBFs is their ability to perform well beyond these specifications and give up to twice the soot control of CBO-based formulations, thus extending equipment life and possibly drain intervals: which explains why major marketers have chosen API Group III for their top grade diesel engine oil in order to remain competitive.

The SAE 10W–40 grade has made little penetration in the heavy-duty engine oil market because of perceived lack of film strength for wear

Table 8 Formulation 0W–30 HDEO with Group III/IV speciality base fluids

Test	*Result*	*Requirement*
Kinematic viscosity at 100°C (cSt)	11.3	9.3 – 12.5
Kinematic viscosity at 100°C, after shear (cSt)	10.0	9.3 min (stay in grade)
Flash point COC (°C)	221	200 min
Pour point (°C)	<–51	none
CCS at –30°C (cP)	2836	3250 max
MRV T-1 at –40°C (cP)	16200	60000 max
GCD, at 371°C (%)	3	17 max
Noack (wt.%)	12.4	22 max
HTHS at 150°C (cP)	3.33	2.9 min. xW–30 3.3 min, OEM specs
Performance (high additive treat rate)	CH-4/SJ/EC Mack EO-M Plus Cummins CES 20076	
Performance (low additive treat rate)	ILSAC GF-2 SJ/EC/CG-4	

protection. SAE J-300 requires a high-temperature/high-shear (HTHS) viscosity at 150°C of 3.7 cP minimum for 15W–40 but only 2.9 for 10W–40. It is possible, using VHVI SBFs, to formulate to 10W–40 and meet all the 15W–40 high-temperature specifications, including HTHS, stay-in-grade, volatility/evaporation, and low-temperature pumpability (**Table 7**).

The example shown meets CH-4/SJ as well as being Mack EO-M Plus and CES 20076 approvals. This is an ideal product for year-round operation or over a wide range. It is also ideal for operations where it is not practical or desirable to leave equipment idling when not in use. The latter is the case for almost all light-duty applications. A further benefit is demonstrated to be fuel saving, as shown in the Test Monitoring Center (ASTM) TMC/SAE procedure for heavy trucks.

The SAE 0W–30 grade is an important viscosity grade for northern latitudes, particularly for equipment which is in intermittent use or not stored indoors. The 0W grade requirement for –40°C pumpability is quite difficult to achieve, especially if one wishes to incorporate vehicle manufacturers' high-temperature requirements. For example, Mack and Cummins require a HTHS

Table 9 Base oil composition of European 5W–40 synthetic PCMO products

Product	*R*	*S*	*T*
Base oil composition (%)			
API Group I	0	0	0
API Group II	0	0	0
API Group III	80–85	0	0
API Group IV	0	80–85	80
API Group V*	15–20	15–20	20

* Ester component

viscosity at 150°C of 3.3 cP minimum versus only 2.9 for 0W–30 in SAE J-300. Producing higher film strength makes it more difficult to retain an excellent low-temperature performance.

With a combination of VHVI SBFs and PAO, it is possible to formulate a 0W–30 heavy-duty engine oil which meets 10W–30 high-temperature requirements, as well as those of CH-4/SJ/EC, Mack EO-M Plus, and CES 20076 (**Table 8**). While not being an all-season product, it does provide some leeway in changing the oil as the temperature rises above freezing.

An extension of this technology of lowering additive treatment to the ILSAC GF-2 level is to incorporate general passenger-car application while maintaining CG-4 diesel performance levels (the product becomes ILSAC GF-2/SJ/EC/CG-4).

Most blenders prefer to blend single grades with the same additive package as their multigrades. Since single grades do not generally meet CH-4, blending at the full additive content represents a performance giveaway which is not recoverable in the market. UCBOs allow single grade blending to API CF/CF-2/SJ with less additive. As well as reducing cost, this makes it easier to meet Detroit Diesel Corporation (DDC) two-stroke requirements of CF-2 and <1.0% ash.

Performance is paramount in marketing heavy-duty engine oils. A VHVI-based SAE 5W–40 heavy-duty engine oil was field tested in extended drain service in Volvo VDE-12 engines in construction haulage service (110,000 lb average load) against a PAO-based synthetic 5W–40 product.[7] Excellent performance was observed with the VHVI-based HDEO, based on analysis of the used oil. In particular, used oil HTHS viscosity and total base number retention were equivalent for both products, whereas a significant benefit was observed for the VHVI heavy-duty engine oil in terms of wear performance (i.e., iron wear), another example of the ability of an API Group III-based product to deliver performance consistent with, and in some areas better than, a PAO-based product.

Group III market penetration

Improved processing technologies produce API Group III SBFs with compositional features and product performance that are increasingly similar to those provided by PAOs.

In case this should be thought of as a North American phenomenon, **Table 9** shows an analysis of three commercially available 'full synthetic' European 5W–40 passenger-car motor oils. The predominant use of an API Group III SBF in Product R demonstrates the presence of these new high-quality fluids in the premium automotive market to help maintain high performance standards. With increasing demands on these oils, combined with greater availability and a better appreciation of their advantages, the range of applications of API Group III SBFs is expected to grow in terms of automotive, drivetrain, and speciality industrial fluid applications in both North America and Europe.

CONCLUSIONS

Reactions designed to occur in hydrocracking, hydroisomerisation, and hydro-finishing processes proprietary to the authors' company, lead to the formation of hydrocarbon chains of lengths different from those of the starting feedstock. Changes also occur in the basic arrangement of the atoms in the hydrocarbon mixture such that it differs chemically from the feedstock components. The consequent VHVI SBFs that are produced have such vastly different chemical and physical properties that they can be considered as 'synthetic'.

The wide variation in compositional properties and performance of API Group III SBFs reflects different feedstock selection, processing design, and performance targets. It may be possible to subdivide this category further, according to composition properties and correlated performance, so distinguishing those higher quality fluids as synthetic.

Based on performance in ASTM sequence tests and in actual vehicles operated under controlled conditions, an SAE 5W–30 engine oil formulated with VHVI SBFs performed similarly to two commercial PAO-based products, with respect to wear control, deposit control, and oil degradation. Improved oil consumption was observed with the VHVI-based formulation.

Heavy-duty diesel engine oils formulated with SBFs or PAO give greater protection from soot than conventional API Group I based products.

Group III SBFs allow formulation of 10W–40 heavy-duty engine oils meeting all 15W–40 high-temperature requirements, and with the advantages of wider temperature ranges and fuel saving.

References

1. Murray, D.W., Clarke, C.T., MacAlpine, G.A., and Wright, P.G., 'The effect of base stock composition on lubricant performance', SAE paper 821236, 1982.
2. Henderson, H.E., Fefer, M., Legzdins, A., Michaluk, P., and Rus, T., 'Compositioned features of new high performance specialty base fluids', in *Symp. Worldwide Perspectives on the Manufacture, Characterization and Application of Lubricant Base Oils*, ACS National Meeting, New Orleans, Louisiana, 1999, Vol. 44, pp. 265–9.
3. Korcek, S., and Jensen, R.K., 'Relation between base oil composition and oxidation stability at increased temperatures', *ASLE Trans.*, **19** (1976) 83–94.
4. Mack, P.D., Zaugg, T.D., and Cohen, S.C., 'Severely hydro-cracked/hydro-isomerized based oils – the key to enhanced performance levels', *NPRA Annual Meeting*, FL-96-114, 1996.
5. Getto, V.J., Grina, M.A., and Ryan, H.T., 'The influence of chemical structure on the physical and performance properties of hydrocracked base stocks and polyalphaolefins', in *Proc. 12th Int. Colloq. Tribol.*, Technische Akademie Esslingen, Germany, Jan. 2000.
6. American Petroleum Institute, Industry Services Department, 'Engine oil and licensing certification system', *API Publication 1509*, 14th ed., New York, December 1998.
7. Henderson, H.E., Steckle, W.M., Mack, P.D., and Simmons, R., 'Advanced performance products from VHVI specialty base fluids', *NPRA Annual Meeting*, LW-98-113, 1998.
8. Henderson, H.E., and Legzdins, A., 'Evaluation of severely hydro-treated and isodewaxed specialty base fluids in industrial oil applications', paper presented at *STLE 54th Annual Meeting*, May 1999.
9. Henderson, H.E., Fefer, M., and Legzdins, A., 'Fundamental oxidation studies of polyalphaolefins and VHVI specialty base fluids', in *Symp. Worldwide Perspectives on the Manufacture, Characterization and Application of Lubricant Base Oils*, ACS National Meeting, New Orleans, Louisiana, August 1999.
10. Kramer, D.C., Sztendderowicz, M.L., Lok, B.K., Krug, R.R., Cheng, M.T., Rechsteiner, C.E., and Wilson, D.M., 'The synthetic nature of Group III base oils', *NPRA Annual Meeting*, LW-99-124, 1999.
11. Chemical Manufacturers' Association, 1300 Wilson Boulevard, Arlington, Virginia 22209, USA.
12. McGeehan, J.A., Alexander III, W., Ziemer, J.N., Roby, S.H., and Graham, J.P., 'The pivotal role of crankcase oil in preventing soot wear and extending filter life in low emission diesel engines', SAE paper 1999-01-1525.
13. Kornbrekke, R.E., Patrzyk-Semanik, P., Kirchner-Jean, T., Raguz, M.G., and Badasz, E.A., 'Understanding soot-mediated oil thickening. Part 6: Base oil effects', SAE paper 982665, 1998.

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