Development of High-Performance, GF-6 Motor Oils using Sustainable Base Oils

Innovation and sustainability are key values at Biosynthetic Technologies (BT) that drive the strategic direction of the company's development programs. The research team at BT spends most of their time at the interface of these domains, looking for creative ways to solve the world's sustainability challenges.

The purpose of this initiative was to develop a commercially viable, GF-6 (API SP-RC) approved, environmentally acceptable passenger car motor oil (PCMO) from sustainable base stocks, capable of competing with other high-performance motor oils on the market. To accomplish this, the following ingredients were selected: (1) BT4, a biodegradable estolide product from BT with high bio-content, (2) a re-refined low viscosity Group III product, (3) two re-refined Group II+ base oils, and (4) two PCMO additive packages (DI and VM) from a major lubricant additive supplier. A description of the three formulations is shown in Table 1.

Three common grades of motor oil were developed, in order of increasing viscosity: 0W-20, 5W-20, and 5W-30. For the 0W-20 grade, a re-refined Group III product was selected as the co-base, helping to meet the low viscosity requirement. To meet the higher viscosity targets of the 5W-20 and 5W-30 grades, however, Group II+ re-refined base oils were used. While the ratios of the Group III/II+ base stocks and the VM package fluctuate for the different grades, the concentration of BT4 in the formulations was held constant at 38%. Because BT4 has renewable carbon content of 68%, the net renewable carbon content for each of the formulations is 25.8%, meeting the requirement for the USDA BioPreferred Program.

Ingredient	Company	0W-20	5W-20	5W-30
BT4 (Estolide)	Biosynthetic Technologies	38	38	38
Additive Package (DI)	Major Additive Company	8.85	8.85	8.85
Additive Package (VM)	Major Additive Company	5.43	2.26	7.11
Group III Re-Refined Base Oil	Major Oil Refiner	47.72	-	-
Group II+ Re-Refined Base Oil	Major Oil Refiner	-	19.79	46.04
Group II+ Re-Refined Base Oil	Major Oil Refiner	-	31.09	-

***Table 1**. Motor oil formulation details.*

Basic Physicals

The table below documents the basic viscometrics and other properties of all three motor oil grades.

		Limits			Results		
	Method	0W-20	5W-20	5W-30	0W-20	5W-20	5W-30
Basic Physicals							
KV 100°C (cSt)	ASTM D445	Report	Report	Report	8.1	7.6	10.3
HTHS 150 (cP)	ASTM D4683	≥2.6	≥2.6	≥2.9 and <3.5	2.60	2.60	2.95
CCS @ Temp (cP)	ASTM D5293	≤6200 @ -35C	≤6600 @ -30C	≤6600 @ -30C	6007 @ -35C	4739 @ -30C	3864 @ -30C
Noack (m%)	ASTM D5800	≤15.0	≤15.0	≤15.0	10.9	7.9	10.3
MRV Vis. @ Temp (cP)	ASTM D4684	≤60000 @ -40C	≤60000 @ -35C	≤60000 @ -35C	25700 @ -35C	14500 @ -35C	23700 @ -35C
Yield Stress @ Temp (Pa)	ASTM D4684	<35, NYS @ -40C	<35, NYS @ -35C	<35, NYS @ -35C	NYS @ -35C	NYS @ -35C	<35 @ -35C
TBN (mg KOH/g)	ASTM D2896	Report	Report	Report	7.5	7.5	7.6

***Table 2**. Basic properties of the motor oils.*

Sequence IIIH: Deposits & Oxidation

The 0W-20 and 5W-30 formulations were evaluated on the Sequence IIIH engine test to determine deposit and oxidation performance (see Table 3). The 5W-20 formulation was not evaluated, and instead relied on viscosity grade read across using the 5W-30 results.

	Limits	0W-20	5W-30
Sequence IIIH - Deposits & Oxidation			
ICP Metals (D5185)		PASS	PASS
IIIH		PASS	PASS
% KV40 Increase	100% max	65.6	42.4
WPD	> 4.2	5.53	5.8
IIIHA		PASS	PASS
EOT CCS (cP) @ -35°C		>25,000	18,380
EOT MRV T(°C)		-35	-30
EOT MRV (cP)	60,000 max	38,876	16,479
EOT MRV (Pa)YS (Pa)	35 max	<35	<35
IIIHB (% P Retention)	≥ 81%	99.29	99.09

Table 3. *Results of the Sequence IIIH (Deposits & Oxidation) test.*

For PCMO formulations using Group III base oils, a typical weighted piston deposit (WPD) result is around 4.7 merits. For formulations using Group II base oils, that increases to around 4.9 merits. The use of BT4 in the formulation, however, increased the WPD ratings to 5.5 and 5.8 merits for the 0W-20 and 5W-30 formulations, respectively. This means increased engine cleanliness, and less deposits on engine surfaces. Figure 1 shows the industry averages, along with BT's results and the minimum limit for the test.

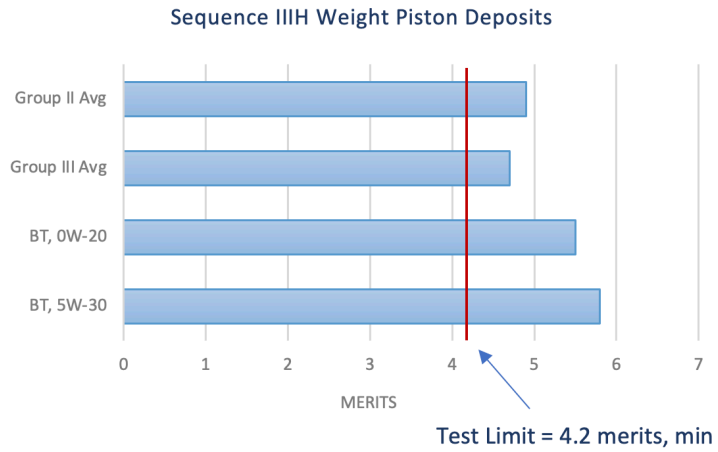

Figure 1. *Comparison of motor oil results to industry averages.*

Sequence VH: Sludge & Varnish Control Testing

Another engine test run on the formulation was Sequence VH, for sludge and varnish control. Again, the base oil and additive selection resulted in superior engine cleanliness in all categories, including engine sludge, rocker cover sludge, engine varnish, piston skirt sludge, oil screen sludge, and had no indication of hot stuck rings. These results are documented in Table 4, below.

	Limits	5W-30
Sequence VH - Sludge & Varnish Control Testing		
Sequence VH		Pass
Average Engine Sludge Merits	7.6 min	8.72
Rocker Cover Sludge Merits	7.7 min	9.3
Average Engine Varnish Merits	8.6 min	9.25
Average Piston Skirt Sludge Merits	7.6 min	8.23
Oil Screen Sludge (% Area)	No Limit	8
Number of Hot Stuck Rings	0 max	0

***Table 4**. Results of the Sequence VH (Sludge & Varnish Control) test.*

Field Trial

The GF-6 formulations are currently being tested in a 100,000-mile taxi-cab field trial in Las Vegas, Nevada. At the end of the test, the engines will be broken down and analyzed for wear, overall cleanliness, and mechanical integrity. End-of-test is currently estimated for 2H 2024.

In a similar past field trial, estolides were evaluated as part of a GF-5 (API SN-RC) formulation. After disassembly, the engine was evaluated and found to be much cleaner than the reference oil, a standard mineral oil-based formulation (see Figure 2, below). The expectation for the current GF-6 formulation is that it will product similar results. When these results are available, this data will be updated.

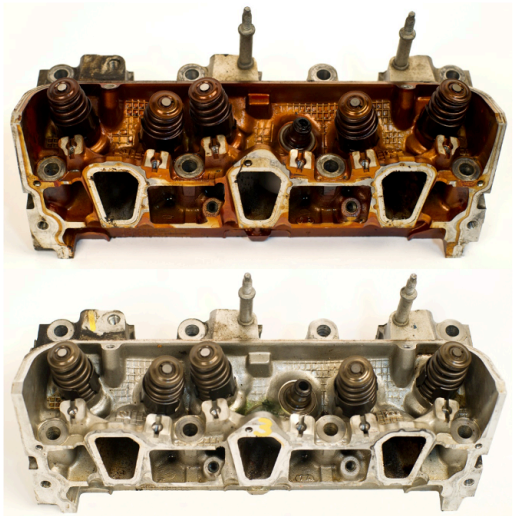

***Figure 2**. GF-5 formulation results. Cylinder heads from two Chevy Impala 3.5 liter V6 engines used in an 18 month 150,000 mile field trial in Las Vegas, NV. The conventional motor oil (top) had a typical level of varnish at the end of the test, while the*

estolide formulation (bottom) showed a high degree of overall cleanliness and minimal varnish.

Environmental Characteristics

In addition to their performance, the PCMO formulations were designed to emphasize sustainability. BT4, a low viscosity base oil offered by Biosynthetic Technologies, is fully biodegradable by OECD 301B, contains 68% renewable carbon content, and is non-toxic by numerous OECD standards. These test results are described in Table 5, below. Additionally, the remaining Group II+ and Group III base oils are recycled products, derived from re-refining technology.

	Method	BT4
Environmental Characteristics		
Biodegradability, %	OECD 301B	88%
Renewable Carbon Content, %	ASTM D6866	68%
Ecotoxicity, mg/L	OECD 201	>1000
Ecotoxicity, mg/L	OECD 202	>1000
Ecotoxicity, mg/L	OECD 203	>1000
Ecotoxicity, mg/L	OECD 209	>1000

***Table 5**. Environmental data for BT's estolide base oil, BT4.*

Conclusion

With a combination of high-performance, bio-content, biodegradability, and recycled material, these API certified formulations demonstrate the convergence of sustainability with cutting edge technology. In a market lacking creativity and differentiation, these products are uniquely set apart from the competition.

If you're interested in commercial opportunities related to manufacturing these products, or any other projects, please contact Matt Kriech at mkriech@biosynthetic.com.