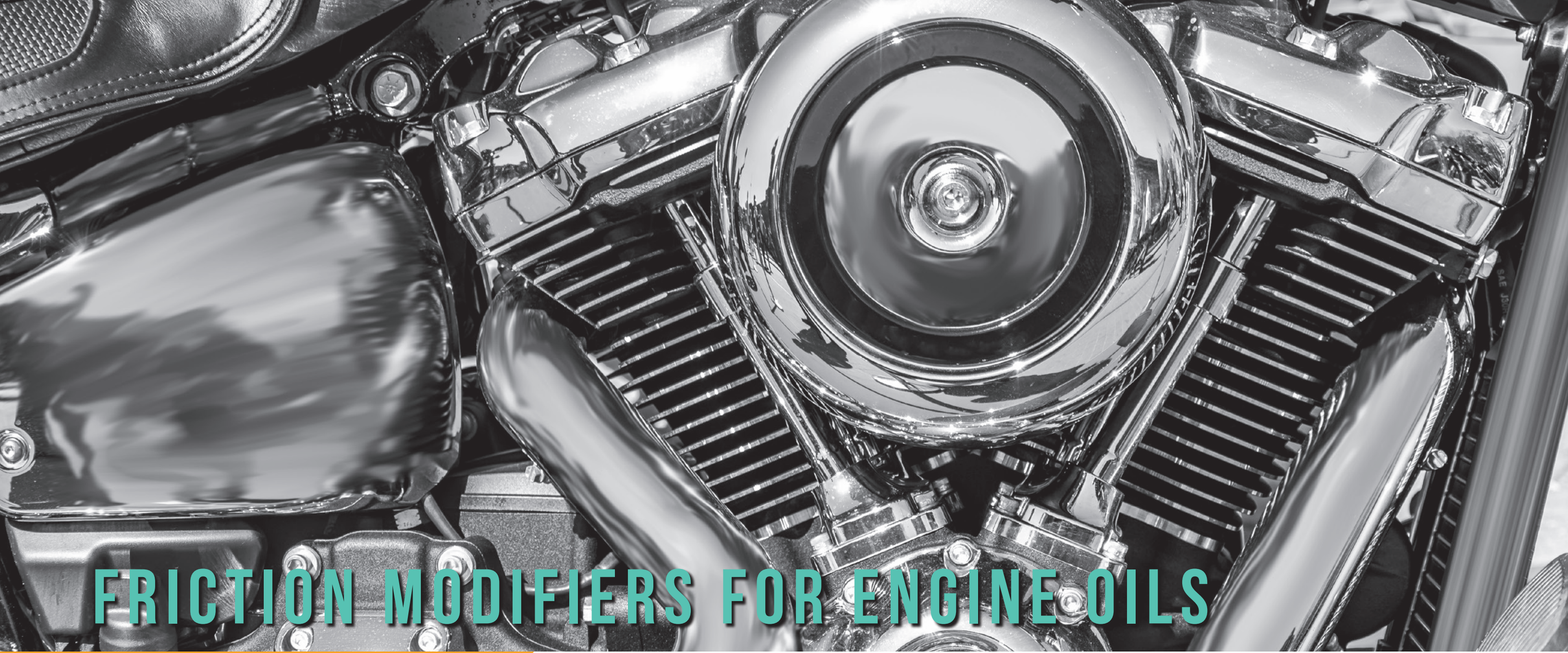
Vanderbilt Chemicals, LLC
A Wholly Owned Subsidiary of R.T. Vanderbilt Holding Company, Inc.

FRICTION MODIFIERS FOR ENGINE OILS

VANDERBILT CHEMICALS, LLC
30 WINFIELD STREET
P.O. BOX 5150
NORWALK, CT 06856-5150
(203) 853-1400
WWW.VANDERBILTCHEMICALS.COM



FRICTION MODIFIERS FOR ENGINE OILS

Organic and Molybdenum Friction Modifiers Used in Engine Oils

OEMs around the globe are pushing the limits of vehicle technology to meet or exceed governmental regulations requiring lower greenhouse emissions and higher fuel economy. One area being examined is the lubricating oil and in particular friction modifiers. It is well known that both organic and molybdenum containing friction modifiers can be added to an engine oil to improve vehicle fuel economy and lower greenhouse emissions. Vanderbilt Chemicals sells a variety of organic and molybdenum containing friction modifiers to help engine oil formulators meet current and future fuel efficient engine oil specifications.

Rev. 12/02/2021

DQS Inc.
VANDERBILT CHEMICALS, LLC
CERTIFIED TO ISO 9001:2015
10002461

ORGANIC AND MOLYBDENUM FRICTION MODIFIER PRODUCT RANGE

Vanderbilt Chemicals, LLC offers a wide variety of friction modifiers for engine oils. All are globally registered and range from organic to molybdenum-containing. We offer three types of molybdenum-containing friction modifiers. They are molybdenum dithiocarbamates (MoDTC), molybdenum ester/amide and molybdenum dialkyldithiophosphates (MoDTP) as shown in the table below.

LIST OF FRICTION REDUCERS FOR ENGINE OILS

	TYPE	MOLYBDENUM, %	SULFUR, %	BORON, %	PHOSPHORUS
VANLUBE® 289	Organic	n/a	n/a	0.9	n/a
MOLYVAN® 807 NT	MoDTC	4.9	5.9	n/a	n/a
MOLYVAN 822 NT	MoDTC	4.9	5.9	n/a	n/a
MOLYVAN 3000	MoDTC	10.0	11.5	n/a	n/a
MOLYVAN 855	Mo ester/amide	8.0	n/a	n/a	n/a
MOLYVAN L	MoDTP	8.3	12.4	n/a	6.3

VANLUBE® 289

A globally registered borated ester/amide organic friction modifier produced from sustainable raw materials, with 76% USDA bio-renewable content.

MOLYVAN® 855

Is built on an OFM backbone and offers 73% USDA bio-renewable content. This unique product combines the friction reduction benefits of both organic and molybdenum friction modifiers. Many formulators favor this additive because the binary functionality lends itself to improved fuel economy retention properties versus molybdenum dithiocarbamates.

MOLYVAN 3000, MOLYVAN 822 NT & MOLYVAN 807 NT

Are all molybdenum dithiocarbamate friction modifiers. **MOLYVAN 3000** is the most popular MoDTC additive for engine oils, because it contains 10% molybdenum and offers formulators a more cost effective MoDTC to reduce engine friction. All three MoDTC additives use a unique, patented branched alkyl-amine technology that provides improved solubility (see Solubility section).

Figure 1
Color Comparison between MOLYVAN® 822 NT and MOLYVAN 807 NT

MOLYVAN 822 NT & MOLYVAN 807 NT

Both contain about 5% molybdenum. The primary difference between these two MoDTC products is their color. **MOLYVAN 822 NT** has the typical brown color associated with MoDTCs, while **MOLYVAN 807 NT** is green (see Figure 1).

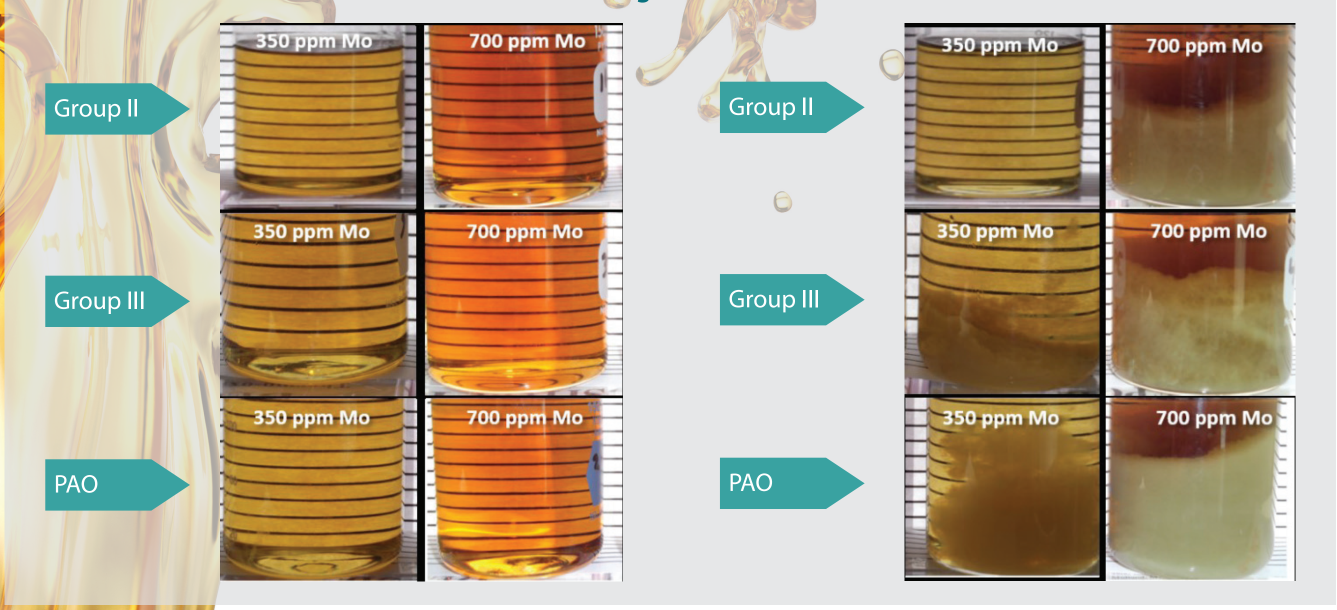
MOLYVAN L

Is used in engine oil applications where phosphorus content is not critical for exhaust catalyst compatibility concerns. The presence of phosphorus helps impart superior EP/antiwear protection to an engine designed for use with high performance engine oils, like racing oils.

ADDITIVE SOLUBILITY

Solubility plays an important role in the performance of any additive. We recently identified new alkyl-amine technology that delivers much-improved finished oil solubility to our entire line of commercial molybdenum dithiocarbamate friction modifiers. The improved solubility of the new alkyl-amine technology is demonstrated with **MOLYVAN® 822 NT** (see Figure 2), in three different base oils at two different molybdenum treat rates after 24 hours at room temperature.

Figure 2



MOLYVAN 3000 demonstrated equivalent or better solubility versus the competitive product. Both products are MoDTC's containing 10% molybdenum dissolved in Group III base oil at a 1.0 wt.% treat rate.

Figure 3
Solubility Comparison Between MOLYVAN® 3000 and Competitive Product

ORGANIC FRICTION MODIFIER VANLUBE® 289

VANLUBE 289, a borated ester/amide, is a globally registered commercial organic friction modifier (OFM). It is recommended to be used alone or in combination with molybdenum containing friction modifiers. Its friction reducing performance is comparable to glycerol mono-oleate (GMO) in a prototype 0W-20 engine oil (see Figure 4). MTM testing demonstrated that **VANLUBE 289** can deliver equivalent friction reduction performance to GMO at 0.8 wt.% treat rate using the following test conditions: 35N, 50% slide/roll, steel on steel at 140°C.

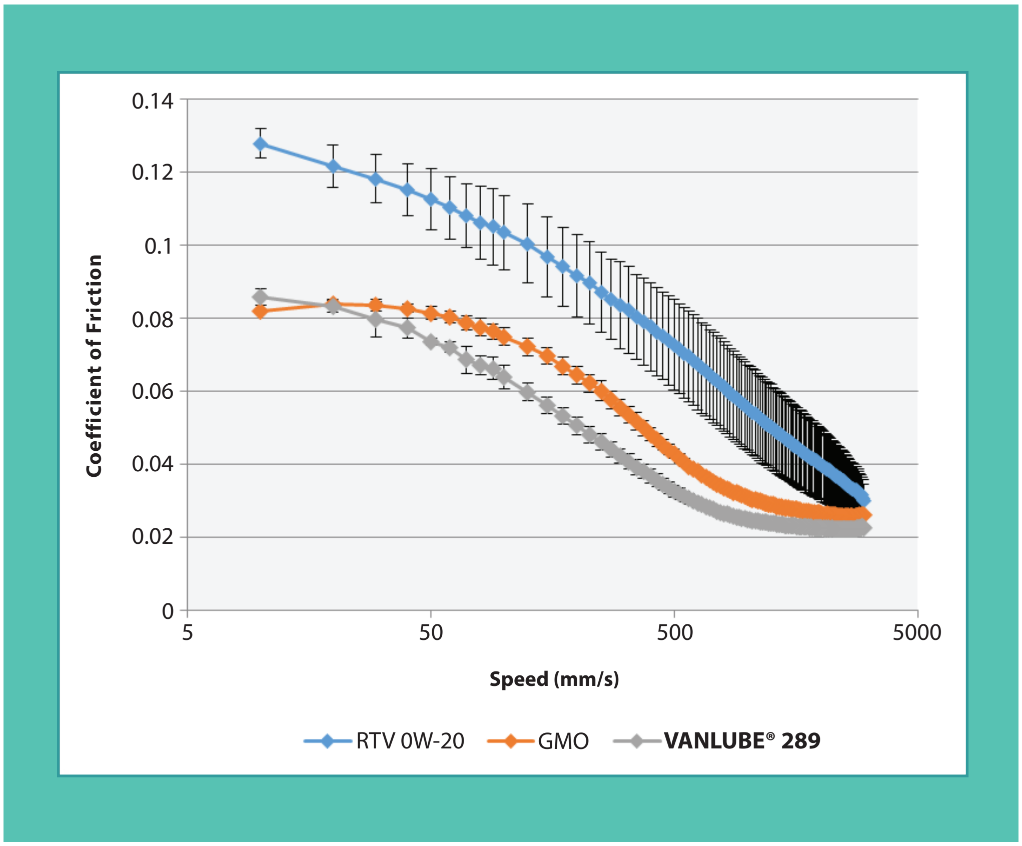


Figure 4
VANLUBE® 289 versus GMO Friction Reduction Comparison

MOLYBDENUM FRICTION MODIFIERS: MOLYVAN® 3000 AND MOLYVAN 855

Our two most popular friction modifiers are **MOLYVAN 855** and **MOLYVAN 3000**. These two molybdenum friction modifiers perform differently in fresh and aged oil conditions. **MOLYVAN 3000** is a MoDTC and performs best in fresh oil friction testing, while **MOLYVAN 855** is a molybdenum amide/ester and performs best in aged oil friction testing. Because it contains no sulfur or phosphorus, **MOLYVAN 855** typically has a higher temperature of activation than **MOLYVAN 3000** and is recommended in areas where fuel economy retention is important. We believe that the molybdenum in **MOLYVAN 855** must first react with sulfur in the finished oil to form molybdenum disulfide, before it becomes an effective molybdenum friction modifier.

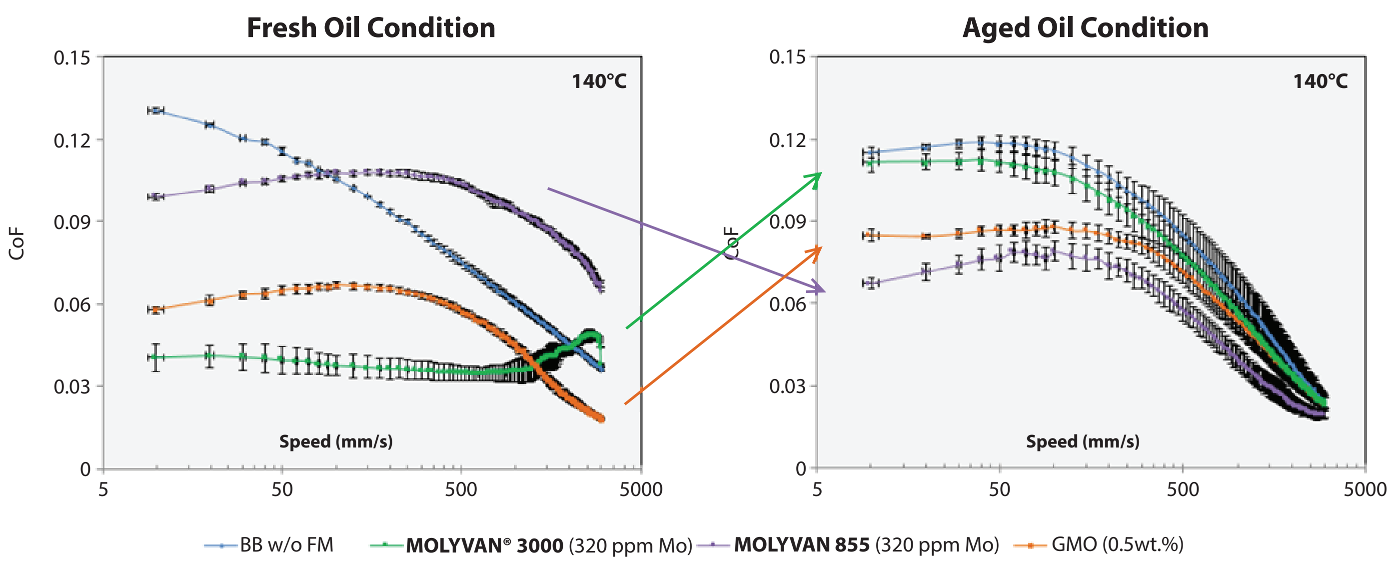
FRESH AND AGED OIL FRICTION TESTING

MOLYVAN® 855, **MOLYVAN 3000**, and GMO were compared to a fully formulated Control Oil, without friction modifier (see Figure 5). As expected, the Control Oil (BB) gave the highest friction in both the fresh and aged oils. The Control Oil was then top treated with various friction modifiers. The test oil with **MOLYVAN 855** gave the highest friction of all treated oils, because of its higher activation temperature and the time needed to react with sulfur scavenged from the formulated engine oil. Interestingly, upon aging, the test oil with **MOLYVAN 855** gave the lowest friction coefficient of all the oils tested.

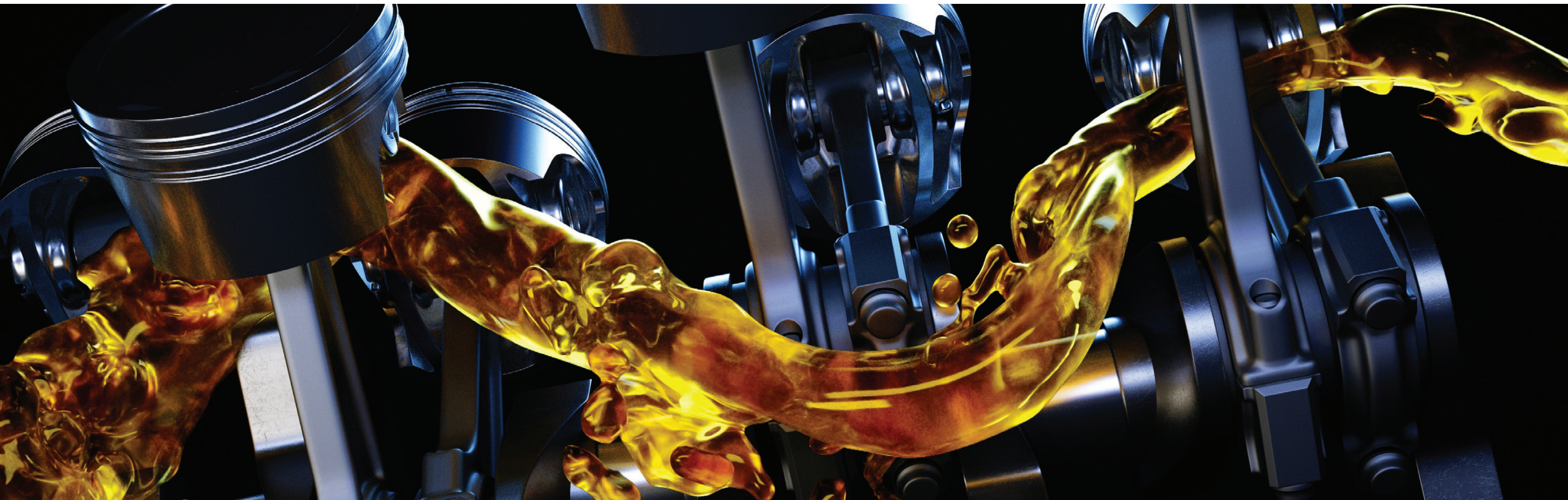
As expected from MoDTC chemistry, the test oil with **MOLYVAN 3000** gave the best (lowest) friction coefficient of all treated oils because of its low activation temperature. After aging, however, the test oil with **MOLYVAN 3000** resulted in the highest level of friction of all treated oils.

The friction performance of the oil containing GMO appeared to split the difference between the oils containing **MOLYVAN 855** and **MOLYVAN 3000** under both the fresh and aged oil test conditions. It is important to note that after aging, the oil containing GMO resulted in higher friction coefficients than its fresh oil counterpart, indicating possible degradation of the additive.

Figure 5
MOLYVAN® 855, MOLYVAN 3000 and GMO Fresh and Aged Oil Friction Reduction Comparison



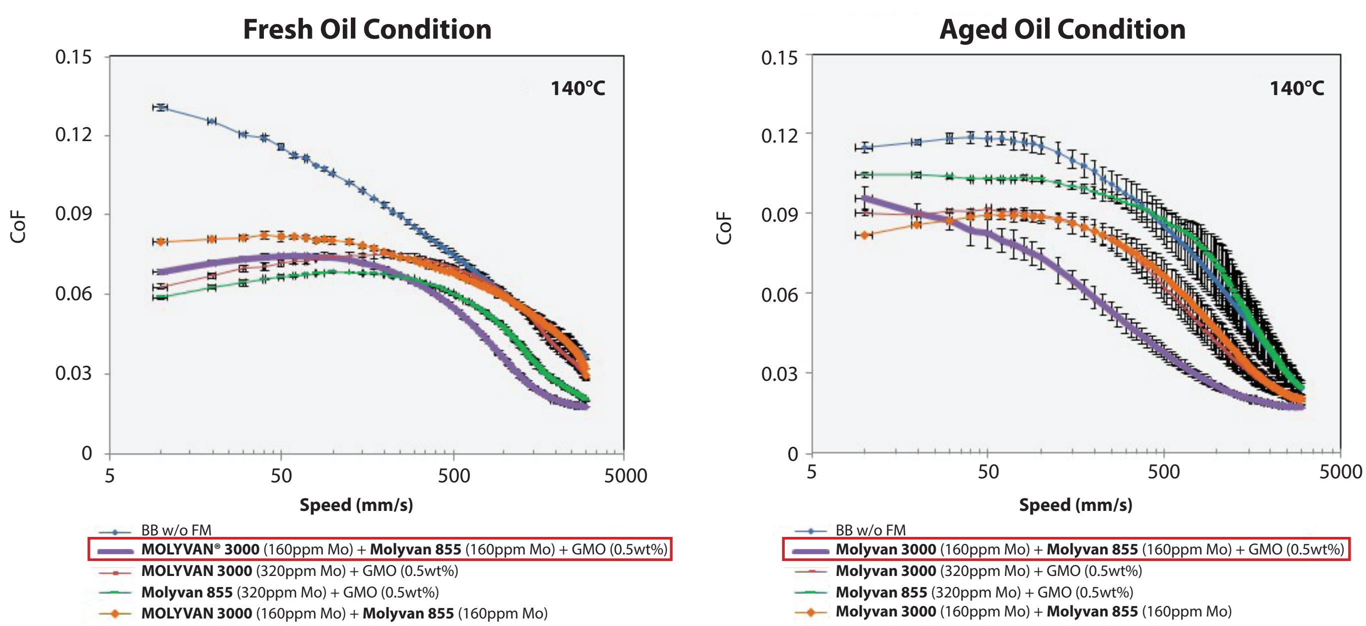
Aging Conditions: Modified ASTM D6594; 165°C for 48 hours, 100 mL oil sample, 5 L/h air flow, metal coupons: copper, lead, tin and phosphor bronze.



FRICTION MODIFIER OPTIMIZATION

Engine oil formulators often mix and match various friction modifiers to obtain the lowest fresh and aged oil friction possible at the lowest possible cost. Our testing has demonstrated that the ternary combinations of **MOLYVAN® 855**, **MOLYVAN 3000** and GMO delivers the best frictional performance across both fresh and aged oil conditions (see Figure 6 below). The ternary combination of 0.5 wt.% GMO and 160 ppm molybdenum each from **MOLYVAN 855** and **MOLYVAN 3000** was compared to several binary combinations of the three components at constant treat rates. This three-way synergy occured as a result of the excellent fresh oil synergy between GMO and **MOLYVAN 3000**, combined with the excellent aged oil performance of **MOLYVAN 855**.

Figure 6
Three Way Friction Reduction Synergism

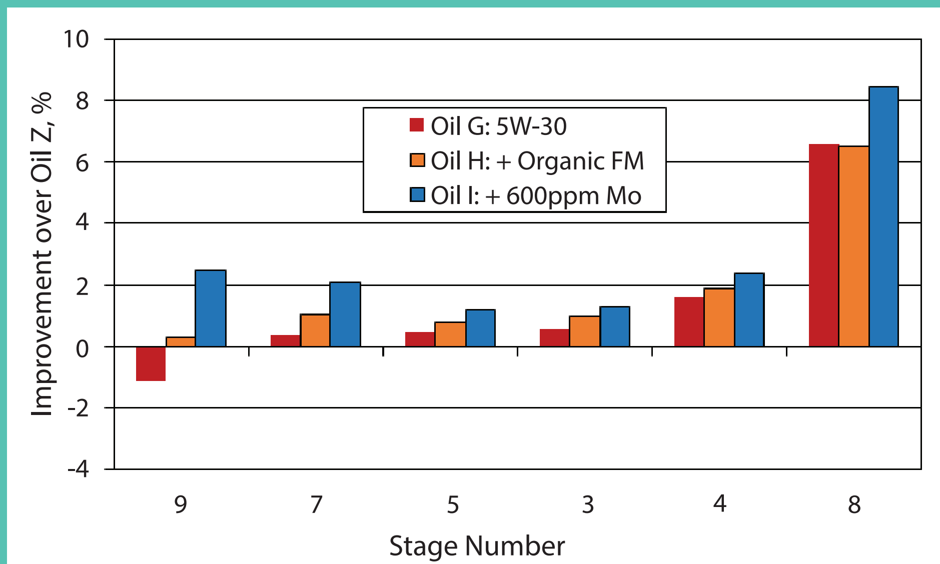


Aging Conditions: Modified ASTM D6594; 165°C for 48 hours, 100 mL oil sample, 5 L/h air flow, metal coupons: copper, lead, tin and phosphor bronze.

SEQUENCE VI FUEL ECONOMY RESULTS

The Sequence VID Consortium was assembled in 2006 to develop the Sequence VID fuel economy engine test for the ILSAC GF-5 specification, which was launched in 2010. During the Sequence VID development, the Consortium ran a number of test oils in the prototype engine test to demonstrate relevance. The control oil was formulated without friction modifier, while two of the test oils were formulated with either an organic friction modifier or molybdenum friction modifier on top of the control oil. The test data in Figure 7 was eventually made public and demonstrated that oil with molybdenum friction modifier had a greater effect on improving fresh oil fuel efficiency than the oil with organic friction modifier.

Figure 7
Sequence VID FEI 1 Fuel Economy Response



Test results are an average of two tests that were compared to Oil Z, the baseline oil, in test stages 3, 4, 5, 7, 8 and 9.

The Sequence VIE was developed during 2016-2018 and was launched with the ILSAC GF-6 specification. We evaluated a 5W-20 engine oil containing a 0.65 wt.% reduced level of ZDDP and 0.9 wt.% **MOLYVAN® 855** and 0.5 wt.% **VANLUBE® 289** friction modifiers in the Sequence VIE as part of a General Motors dexos1™ gen 3 program. Once again, the benefit of a combination of OFM and molybdenum friction modifier for improving vehicle fuel economy is demonstrated by these excellent Sequence VIE engine test results in a 5W-20 engine oil (see Table below).

SEQUENCE VIE TEST RESULTS		
	VANDERBILT TEST OIL (5W-20) CONTAINING MOLYVAN® 855 AND VANLUBE® 289	5W-20 GF-6A LIMIT
FEI 1, %	2.63	—
FEI 2, %	2.11	1.8 min.
FEI SUM, %	4.74	3.8 min.

dexos1 is a trademark of General Motors.

SUMMARY

Climate change and governmental regulations are forcing OEMs around the world to develop fuel-efficient, low emission vehicles. This in turn has forced OEMs to commercialize a number of engine innovations that has increased the demand for friction modifier solutions. Formulators are turning to molybdenum containing additives to improve the friction performance of engine oils. Vanderbilt Chemicals offers a robust line of organic and molybdenum containing friction modifiers to meet your needs. We continue to develop new friction modifiers and can tailor them to specific needs.

FOR SAMPLES, PRODUCT INFORMATION AND/OR TECHNICAL SERVICE PLEASE CONTACT VANDERBILT CHEMICALS, LLC, OR THE VANDERBILT REPRESENTATIVE IN YOUR AREA:

VANDERBILT CHEMICALS, LLC
30 Winfield Street, P.O. Box 5150
Norwalk, CT 06856-5150
P: (203) 853-1400
F: (203) 853-1452
WWW.VANDERBILTCHEMICALS.COM

VANDERBILT (BEIJING) TRADING, LTD
Room 220A, Tower A
No. 8 Hengfeng Road
Science Town, Fengtai District
Beijing 100070 P. R. China
P: 011- 86 10 56541176
F: 011- 86 10 56541175

VANDERBILT WORLDWIDE LTD
12 Park House Alvaston Business Park, Middlewich Road
Nantwich, Cheshire, CW5 6PF
United Kingdom
WWW.VANDERBILTWORLDWIDE.COM

Vanderbilt Chemicals, LLC

A Wholly Owned Subsidiary of R.T. Vanderbilt Holding Company, Inc.

VANDERBILT CHEMICALS, LLC
30 WINFIELD STREET
P.O. BOX 5150
NORWALK, CT 06856-5150
(203) 853-1400
WWW.VANDERBILTCHEMICALS.COM