Renewable Engine Oils Test

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Abstract. Evaluation of the Evolve Lubricants, Inc. ("Evolve Lubricants") renewable non-petroleum crankcase finished lubricant with respect to wear under severe operating conditions using the Porsche MA203 3.0-liter turbo charged engine and gasoline fuel POSK E25. The test was performed on behalf of Porsche AG ("Porsche") by APL Automobil-Pruftechnik Landau GmbH, Landau, Germany during July 2021. The unique test is designed to provide valuable data not highlighted in current ACEA tests. This includes oil ageing before wear testing, simulated high performance and racetrack conditions, high piston ring grove temperatures, worst case fuel scenarios addressing hybrid use cases with significant oil dilution and no oil top up or revitalization during the test. The entirety of the testing sequence and total test length is proprietary to Porsche. The length and duration of the test exceeded one hundred hours.

Keywords: renewable base oil, oil dilution, viscosity change

1 Evolve Lubricants, Inc. Renewable Engine Oil

Evolve Lubricants provided Porsche with the Evolve Lubricants, Inc. EvoSyn™ 0W-40 European Car Formula Non-Petroleum Engine Oil composition, comprising of renewable base oils as embodied by hydrocarbon mixtures with controlled structure characteristics in combination with lubricant additives that address high performance requirements. The lubricant composition provides performance in the cold crank viscosity (CCS) vs. Noack volatility relationship which allows for the formation of lower viscosity engine oils with improved engine wear results, gains in maximum power output, retained low-speed pre-ignition (LSPI) prevention, additionally conferring improved characteristics to the Porsche MA203 turbo charged engine.

2 Test Purpose

Examination of the engine lubricant performance in respect to the suitability for oil change interval of 30,000km/2 years in a 9A2 (MA203). Target is A40/C40 Approval.

3 Test Hardware

The test is performed on Porsche MA203 3.0-liter engine. The engine is a 6-cylinder horizontally opposed gasoline direct injection and turbo charged engine. Cylinder capacity: 2981 cm^3, maximum power: 331 kW at 6500 rpm, Maximum Torque: 520 Nm at 2200-5000 rpm.

Industry trends in engine oil formulations are moving to increasingly lower viscosity regimes to enhance fuel economy benefits while also expecting to maintain current or better levels of performance. However, as the industry moves to lower viscosity, maintaining low oil consumption and durability becomes challenging or even unobtainable with available petroleum technology.

3.1 Volatility

As the viscosity of the petroleum motor oils are reduced, the volatility increases leading to increased evaporation of the engine oil and increased viscosity.

3.2 Base Stocks

Base stocks (base oils) are commonly used to produce various lubricants including lubricating oils for internal combustion engines. Finished lubricants generally consist of two components: base oil and additives. Base oil which could be one or a mixture of base stocks is the major constituent in these finished lubricants and contributes significantly to their performances, such as viscosity, viscosity index, volatility, and thermal and mechanical stability.

3.3 Base Stock Categorization

The American Petroleum Institute (API) categorizes base stocks in five groups based on their saturated hydrocarbon content, sulfur level, and viscosity index. Group I, II, and III base stocks are mostly derived from crude oil after extensive processing such as solvent refining for group I, and hydro processing for Group II and III. Certain Group III base stocks can also be produced from synthetic hydrocarbon liquids via various gas-to-liquid processes (GTL) and are obtained from natural gas, coal, or other fossil-based resources. Group IV base stocks are called polyalphaolefins (PAOs), which are produced by oligomerization of alpha olefins such as a 1-decine. Group V base stocks include everything that does not belong in Groups I-IV, such as naphthenic base stocks, polyalkylene glycols (PAG), and esters. Most of the feedstocks that are required for large scale base stock manufacturing are non-renewable.

3.4 Increasing Performance Requirements

The automotive industry has been placing increasingly stringent performance specifications on engine oils due to mandate requirements for lower emissions, longer drain intervals, and improved fuel economy. Specifically, OEMs have been pushing for the adoption of lower viscosity engine oils such as 0W-20 down to 0W-8 and 0W-4 to lower friction losses and achieve fuel economy improvements. Base oils with a lower Noack volatility percentage in an engine oil formulation can retain the designed viscosity for a longer operational time resulting in longer drain intervals. Group I and II base oil formulation usage in engine oils with viscosity below the 0W-20 viscosity are highly limited due to their high Noack percentages. These formulations using Group I and II oils cannot meet increasingly stringent performance specifications for lower than 0W-20 engine oils.

3.5 Group III Oil Manufacturing Processes

Group III base oils are almost entirely manufactured from Vacuum Gas Oils (VGO) through hydrocracking and catalytic dewaxing of slack waxes. These slack waxes originate from solvent refining or catalytic dewaxing of waxes from the Fisher-Tropsch synthesis process of natural gas or coal-based raw materials also known as gas-to-liquid base oils (GTL). Their boiling point ranges are typically higher when compared to PAOs of the same viscosity, causing them to have higher volatility than PAOs.

3.6 Group IV Oil Manufacturing

Polyalphaolefins (PAOs) are produced by the polymerization of alpha olefins in the presence of Friedel Craft catalysts. 1-octene, 1-decine, and 1-dodecene molecules are used to manufacture PAOs that have a wide range of viscosities with varying molecular weight and viscosity from 2cSt-100cSt at 100C°. The polymerization reaction is typically completed in the absence of hydrogen. The lubricants are then polished or hydrogenated to reduce residual saturation.

3.7 Renewable Hydrocarbon Performance Requirements

Common biological sources for renewable hydrocarbons are non-petroleum natural oils containing a high linoleic acid content which can be derived from plant biomass such as soy, rapeseed, peanut, sunflower, and palm oil. Due to increasing performance requirements driving demand for high performing lubricant base stocks, there is a need for high performing hydrocarbon mixtures. The automotive industry requires hydrocarbon lubricant mixtures to have superior Noack volatility which Evolve Lubricants' non-petroleum engine oils have using only renewable base oil.

3.8 Importance Of Volatility And Noack Scores

Volatility is a measurement of oil loss from evaporation at an elevated temperature. Volatility is dependent on the oil's molecular composition, especially at the front end of the boiling point curve. ASTM D5800 is the commonly accepted method to measure volatility in automotive lubricants. The Noack test method itself simulates evaporative loss in high temperature service such as an operating internal combustion engine. Pour point is the lowest temperature at which movement of the test specimen is observed. It is a very important specification as engine oils are designed to operate in liquid phase.

3.9 Physical Performance Property Requirements Dictate Molecular Design

The result is precise control over the critical physical properties to improve performance of: Viscosity, volatility/vapor pressure, freezing point (pour point), low temp viscosity Brookfield (CCS), temperature-dependent viscosity (VI), traction coefficient and pressure viscosity relationship inherent or correlated properties (thermal Cp k) dielectric, and stability (shear, thermal and chemical).

- Precise control over branch length position and proximity and degree
- Linear olefins control of the average double-bond position
- Dimer and trimer control of alkyl branching
- Final product is selective isomerization-optimized structure
- Precise control over linear olein chain length and average branching point
- Oligomerization and alkyl branch formation
- Selective isomerization and methyl branch addition

More consistent lubrication film thicknesses and strength under a wider range of operating conditions offers higher performance base oils for given viscosity grades. Lower Noack volatility resulting in higher flash points than same grade PAOs with more efficient heat transfer, high thermal conductivity, and heat capacity for ultra-low viscosities. For electric vehicle fluids – highest volume resistivity and dielectric strength for a given viscosity grade. Evolve's base oil by Novvi LLC has the environmental benefit of being 100% renewable carbon.

4 Test Results

4.1 Piston Ring Groove Widening Severe Oxidation And Wear Test

Aged Oil under High Performance racetrack conditions, worst case fuel E25 with a boiling point up to 230°C, high piston groove temperatures up to 280°C.

Typical failures include broken 1st ring, excessive aluminum wear rate, groove widening.

Result – No issues with Evolve renewable motor oil

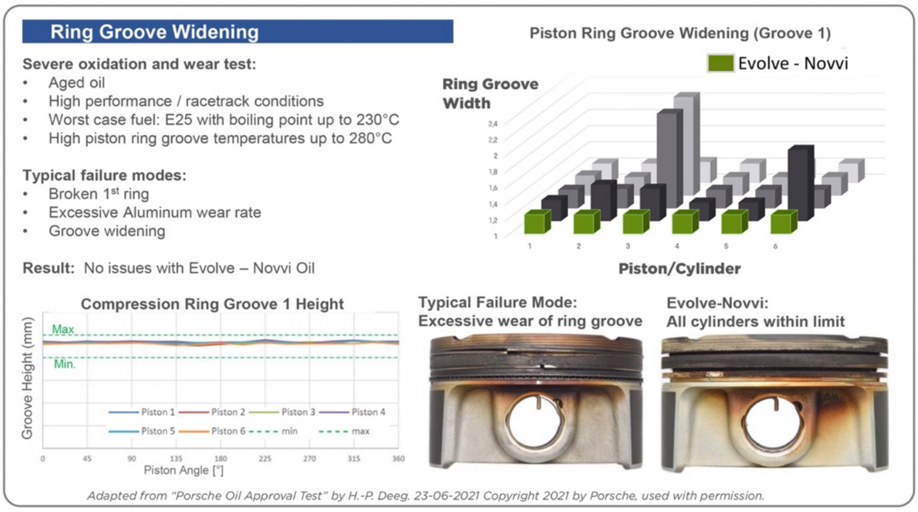

Fig. 1. Ring Groove Widening. Wells, J. Novvi LLC, 2021

4.2 Oil Dilution Vs. Viscosity Change Test

Causes – higher torque at rated power with longer injector duration, cold cycles short range and hybrid vehicles.

Effects – Oil viscosity drop and increased wear, oil oxidation/blowby create piston deposits, oil additive dilution or degradation.

Result – Low viscosity change at high dilution rate.

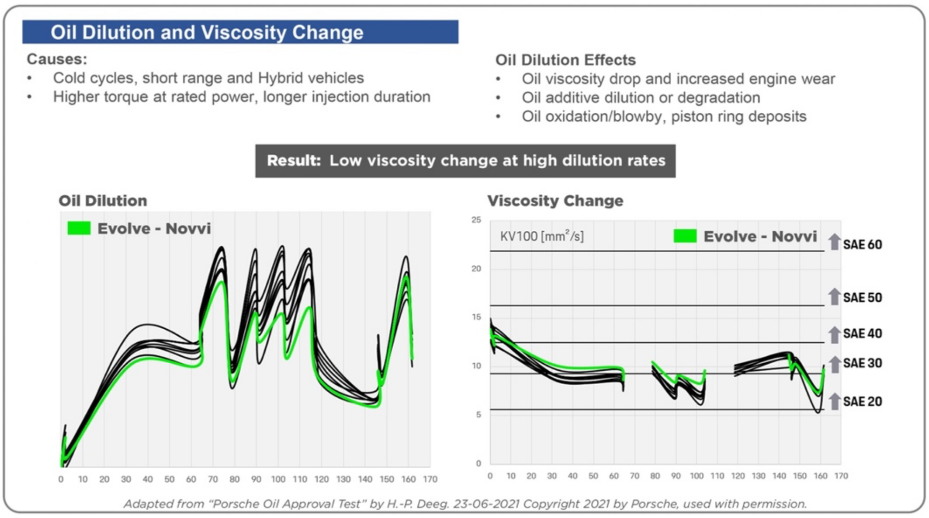

Fig. 2. Results for oil dilution vs. viscosity change. Wells, J. Novvi LLC, 2021

4.3 Piston Groove Deposits Test

Causes: Oil oxidation, soot wear or damage to piston rings or ring grooves, fuel dilution

Effects: Oil degradation and wear to the piston rings

Results: Evolve oil below limit on all cylinders

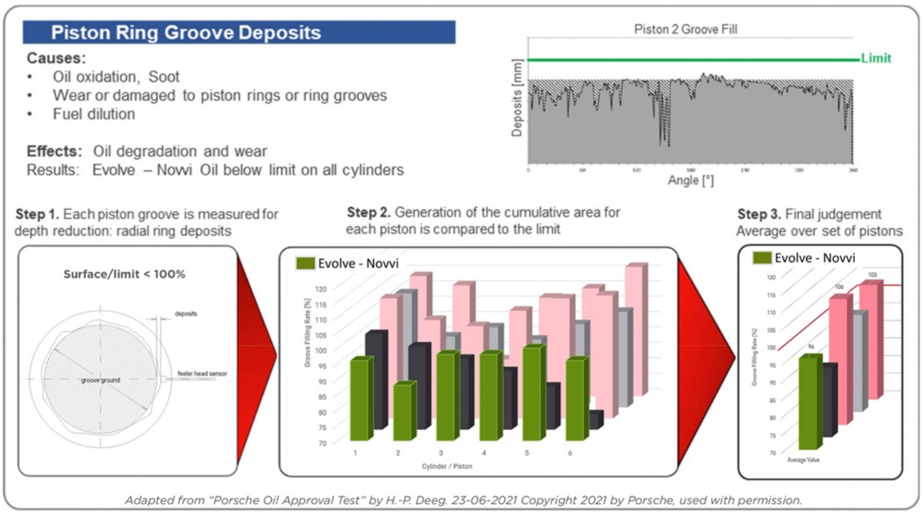

Fig. 3. Results Of Piston Ring Groove Deposits. Wells, J. Novvi LLC, 2021

4.4 Other Deposits And Wear Testing

- Cylinder liner wear - no harm
- Filter blocking hydraulic valves - no harm
- Turbocharger variable turbine sticking - no harm
- Turbocharger sealing ring sticking - no harm
- Tappet surface DLC - no harm
- Tappet wear outlet small lift DLC - no harm
- Tappet wear inlet big lift DLC - no harm
- Cam wear outlet DLC - no harm
- Cam wear inlet small lift DLC- no harm
- Cam wear inlet big lift DLC - no harm
- Piston ring sticking - no harm

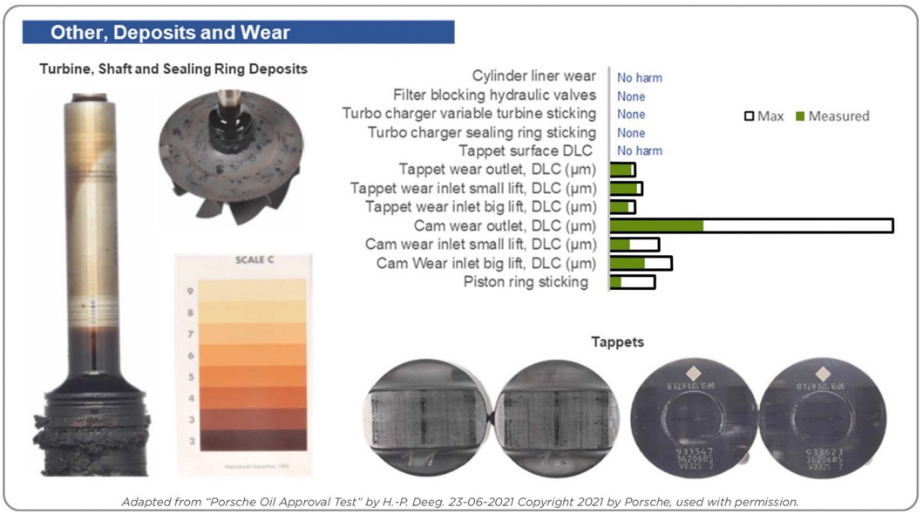

Fig. 4. Other Deposits And Wear. Wells, J. Novvi LLC, 2021

4.5 Horsepower and Torque Maximum For The Porsche MA203

The published (MAX) horsepower for this engine on Porsche's website is 443 HP (6500rpm).

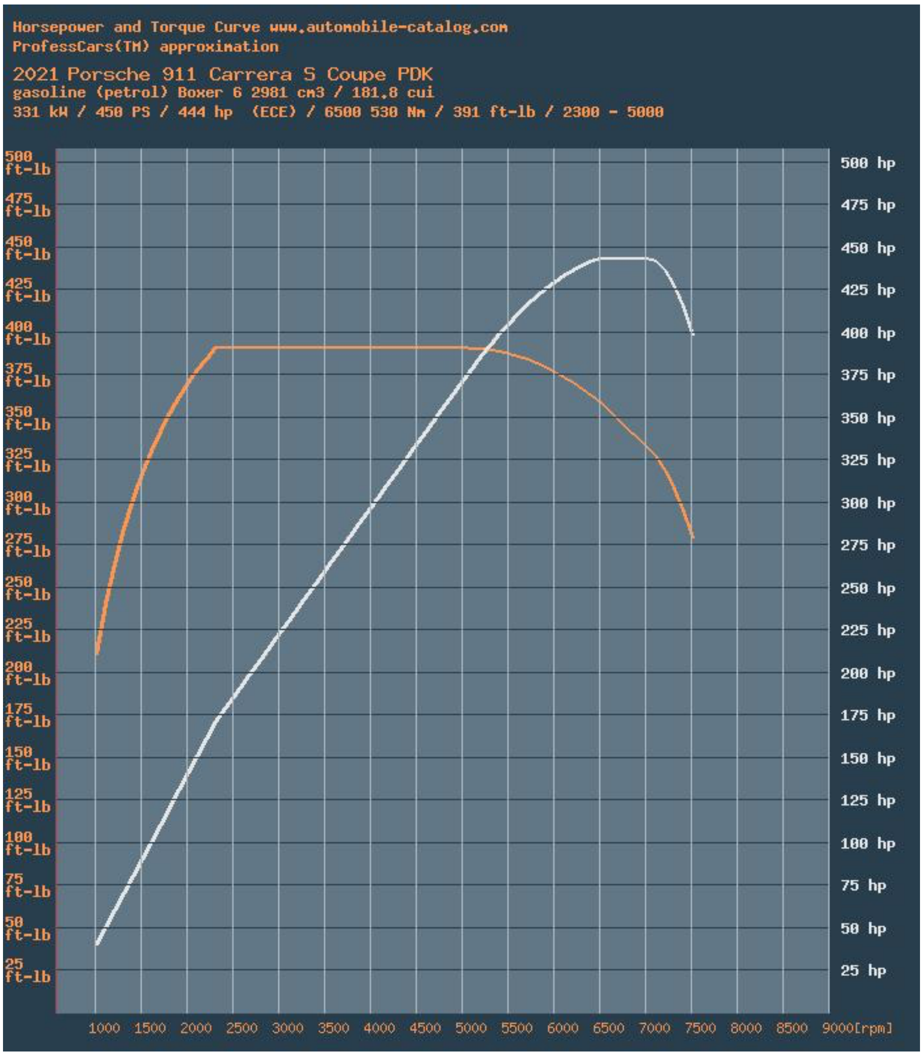

Fig. 5. 2021 Porsche 911 Carrera S Coupe PDK Horsepower and Torque

Test Result – The max HP specifically-full load power curve @SoT Evolve Renewable 0W-40 reference 156 071 0210025 Test is 455HP (7,000RPM).

A positive variance of 12 metric horsepower.

4.6 Evolve Renewable Engine Oil Extended Drain Interval

Advanced oil formulations have allowed the industry to make great strides in extending drain intervals. The CK-4 and CK-4 Plus oils used in diesel engines manufactured prior to 2007 had a significant impact. Although many felt this progress would be jeopardized by the CJ-4 oils that were later introduced with a lower starting base number (BN), better CJ-4 additive technology enabled many fleets to increase drain intervals even further.

While fluid analysis is the best way to safely determine an optimal drain interval, the appropriate testing should be done by a reputable laboratory that uses reliable testing methods.

Safely extending engine drain intervals requires the following tests:

- Elemental analysis
- Wear metals
- Contaminant metals
- Additive metals
- Fuel dilution percentage by gas chromatography
- Soot percentage by Fourier transform infrared (FTIR) spectroscopy
- Viscosity at 100 degrees Celsius (ASTM D-445)
- Water by crackle
- BN ASTM D-4739
- Oxidation/nitration by FTIR

In the past, standard practices for determining optimal drain intervals using fluid analysis have required testing the oil for base number (BN) and acid number (AN). The theory was that when new, an oil's BN is high and it’s AN is low; and the longer the oil is used, BN decreases while AN increases. The point at which they meet is the optimal time to change the oil. It is important to note that ASTM D-4739 should be used when testing the BN of used (in-service) oils as opposed to ASTM D-2896, which may be used when testing BN in new oils. ASTM D-4739 uses a weaker acid for titration than does ASTM D-2896 and, therefore, produces slightly lower BN results.

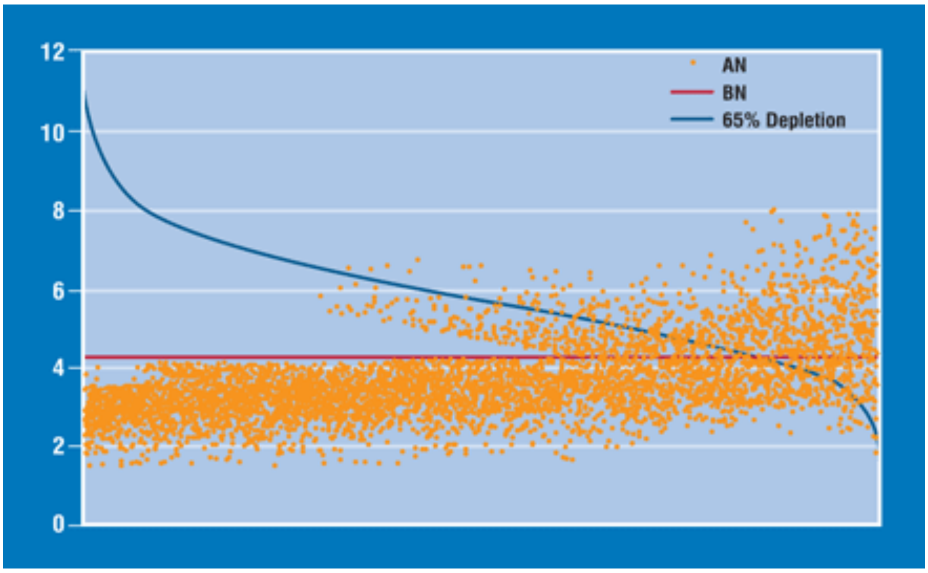

Fig. 6. Determining Optimal Drain Intervals Using Acid Number (AN)

Historical test data shows the relationship between BN and AN to be quite consistent. AN just begins to increase when BN depletion reaches 50 percent. As the BN drops below 50 percent, AN begins increasing rapidly. So, in reality, BN depletion can reach about 65 percent before it becomes necessary to change the oil.

Consider a CJ-4 engine oil with a starting BN of 9.0. AN will hold steady at around 1.75 to 2.0 until BN depletes to approximately 5.5, at which point AN begins to increase. The two will meet at around 3.15 to 3.5. As a result, most laboratories do not require both an AN and a BN to make extended drain recommendations.

Table 6 represents BN/AN test results across a fleet of more than 450 pick-up/delivery trucks. AN remains steady until the BN depletes from 12 to about 6. The two meet at between 50 and 65 percent depletion of the BN. The AN is significantly higher than the BN after the BN has reached 65 percent depletion, which indicates that the oil's ability to neutralize acids has dropped significantly. The oil should be changed to prevent corrosive engine wear from occurring.

Monitoring BN, viscosity, oxidation, and nitration simultaneously and changing both the oil and filters when contamination from dirt, coolant, fuel dilution or soot reaches critical alarm limits is ultimately the best way to determine optimal engine oil drain intervals regardless of the time on the oil.

The Evolve engine oil has a starting TBN of 7. Evolve Lubricants can extend intervals at the basic methodology of testing above. The accelerated oxidation test to determine time to break test is a proprietary test performed with Novvi proprietary testing apparatuses. The methodology, parameters and data were accepted by Porsche. The testing exceeds current known hours for oxidation testing.

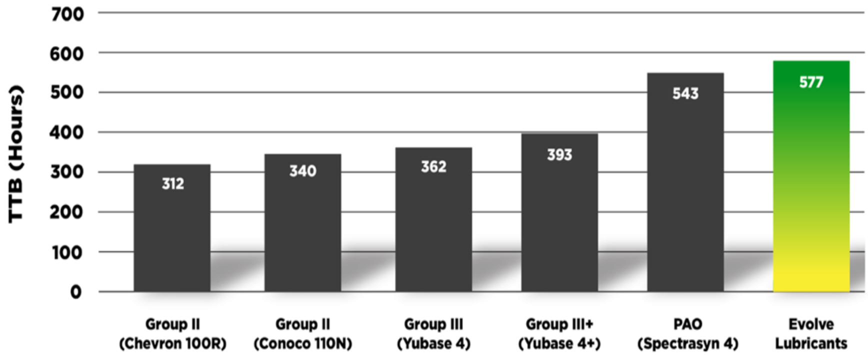

Fig. 7. Accelerated Oxidation Test. Wells, J. Novvi LLC, 2021

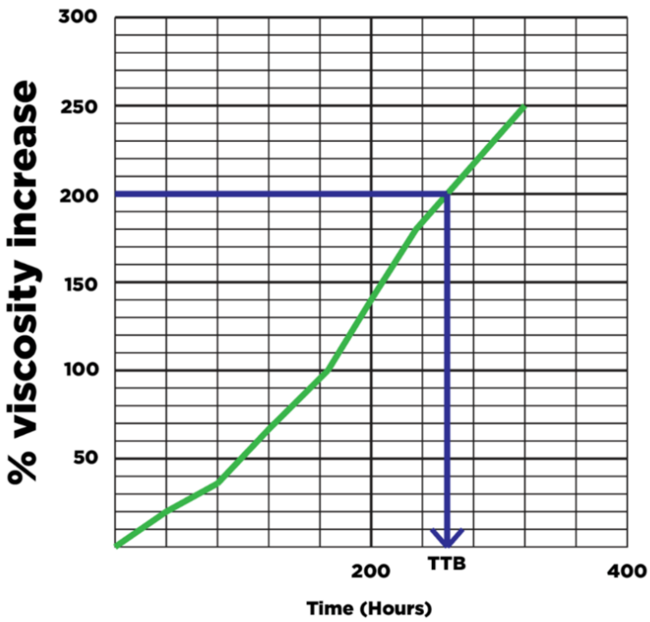

Fig. 8. Time To Break Vs. % Viscosity Increase. Wells, J. Novvi LLC, 2021

5 Summary

When energy is transmitted through a fluid there is an intermolecular interaction. Heat transfer presents through the exchanging of kinetic energy, but the primary mode of heat transfer is conduction through the carbon backbone of the molecule. What is found is that the longer the carbon chain (or more linear), energy is more efficiently transmitted across the carbon bonds.

To that extent, if you can have a longer backbone or longer continuous carbon chain, this allows for much higher thermal conductivity. In PAOs or another given molecular structure, increases in weight of the hydrocarbon produce an increase in thermal conductivity.

If you reduce the branching and increase the linearity of a pure paraffin it has a much higher thermal conductivity than a branching molecule. There are some additional complications due to changing the density, but in Evolve Lubricants' case the densities are very close.

The primary mechanism in which Evolve is affecting thermal conductivity in its base oils is the average carbon backbone length and heat capacity. This is a function of the degrees of freedom with the molecule. These molecules can store energy in many ways and that can be seen through molecular dynamics, and approaches of modeling these molecules, which is a well understood trend.

It is logical that an engine oil made entirely from renewable base oil is superior to traditional petroleum engine oil in terms of resistance to acid formation. Petroleum base oils contain significant amounts of sulfur. Sulfur is easily converted into sulphur dioxide and trioxide, and these in turn combine readily with condensation to form sulfuric acid. It follows that oil produced with no sulfur cannot subsequently form sulphuric acid.

The use of renewable hydrocarbon base oil can help protect against micro pitting, without compromising other wear and lubricant properties, while having excellent foaming control, good corrosion protection, and compatibility with seal materials.

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