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# OVERVIEW OF DYNAMOMETER BASED ENGINE FUELS AND LUBRICANTS TESTING

## San Antonio, Texas

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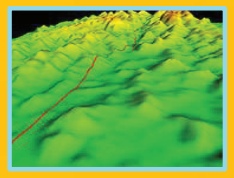
# INTERTEK INTRODUCTION: OUR HERITAGE

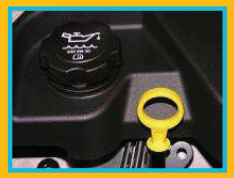


**1885**

Caleb Brett founded a marine surveying business

**1896**

Thomas Edison established what is later renamed as the Electrical Testing Laboratories (ETL)



**1953**

Automotive testing focused on engines, fuels and lubricants


**2006-present**

Expansion of Engine dyno based Fuels and lubricants testing – Europe, USA, China

**2013 & 2017**

Expansion of Fleet Testing Services with Phoenix and German Labs

**Today**

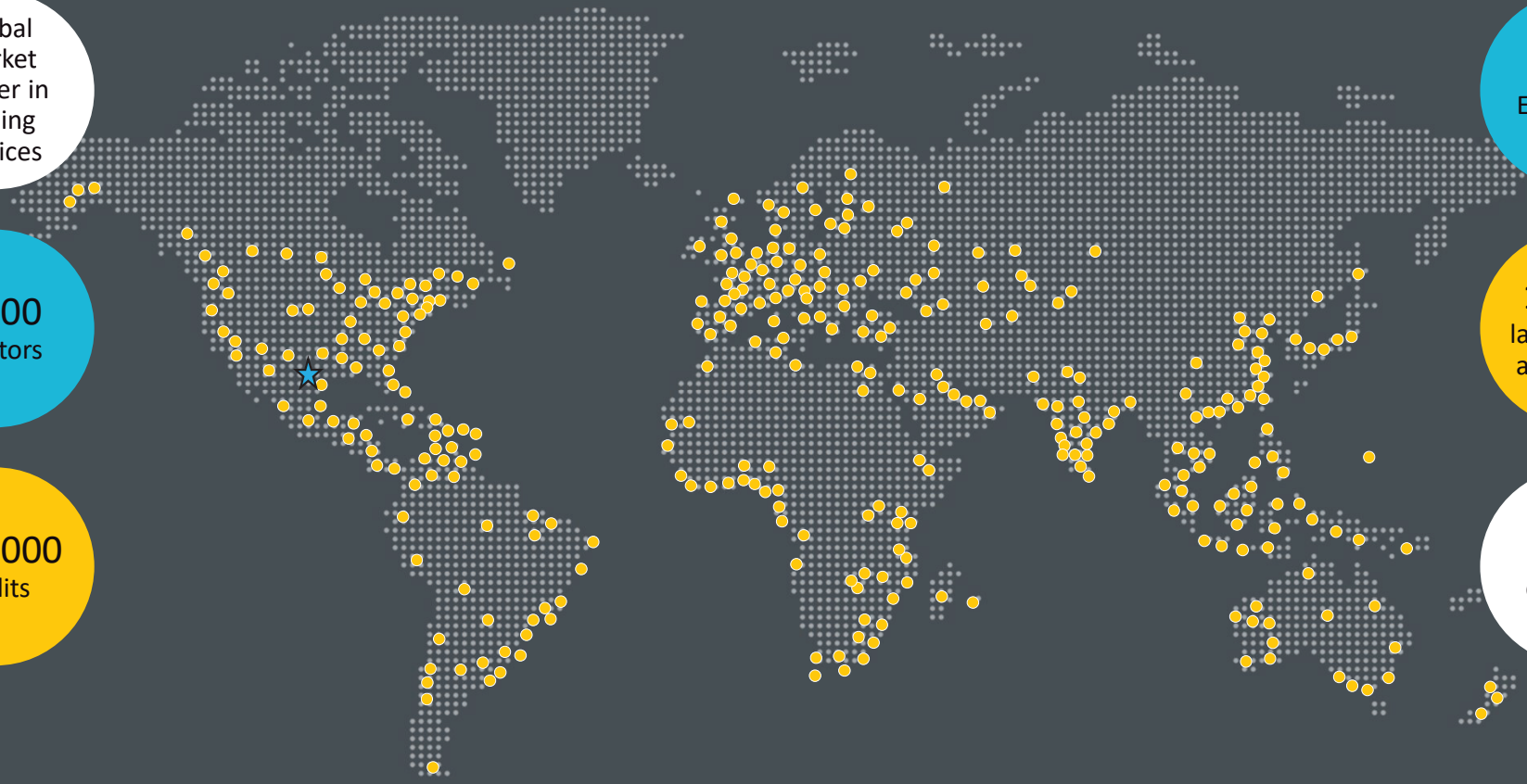
Intertek Today: **Valued Quality. Delivered.**

# INTERTEK IS GLOBAL! OUR GLOBAL NETWORK AND CAPABILITIES

Global Market Leader in Testing Services

3,000 auditors

100,000 audits



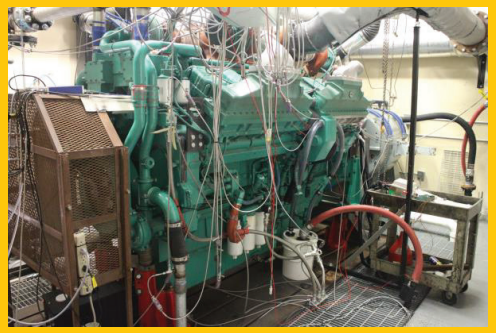
43,000 Employees

1,000+ laboratories and offices

100+ countries

# SAN ANTONIO - AUTOMOTIVE RESEARCH OVERVIEW

- 70 years of independent testing
- Fuels and Lubricants Industry
- Engine/Vehicle OEM and Tiered Suppliers
- 4 stand alone laboratories in San Antonio, Texas
- 30+ Engineers, ~300 employees
- 24/7/365 operation
- **Over 120 Engine Dynamometer Test Cells**
- Vehicle level Development and Durability Testing
- Fuel System Testing
- Evaporative Emission (SHED) Testing
- Automatic Transmission Fluid Testing
- Axle efficiency Testing
- Analytical Testing
- Quality:  ISO 17025

# WIDE RANGE OF FLUID TESTING CAPABILITIES



**Crankcase Lubes**

- ASTM/API/dexos®
- Diesel HD Tests
- Gasoline PC Tests
- Research/Special Projects

**Fuels**

- Diesel
- Gasoline
  - IVD
  - CCD
  - GDI Injector Deposits
  - Preignition
  - Top Tier Protocol

**Driveline**

- Gear
- Efficiency
- ASTM
  - L37, L42, ….
- OEM

**Transmission**

- 21 Test Types
- GM, Ford, Chrysler
- FZG
- JASO

# CRANKCASE LUBRICANT TESTING DETAILS

## Light Duty/PCMO

### JASO/GF6/7 & dexos™

| |
|---|
| Oxidation - GMOD/Chrysler (IIIH) |
| Fuel Econ – (VIE / VIF) |
| Toyota Wear (IVB) |
| Ford Sludge (VH) |
| Ford Chain Wear (X) |
| Bearing Corrosion – (VIII) |
| GM and Ford LSPI (GMSPI3, IX) |
| GM Turbo Deposit – (GMTC) |
| GM Aeration – (GMAER) |
| JASO M366 |

## Heavy Duty

### API / PC12 / OEM

| |
|---|
| 1K, 1N, 1P |
| C13 |
| T-8A/E |
| T-8 |
| T-8 E |
| T-11 |
| T-12 |
| T-13 |
| ISM |
| ISB |
| DD13 |
| COAT |
| Ford 6.7L |
| Cummins COP (Nat Gas) |

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# PASSENGER CAR MOTOR OIL TESTS

# SEQUENCE IIIH, ASTM 8111

**Objective** – The test method was developed to evaluate an automotive engine oil's ability to protect against oil thickening and piston deposits during moderate high speed, high temperature conditions.

**Specifications**

- API Category – SJ, SL, SM, SN, SN+, SP
- ILSAC – GF-6

**Engine -** 2014 Chrysler Pentastar 3.6 Liter, V-6 engine.

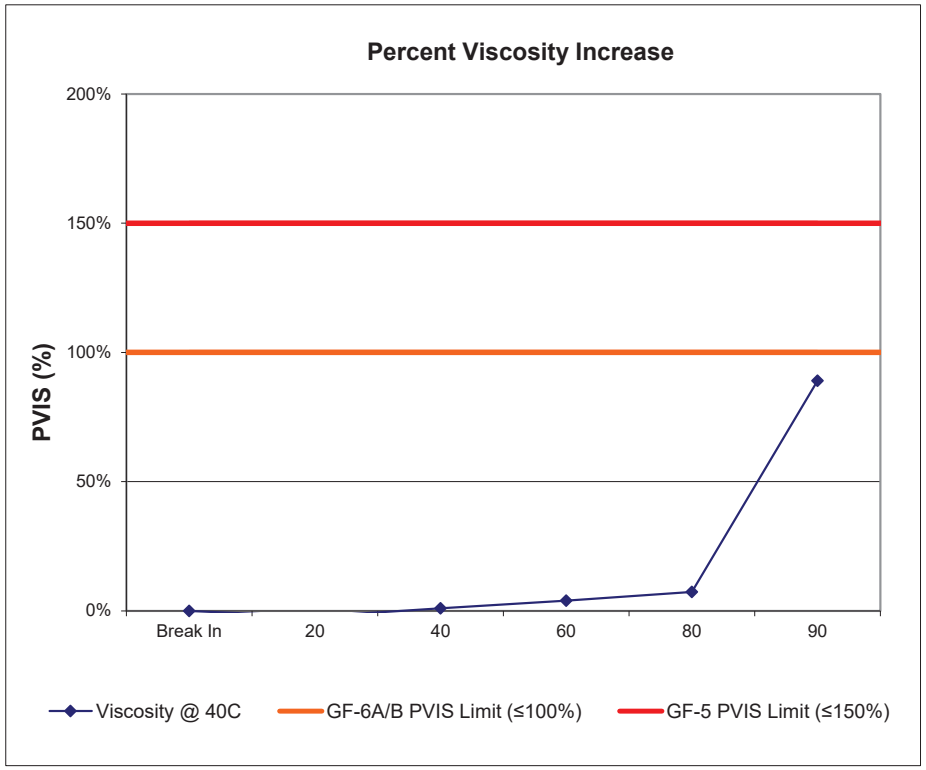
**Operating Conditions–** . The Sequence IIIH Test consists 90 hours of engine operation at moderately high speed, load, and temperature conditions. The 90-hour segment is broken down into four 20-hour test segments and one 10-hour segment. Oil samples are taken after each segment and analyzed for viscosity, FTIR, wear metals (ICP), TAN and TBN.

| Test Conditions | | |
|---|---|---|
| | Units | Target |
| Test Duration | hours | 90 |
| Speed | rpm | 3900 |
| Load | Nm | 250 |
| Oil Block Temperature | °C | 151 |
| Coolant Out Temperature | °C | 115 |
| Intake Air Temperatures | °C | 35 |
| Fuel Temperature | °C | 30 |
| Dew Point | °C | 16.1 |
| Intake Air Pressure | kPa gauge | 0.05 |
| Right Exhaust Pressure | kPa gauge | 4.5 |
| Left Exhaust Pressure | kPa gauge | 4.5 |
| Coolant Flow Rate | LPM | 170 |

# SEQUENCE IIIH PASS / FAIL CRITERIA

| ASTM TEST | SEQUENCE TEST | PARAMETER | API SP 2020 and newer vehicles | | API SN Plus 2020 and older engines | | SM 2010 and older engines | SL 2004 and older engines | SJ 2001 and older engines |
|---|---|---|---|---|---|---|---|---|---|
| | | | API SP LIMITS | Resource Conserving / ILSAC GF-6 | API SN LIMITS | Resource Conserving | API SM LIMITS | API SL LIMITS | API SJ LIMITS |
| D8111 | IIIH | PVIS @40C, % | ≤ 100 | ≤ 100 | ≤ 150 | ≤ 150 | ≤ 150 | -- | -- |
| | | Ave Weighted Piston Deposits, Merits | ≥ 4.2 | ≥ 4.2 | ≥ 3.7 | ≥ 3.7 | ≥ 3.2 | -- | -- |
| | | Hot Stuck Rings | None | None | None | None | None | -- | -- |
| D8111 | IIIHA or ROBO | MRV, cP | 60,000 | 60,000 | 60,000 | 60,000 | 60,000 | -- | -- |
| | | Yield Stress | <35 | <35 | <35 | <35 | <35 | -- | -- |
| D8111 | IIIHB | Phos Retention | -- | ≥ 81 | -- | ≥ 81 | -- | -- | -- |
| D8111 | IIIH 60 | 60h Kinematic Vis Increase, % | -- | -- | -- | -- | -- | -- | ≤ 307 |
| | | 60h Ave Weighted Piston Deposits, Merits | -- | -- | -- | -- | -- | -- | -- |
| | | 60h Avg Piston Skirt Varnish, Merits | -- | -- | ` | -- | -- | -- | -- |
| D8111 | IIIH 70 | 70h Kinematic Vis Increase, % | -- | -- | -- | -- | -- | ≤ 181 | -- |
| | | 70h Ave Weighted Piston Deposits, Merits | -- | -- | -- | -- | -- | ≥ 3.3 | ≥ 2.5 |
| | | 70h Avg Piston Skirt Varnish, Merits | -- | -- | -- | -- | -- | ≥ 7.9 | ≥ 7.5 |

# SEQUENCE IIIH, TEST EVALUATION (PVIS AND WPD)




Pass

Fail

# SEQUENCE IVA, ASTM D6891

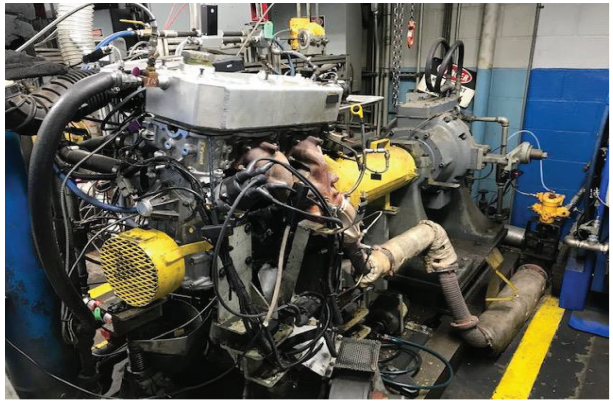
**Objective** – The test method was developed to measure an oil's ability to protect against camshaft lobe wear for overhead camshafts with sliding camshaft followers at low temperature operating conditions.

**Specifications**

- API Category – SJ, SL, SM, SN

**Engine -** 1994 Nissan KA24E 2.4 L

**Operating Conditions–** . The Sequence IVA Test consists 100 hours of continuous engine running, cycling from 800 rpm to a short 1500 rpm stage, 100 times. Oil samples are taken at 25 h, 50 hr, 75 hr and 100 hr and analyzed for viscosity, wear metals (ICP) and fuel dilution,



| Test Conditions | | | |
|---|---|---|---|
| | Units | Stage 1 | Stage 2 |
| Duration | Min | 50 | 10 |
| Speed | RPM | 800 | 1500 |
| Engine Torque | Nm | 25 | 25 |
| Coolant Out Temperature | °C | 50 | 55 |
| Oil Cylinder Head Temperature | °C | 49 | 59 |
| Intake Air Temperature | kPa | 32 | 32 |
| Intake Air Pressure | kPa | 0.05 | 0.05 |
| Intake Air Humidity | g/kg | 11.5 | 11.5 |
| Exhaust Pressure, absolute | kPa | 103.5 | 103.5 |
| Engine Coolant Flow | LPM | 30 | 30 |
| Rocker Cover Fresh Air Flow | SLPM | 10 | 10 |
| Ignition Timing | °BTDC | 10 | N/A |

# SEQUENCE IVA PASS / FAIL CRITERIA

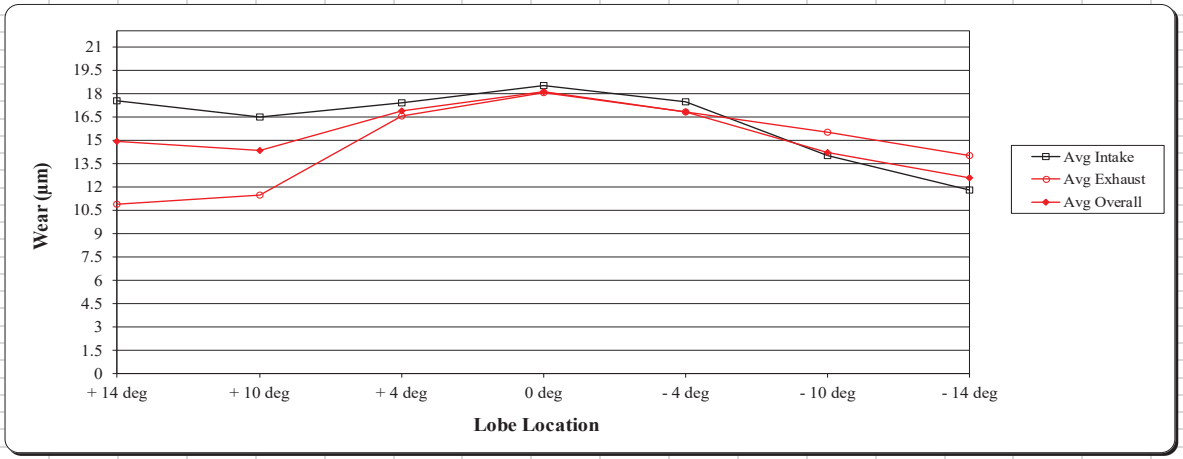
| ASTM TEST | SEQUENCE TEST | PARAMETER | API SP 2020 and newer vehicles | | API SN Plus 2020 and older engines | | SM 2010 and older engines | SL 2004 and older engines | SJ 2001 and older engines |
|---|---|---|---|---|---|---|---|---|---|
| | | | API SP LIMITS | Resource Conserving / ILSAC GF-6 | API SN LIMITS | Resource Conserving | API SM LIMITS | API SL LIMITS | API SJ LIMITS |
| D6891 | IVA | Avg Cam Wear, µm | -- | -- | ≤ 90 | ≤ 90 | ≤ 90 | ≤ 120 | ≤ 120 |

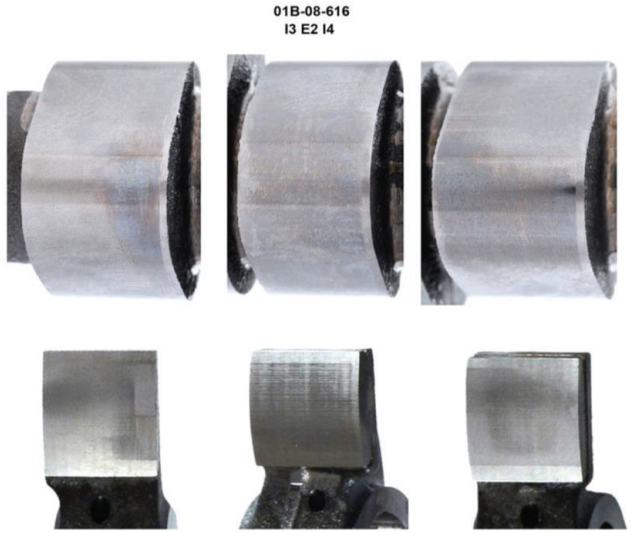
# IVA CAM WEAR SUMMARY

## KA24E LOBE WEAR SUMMARY

Oil Code: EG-0235/CMIR-169637 | Test Number: 01B-00-0831
EOT Date: August 1, 2022 | Lobe 1 9091 | Lobe 2 9063 | Camshaft Number: 0865-3

| | Measurement Location | 1 Intake | 2 Exhaust | 3 Intake | 4 Intake | 5 Exhaust | 6 Intake | 7 Intake | 8 Exhaust | 9 Intake | 10 Intake | 11 Exhaust | 12 Intake | Avg Intake | Avg Exhaust | Avg Overall |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BTDC | + 14 deg | 19.78 | 1.94 | 19.42 | 18.49 | 2.86 | 21.52 | 20.61 | 21.64 | 2.58 | 17.72 | 17.01 | 20.11 | 17.53 | 10.86 | 14.90 |
| | + 10 deg | 20.27 | 8.83 | 15.79 | 15.60 | 16.52 | 18.97 | 17.82 | 5.53 | 16.59 | 13.68 | 14.90 | 13.04 | 16.47 | 11.45 | 14.30 |
| Positive | + 4 deg | 20.12 | 14.68 | 17.82 | 15.37 | 17.43 | 20.28 | 18.06 | 22.90 | 16.01 | 16.30 | 11.11 | 15.30 | 17.41 | 16.53 | 16.84 |
| | 0 deg | 20.9 | 20.28 | 19.18 | 16.23 | 17.53 | 23.31 | 19.61 | 21.89 | 16.13 | 17.11 | 12.44 | 15.36 | 18.48 | 18.04 | 18.10 |
| ATDC | - 4 deg | 22 | 18.68 | 20.79 | 15.41 | 16.07 | 22.96 | 17.51 | 19.91 | 13.50 | 13.60 | 12.52 | 14.03 | 17.48 | 16.80 | 16.82 |
| | - 10 deg | 17.8 | 16.93 | 13.16 | 14.26 | 15.07 | 14.90 | 11.13 | 18.08 | 11.49 | 12.90 | 11.88 | 16.09 | 13.97 | 15.49 | 14.17 |
| Negative | - 14 deg | 12.35 | 18.98 | 12.57 | 16.82 | 10.43 | 9.99 | 11.50 | 15.97 | 12.15 | 7.39 | 10.72 | 11.59 | 11.80 | 14.03 | 12.56 |
| | **Total Lobe Wear** | **133.22** | **100.32** | **118.73** | **112.18** | **95.91** | **131.93** | **116.24** | **125.92** | **88.45** | **98.70** | **90.58** | **105.52** | **Max Cam Wear** | | **133.22** |
| Document No. | | | | | | | | | | | | | | **Average Cam Wear** | | **109.81** |



# SEQUENCE IVB, ASTM D8350

**Objective** – The test method was developed to measure an oil's ability to control valve-train wear and overall engine wear, at low temperature operating conditions.

**Specifications**

- API Category – SP
- ILSAC – GF-6A/B
- JASO GLV-1
- ACEA A7/B7, A3/B4, A5/B5, C2, C3, C4, C5, and C6

**Engine –** 2011 Toyota 2NR-FE, 1.5 L, Dual overhead cams

**Operating Conditions–** . The Sequence IVB Test consists 200 hours of cyclic operation with a minimum of 24,000 cycles. Oil samples are taken every 25 hrs and analyzed for viscosity, wear metals (ICP), oxidation (FTIR), Karl Fischer water content, fuel dilution, TAN and TBN.

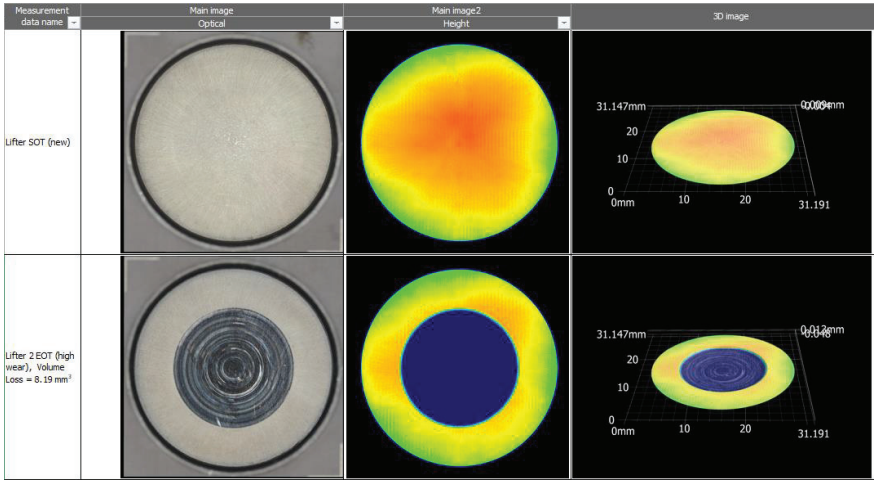
| | | Operating Conditions | | | |
|---|---|---|---|---|---|
| | Units | Ramp to Stage 1 | Stage 1 | Ramp to Stage 2 | Stage 2 |
| Test Duration | Seconds | 8 | 7 | 8 | 7 |
| Engine Speed | RPM | 4300 to 800 | 800 | 800 to 4300 | 4300 |
| Engine Torque | N-m | 25 | 25 | 25 | 25 |
| Coolant Out Temperature | °C | 52 | 52 | 52 | 52 |
| Oil Gallery Temperature | °C | 54 | 54 | 54 | 54 |
| RAC Coolant Out Temperature | °C | 20 | 20 | 20 | 20 |
| Fuel Rail Temperature | °C | 24 | 24 | 24 | 24 |
| Load Cell Temperature | °C | 45 | 45 | 45 | 45 |
| Intake Air Temperature | °C | 32 | 32 | 32 | 32 |
| Blow-by Gas Temperature | °C | 29 | 29 | 29 | 29 |
| Intake Air Pressure | kPa | 0.25 | 0.25 | 0.25 | 0.25 |
| Exhaust Pressure (Absolute) | kPa | - | - | - | 104.5 |

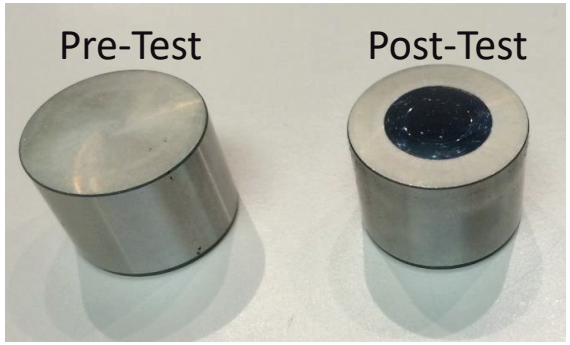
# SEQUENCE IVB PASS / FAIL CRITERIA

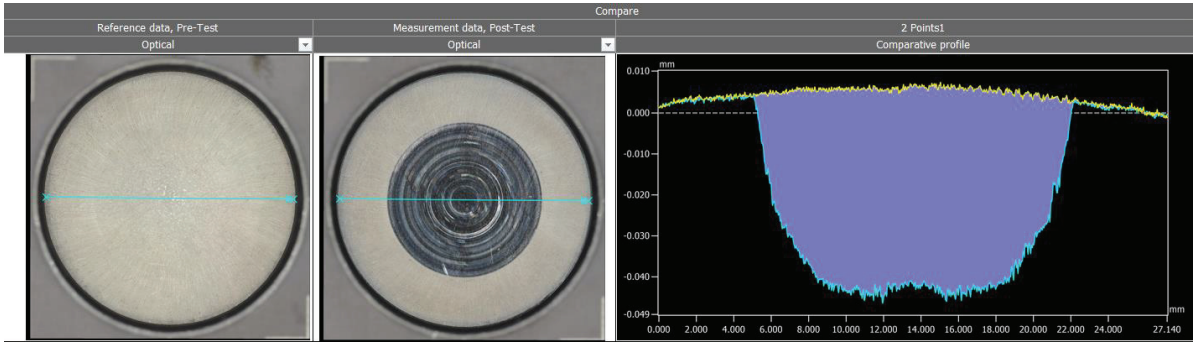
| ASTM TEST | SEQUENCE TEST | PARAMETER | API SP LIMITS | Resource Conserving / ILSAC GF-6 | ILSAC GF-6 A/B | JASO GLV-1 | ACEA A7/B7 and C6 | ACEA A3/B4, A5/B5, C2, C3, C4 and C5 |
|---|---|---|---|---|---|---|---|---|
| D8350 | IVB | Avg Intake Lifter Volume Loss, | ≤ 2.7 | ≤ 2.7 | ≤ 2.7 | ≤ 2.7 | ≤ 2.7 | ≤ 3.3 |
| | | End of Test Iron | ≤ 400 | ≤ 400 | ≤ 400 | ≤ 400 | ≤ 400 | ≤ 400 |

# SEQUENCE IVB CAM TAPPET WEAR SUMMARY

| Measureable Paramaters | Units | Value |
|---|---|---|
| Intake Lifter Average Volume Loss by Keyence, | $mm^3$ | 2.15 |
| End of Test Iron | ppm | 222 |
| Exhaust Lifter Average Volume Loss by Keyence | $mm^3$ | 1.74 |
| Intake Lifter Average Mass Loss, | mg | 18 |
| Exhaust Lifter Average Mass Loss | mg | 16.6 |
| Camshaft Lobe Failure | (Y or N) | N |
| Intake Camshaft Average Heel to Toe Wear | µm | 0.5 |
| Exhaust Camshaft Average Heel to Toe Wear | µm | 1.9 |
| Oil Consumption | g | 152 |



# SEQUENCE VH, ASTM D8256

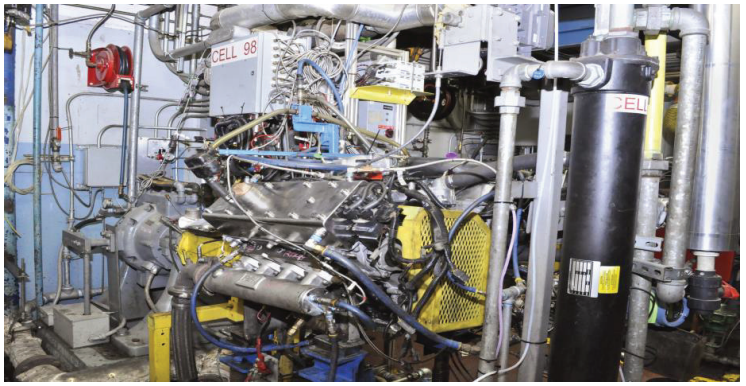
**Objective** –The test method is used to evaluate an engine's oil ability to control engine deposits under operating condition selected to accelerated deposit formation. Deposit formation includes but not limited to engine varnish and oil sludge.

**Specifications**

- API Category – SJ, SL, SM, SN, SN+, SP
- ILSAC- GF-6
- dexos ™ I Gen III

**Engine –** 2013 Ford 4.6L V8, Port Fuel Injected

**Operating Conditions–** . The Sequence VH Test consists of 216 hours total run time, consisting of 54 cycles, 4 hours each. Each cycle consists of three stages. Oil samples are taken every 24 hrs and analyzed for kinematic viscosity, wear metals (ICP), fuel dilution, TAN and TBN.



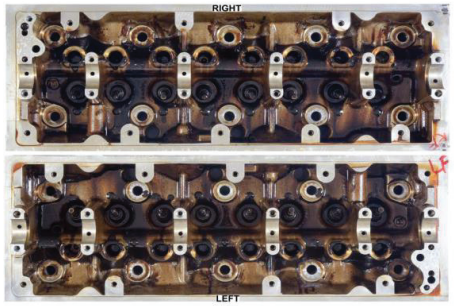

| | Operating Conditions | | | |
|---|---|---|---|---|
| | **Units** | **Stage 1** | **Stage 2** | **Stage 3** |
| Test Duration | Minutes | 120 | 75 | 45 |
| Speed | RPM | 1200 | 2900 | 700 |
| Manifold Abs Press, kPa (abs) | kPa | 69 | 66 | Record |
| Engine Oil In | °C | 68 | 100 | 45 |
| Engine Coolant Out | °C | 57 | 85 | 45 |
| Engine Coolant Flow | LPM | 48 | Record | Record |
| Engine Coolant Pressure | kPa gauge | 70 | 70 | 70 |
| RAC Coolant In | °C | 29 | 85 | 29 |
| Rocker Cover Flow | LPM | 15 | 15 | 15 |
| Intake Air Temp | °C | 30 | 30 | 30 |
| Intake Air, Press | kPa gauge | 0.05 | 0.05 | 0.05 |
| Intake Air Humidity | g/ Kg | 11.4 | 11.4 | 11.4 |

# SEQUENCE VH PASS / FAIL CRITERIA

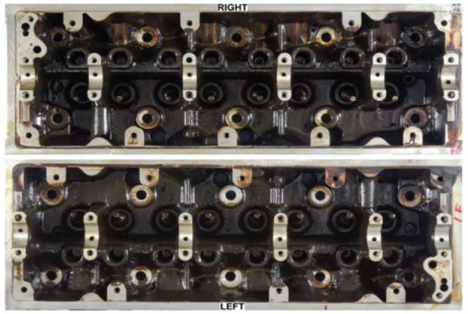
| ASTM TEST | SEQUENCE TEST | PARAMETER | API SP 2020 and newer vehicles | | API SN Plus 2020 and older engines | | SM 2010 and older engines | SL 2004 and older engines | SJ 2001 and older engines |
|---|---|---|---|---|---|---|---|---|---|
| | | | API SP LIMITS | Resource Conserving / ILSAC GF-6 | API SN LIMITS | Resource Conserving | API SM LIMITS | API SL LIMITS | API SJ LIMITS |
| D8256 | VH | Avg Engine Sludge. Merits | ≥ 7.6 | ≥ 7.6 | ≥ 7.6 | ≥ 7.6 | ≥ 7.4 | ≥ 7.8 | ≥ 7.8 |
| | | Rocker Cover Sludge, Merits | ≥ 7.7 | ≥ 7.7 | ≥ 7.7 | ≥ 7.7 | ≥ 7.4 | ≥ 8 | ≥ 8 |
| | | Avg Engine Varnish, Merits | ≥ 8.6 | ≥ 8.6 | ≥ 8.6 | ≥ 8.6 | ≥ 8.6 | ≥ 8.9 | ≥ 8.9 |
| | | Avg Piston Varnish, Merits | ≥ 7.6 | ≥ 7.6 | ≥ 7.6 | ≥ 7.6 | ≥ 7.6 | ≥ 7.5 | ≥ 7.5 |
| | | Oil Screen Sludge, % | Report | Report | Report | Report | -- | -- | -- |
| | | Hot Stuck Compression Rings | None | None | None | None | None | None | None |
| | | Cold Stuck Ring | Report | Report | -- | -- | -- | Report | Report |
| | | Oil Ring Clogging, % | Report | Report | -- | -- | -- | Report | Report |
| | | Oil Screen Clogging, % | -- | -- | Report | Report | Report | ≤ 20 | ≤ 20 |

# SEQUENCE VH HARDWARE EVALUATION

## Cylinder head and Timing Cover




EG-0076/CMIR-155149
VH97-00-0044




EG-0080/CMIR-160117
VH87-00-0404

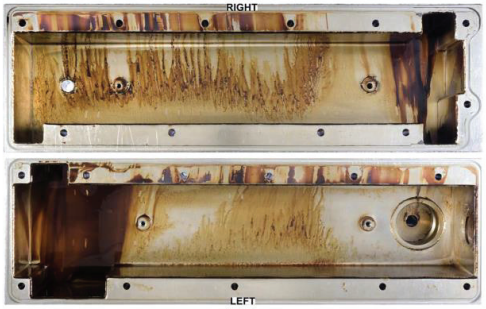
## Pistons and Rear Engine Cover


EG-0076/CMIR-155149
VH97-00-0044


EG-0080/CMIR-160117
VH87-00-0404

# SEQUENCE VH HARDWARE EVALUATION CONT'D

## Rocker Cover and Rocker Cover baffles

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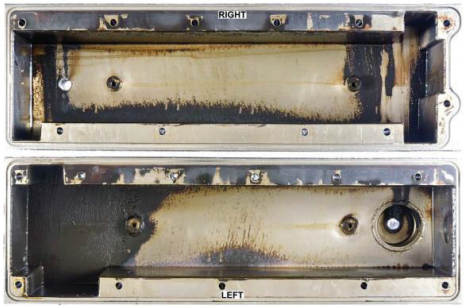
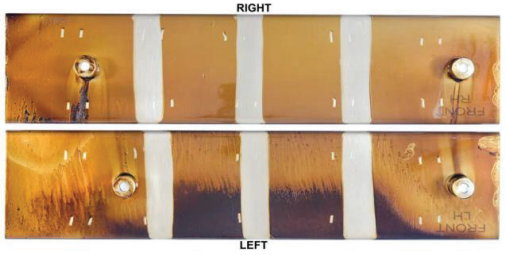
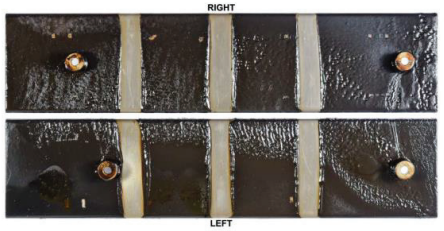
VH97-00-0044

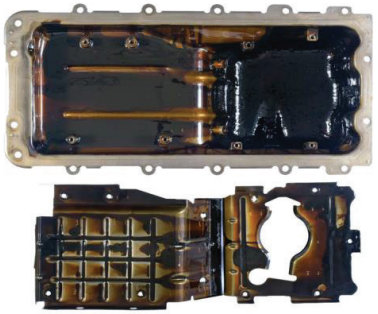



EG-0080/CMIR-160117
VH87-00-0404

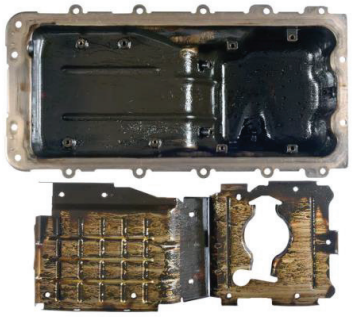



## Oil Pan, Baffle and Screen



EG-0076/CMIR-155149
VH97-00-0044



EG-0080/CMIR-160117
VH87-00-0404

# SEQUENCE VIE, ASTM D8114

**Objective** – The test method was developed to measure an oil's comparative fuel economy index (FEI) of the fuel-saving capabilities of automotive engine oils under repeatable laboratory conditions.

**Specifications**

- API Category – SN+, SP
- ILSAC – GF-6A

**Engine –** 2012 General Motors V6 DOHC with a displacement of 3.6L

**Operating Conditions–** . The Sequence VIE test method is used to measure the laboratory engine break specific fuel consumption (BSFC) at six constant speed/torque/temperature conditions for the baseline calibration oil, test oil, and repeated of the baseline calibration oil. New and used oil samples are analyzed for viscosity.

| Operating Conditions | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Units | Stage 1 | Stage 2 | Stage 3 | Stage 4 | Stage 5 | Stage 6 |
| Duration | Min | 90 | 90 | 90 | 90 | 90 | 90 |
| Speed | RPM | 2000 | 2000 | 1500 | 695 | 695 | 695 |
| Torque | Nm | 105 | 105 | 105 | 20 | 20 | 40 |
| Oil Gallery Temp | °C | 115 | 65 | 115 | 115 | 35 | 115 |
| Coolant Inlet Temp | °C | 109 | 65 | 109 | 109 | 35 | 109 |
| Intake Air Temperature | °C | 29 | 29 | 29 | 29 | 29 | 29 |
| Fuel to Fuel Rail Temp | °C | 22 | 22 | 22 | 22 | 22 | 22 |
| Fuel to Flowmeter Temp | °C | 26 | 26 | 26 | 26 | 26 | 26 |
| Intake Air Pressure | kPa | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| Exhaust back Pressure, abs | kPa abs | 105 | 105 | 105 | 104 | 104 | 104 |

# SEQUENCE VIE PASS / FAIL CRITERIA

| ASTM TEST | SEQUENCE TEST | PARAMETER | API SP 2020 and newer vehicles | | API SN Plus 2020 and older engines | | SM 2010 and older engines | SL 2004 and older engines | SJ 2001 and older engines |
|---|---|---|---|---|---|---|---|---|---|
| | | | API SP LIMITS | Resource Conserving / ILSAC GF-6 | API SN LIMITS | Resource Conserving | API SM LIMITS | API SL LIMITS | API SJ LIMITS |
| D8114 | VIE | XW-20 FEI SUM, % | -- | ≥ 3.8 | -- | ≥ 3.2 | -- | -- | -- |
| | | XW-20 FEI 2, % | -- | ≥ 1.8 | -- | ≥ 1.5 | -- | -- | -- |
| | | XW-30 FEI SUM, % | -- | ≥ 3.1 | -- | ≥ 2.5 | -- | -- | -- |
| | | XW-30 FEI 2, % | -- | ≥ 1.5 | -- | ≥ 1.2 | -- | -- | -- |
| | | 10W-30 FEI SUM, % | -- | ≥ 2.8 | -- | ≥ 2.2 | -- | -- | -- |
| | | 10W-30 FEI 2, % | -- | ≥ 1.3 | -- | ≥ 1.0 | -- | -- | -- |

# SEQUENCE VIF, ASTM 8226

**Objective** – The test method was developed to measure an oil's comparative fuel economy index (FEI) of the fuel-saving capabilities of automotive engine oils under repeatable laboratory conditions for viscosity 0W-16 or lower.

**Specifications**

- API Category – SN+, SP
- ILSAC – GF-6B

**Engine –** 2012 General Motors V6 DOHC with a displacement of 3.6L

**Operating Conditions–** . The Sequence VIF test method is used to measure the laboratory engine break specific fuel consumption (BSFC) at six constant speed/torque/temperature conditions for the baseline calibration oil, test oil, and repeated of the baseline calibration oil. New and used oil samples are analyzed for viscosity.

| Operating Conditions | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Units | Stage 1 | Stage 2 | Stage 3 | Stage 4 | Stage 5 | Stage 6 |
| Duration | Min | 90 | 90 | 90 | 90 | 90 | 90 |
| Speed | RPM | 2000 | 2000 | 1500 | 695 | 695 | 695 |
| Torque | Nm | 105 | 105 | 105 | 20 | 20 | 40 |
| Oil Gallery Temp | °C | 100 | 65 | 100 | 100 | 35 | 100 |
| Coolant Inlet Temp | °C | 94 | 65 | 94 | 94 | 35 | 94 |
| Intake Air Temperature | °C | 29 | 29 | 29 | 29 | 29 | 29 |
| Fuel to Fuel Rail Temp | °C | 22 | 22 | 22 | 22 | 22 | 22 |
| Fuel to Flowmeter Temp | °C | 26 | 26 | 26 | 26 | 26 | 26 |
| Intake Air Pressure | kPa | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| Exhaust back Pressure, abs | kPa abs | 105 | 105 | 105 | 104 | 104 | 104 |

# SEQUENCE VIF PASS / FAIL CRITERIA

| ASTM TEST | SEQUENCE TEST | PARAMETER | API SP 2020 and newer vehicles | | API SN Plus 2020 and older engines | | SM 2010 and older engines | SL 2004 and older engines | SJ 2001 and older engines |
|---|---|---|---|---|---|---|---|---|---|
| | | | API SP LIMITS | Resource Conserving / ILSAC GF-6 | API SN LIMITS | Resource Conserving | API SM LIMITS | API SL LIMITS | API SJ LIMITS |
| D8226 | VIF | 0W-16 FEI SUM, % | -- | ≥ 4.1 | -- | ≥ 3.7 | -- | -- | -- |
| | | 0W-16 FEI 2, % | -- | ≥ 1.9 | -- | ≥ 1.8 | -- | -- | -- |

# SEQUENCE VIII, ASTM D6709

**Objective** – The test method was developed to evaluate automotive engine oil for protection of engines against bearing weight loss.

**Specifications**

- API Category – SJ, SL, SM, SN, SN+, SP
- ILSAC – GF-6

**Engine –** Various designation such as the L-38 engine, the CLR engine or the Seq VIII engine.

**Operating Conditions–** . The Sequence VIII Test consists 40 hours of operation at a constant speed and fuel flow. New and used oil samples are analyzed for viscosity.

| | Operating Conditions | |
|---|---|---|
| | **Units** | **Settings** |
| Duration | hrs | 40 |
| Speed | RPM | 3150 |
| Air-to-Fuel Ratio | Lamda | 13.43 |
| Fuel Flow | kg/h | 2.25 |
| Gallery Oil Temperature | $^{o}$C | 135 or 143.5* |
| Coolant Out Temperature | $^{o}$C | 93.5 |
| Coolant Delta Temperature | $^{o}$C | 5.6 |
| Oil Pressure | kPa | 276 |
| Exhaust back pressure | kPa | 0 - 3.4 |
| Crankcase Vacuum | Pa | 500 |
| Crankcase Off Gas | SLH | 850 |
| Spark Advance | $^{o}$BTDC | 35 |

# SEQUENCE VIII

| ASTM TEST | SEQUENCE TEST | PARAMETER | API SP 2020 and newer vehicles | | API SN Plus 2020 and older engines | | SM 2010 and older engines | SL 2004 and older engines | SJ 2001 and older engines |
|---|---|---|---|---|---|---|---|---|---|
| | | | API SP LIMITS | Resource Conserving / ILSAC GF-6 | API SN LIMITS | Resource Conserving | API SM LIMITS | API SL LIMITS | API SJ LIMITS |
| D6709 | VIII | Bearing Weight Loss, mg | ≤ 26 | ≤ 26 | ≤ 26 | ≤ 26 | ≤ 26 | ≤ 26.4 | ≤ 26.4 |

# SEQUENCE VIII HARDWARE EVALUATION

Rod Bearing, Pass

Rod Bearing, Fail

# SEQUENCE IX, ASTM D8291

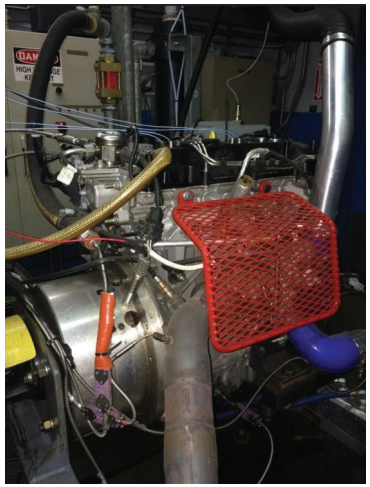
**Objective** – The test method was developed to evaluate an engine oil's ability to mitigate preignition in the combustion chambers in a turbocharged, direct injection, gasoline engines under low speed and high-load operating conditions.

**Specifications**

- API Category –SN+, SP
- ILSAC – GF-6

**Engine –** 2012 Ford Ecoboost 2.0L inline four-cylinder.

**Operating Conditions–** . The Sequence IX test procedure is conducted in four iterations. Each iterations is approximately 4 hours and 19 minutes in length. New oil samples are analyzed for viscosity, fuel dilution and wear metals (ICP).



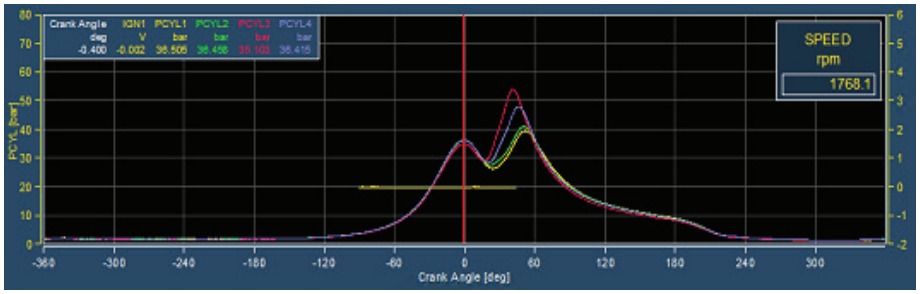
| Operating Conditions | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Units** | **Stage 1** | **Stage 2** | **Stage 3** | **Stage 4** | **Stage 5** | **Stage 6** |
| Time per Stage | h:mm | 0:02 | 0:15 | 0:25 | ~3:20 | 0:15 | 0:02 |
| Engine Speed | r/min | Idle | 2000 | 1750 | 1750 | 2000 | Idle |
| Engine Torque | N·m | 0 | 100 | 269 | 269 | 50 | 0 |
| Coolant Temp | °C | 95 | 95 | 95 | 95 | 45 | 45 |
| Oil Gallery Temp | °C | 95 | 95 | 95 | 95 | 45 | 45 |
| Intake Air Temperature | °C | 43 | 43 | 43 | 43 | 30 | 30 |

# SEQUENCE IX PASS / FAIL CRITERIA

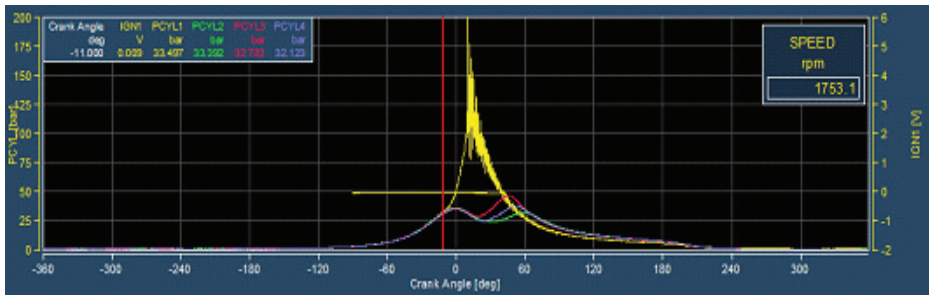
| ASTM TEST | SEQUENCE TEST | PARAMETER | API SP 2020 and newer vehicles | | API SN Plus 2020 and older engines | | SM 2010 and older engines | SL 2004 and older engines | SJ 2001 and older engines |
|---|---|---|---|---|---|---|---|---|---|
| | | | API SP LIMITS | Resource Conserving / ILSAC GF-6 | API SN LIMITS | Resource Conserving | API SM LIMITS | API SL LIMITS | API SJ LIMITS |
| D8291 | IX | Avg Number of Events | ≤ 5 | ≤ 5 | ≤ 5 | ≤ 5 | -- | -- | -- |
| | | Number of Events per Iteration | ≤ 8 | ≤ 8 | -- | -- | -- | -- | -- |

# SEQUENCE IX, EVALUATION OF CYCLES USING AVL SOFTWARE

Normal combustion pressure graph




Preignition event in cylinder 1




Piston damage due to preignition events

# SEQUENCE X, ASTM D8279

**Objective** – The test method was developed to evaluate an engine oil's ability to protect against timing chain lengthening under operation conditions selected to accelerate timing chain wear.

**Specifications**

- API Category – SP
- ILSAC – GF-6

**Engine –** 2012 Ford Ecoboost 2.0L inline four-cylinder.

**Operating Conditions–** . The Sequence X test procedure is composed of two stages. Together the two stages and two ramps comprise of one cycle repeated 54 times for a total of 216 hours. New oil samples are analyzed for viscosity, fuel dilution, TGA soot and wear metals (ICP).

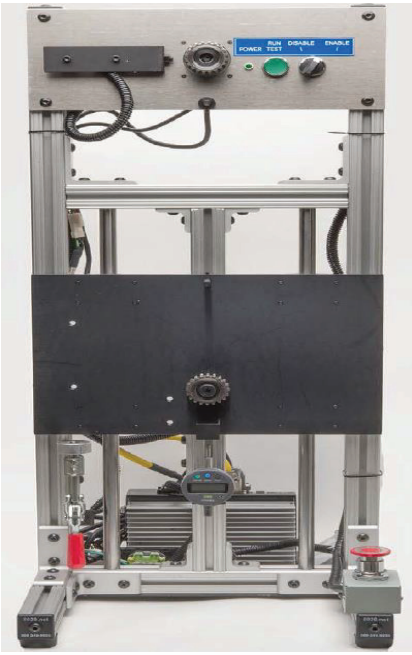
| Operating Conditions | | | |
|---|---|---|---|
| | **Units** | **Stage 1** | **Stage 2** |
| Test Duration | Minutes | 120 | 60 |
| Engine Speed | RPM | 1550 | 2500 |
| Torque | Nm | 50 | 128 |
| Oil Gallery Temperature | °C | 50 | 100 |
| Coolant Out Temperature | °C | 45 | 85 |
| Coolant Flow | LPM | 40 | 70 |
| Inlet Air Pressure | kPa | 0.05 | 0.05 |
| Coolant Pressure | kPa | 70 | 70 |
| Inlet Air Temperature | °C | 32 | 32 |
| Exhaust Back Pressure | kPaA | 104 | 107 |
| Air Charge Temperature | °C | 30 | 30 |
| Air Fuel Ratio (AFR) | Lamda | 0.78 | 1 |
| Blowby-outlet Temperature | kPa Abs | 23 | 78 |
| Blowby | LPM | Not Measured | 65 - 75 |

# SEQUENCE IX PASS / FAIL CRITERIA

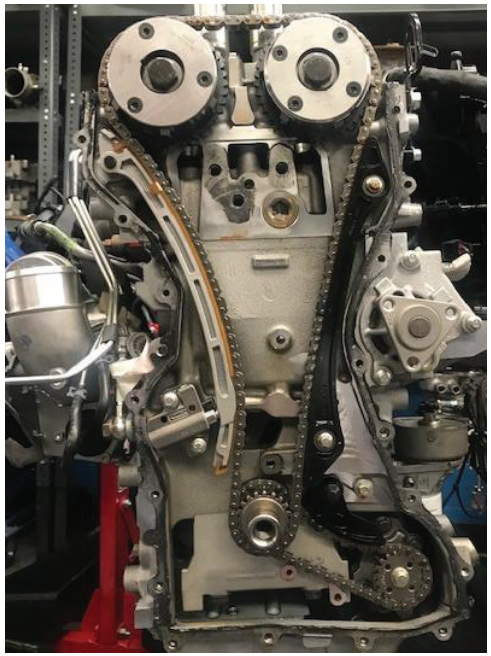
| ASTM TEST | SEQUENCE TEST | PARAMETER | API SP 2020 and newer vehicles | | API SN Plus 2020 and older engines | | SM 2010 and older engines | SL 2004 and older engines | SJ 2001 and older engines |
|---|---|---|---|---|---|---|---|---|---|
| | | | API SP LIMITS | Resource Conserving / ILSAC GF-6 | API SN LIMITS | Resource Conserving | API SM LIMITS | API SL LIMITS | API SJ LIMITS |
| D8279 | X | Chain Stretch, % | ≤ 0.085 | ≤ 0.085 | -- | -- | -- | -- | -- |

# SEQUENCE X EVALUATION OF HARDWARE

## Chain Measurement Rig



## Timing Chain on Engine



## Chain wear measurements

| | | 0 Hour | 216hr |
|---|---|---|---|
| Reference | 1 | 0.0000 | 0.0000 |
| | 2 | 0.0001 | 0.0001 |
| | 3 | 0.0001 | 0.0001 |
| | Average | 0.0001 | 0.0001 |
| Test Chain | 1 | 0.0024 | 0.0226 |
| | 2 | 0.0025 | 0.0226 |
| | 3 | 0.0025 | 0.0226 |
| | Average | 0.0025 | 0.0226 |
| | % Change | | 0.0934 |
| | | Current Severity Adjustment | |
| | | Final % Change | **0.0934** |

# JASO M366

**Objective** – The **JASO M366** is a fired engine fuel economy test developed for use with ultra-low viscosity engine oils

**Specifications**

- JASO GLV-1 / GLV-2
- ACEA C6

**Engine –**Toyota **2ZR-FXE** 1.8L inline four-cylinder engine

**Operating Conditions–** . Test conditions are based on actual Prius data obtained from the **WLTC** (Worldwide Harmonized Light Vehicles Test Cycle). A single test consists of one flush sequence, 10-hour aging and 6 fuel economy stages New Oil samples are analyzed for viscosity.

# JASO GLV-1 SPECIFICATION – TEST REQUIREMENTS

| Test | Test Method | | JASO GLV-1 Specification Requirements |
|---|---|---|---|
| Fuel Economy | JASO M365 (Motoring FE) | OR | 0W-8: 2.0% min, 0W-12: 1.7 min |
| | JASO M366 (Firing FE) | | 1.1% min |
| Oil Thickening | Sequence IIIH | | ILSAC GF-5 level |
| Valve Train Wear | Sequence IVA | OR | ILSAC GF-5 level |
| | Sequence IVB | | ILSAC GF-6 level |
| Sludge and Varnish | Sequence VH | | ILSAC GF-6 level |
| Chain Wear | Sequence X | | ILSAC GF-6 level |
| **Bench Tests:**<br>• SAE J300, Shear Stability, Aged Oil Low Temp Viscosity<br>• Catalyst Compatibility, Wear, Homogeneity and Miscibility<br>• Volatility, Filterability, Foaming, Emulsion Retention<br>• Elastomer Compatibility, Gelation Index | | | ILSAC GF-6B level |

# GENERAL MOTORS DEXOS™ TESTS, GMAER

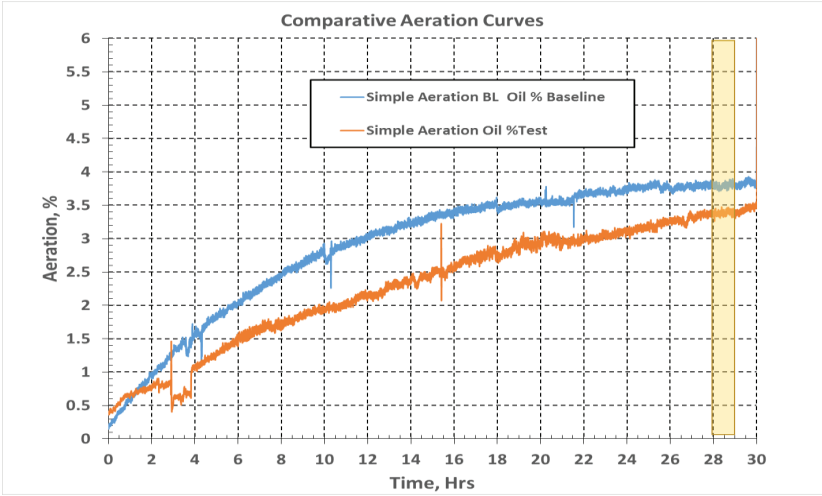
**Objective**– This test was developed to measure an oil's tendency to entrain free air during engine operation.

**Specifications**

- GM's dexos ™ 1 Gen III

**Engine –** GM 5.3L V8 LS

**Operating Conditions–** . The test runs for a total of 60 hours and compares the aeration of a baseline to a candidate oil. New oil samples are analyzed for viscosity, fuel dilution and wear metals (ICP).




| |
|---|
| * 5 Gallons required for each Run |
| *2nd Run much be performed within 72 hours of 1st Run to compare. |
| *Typically 4 days to run full Paired Test |
| *We request 10 gallons in the event of a shutdown to prevent the loss of a paired run |

# GENERAL MOTORS DEXOS™ TESTS, GMTC

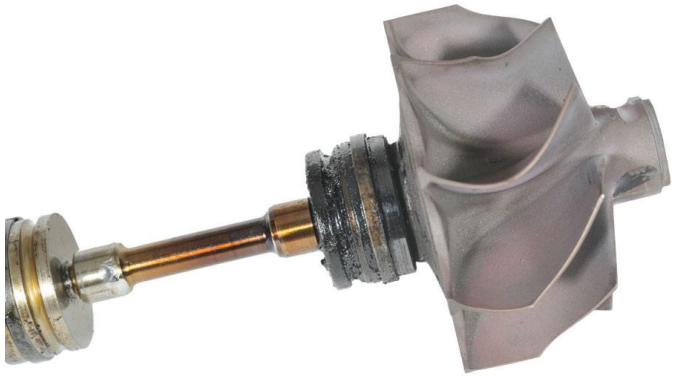
**Objective**– This test was developed to determine the level of turbocharger oil coking which is achieved with an engine oil formulation.

**Specifications**

- GM's dexos ™ 1 and dexos ™ 2

**Engine –** GM 1.4L Turbo I4 Ecotec LUV Engine

**Operating Conditions–** . The GMTC test runs for 2000 cycles, approximately 540 hours. New oil samples are analyzed for viscosity, fuel dilution and wear metals (ICP).



# GENERAL MOTORS DEXOS™ TESTS, GMSPI AND GMPSI3

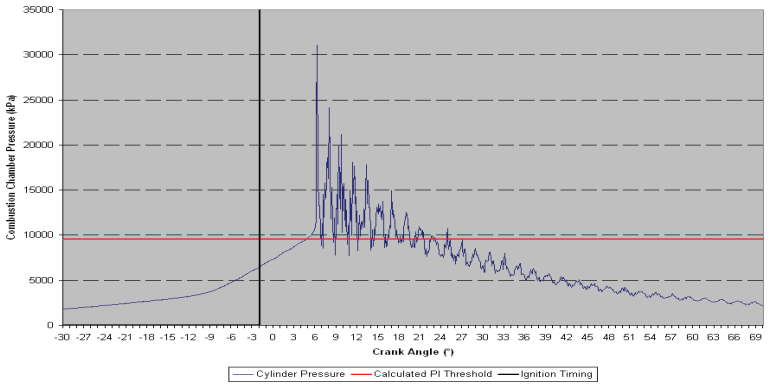
**Objective**– This test was developed to evaluate the stochastic pre-ignition (SPI) tendency of engine oils seeking dexos™ licensing approval.

**Specifications**

- GM's dexos ™ 1 Gen III

**Engine –** 2013 GM 2.0L Turbo I4 Ecotec LHU Engine

**Operating Conditions–** A full SPI evaluation requires five SPI consecutive tests. Each test is comprised of various speeds and loads.



# GENERAL MOTORS DEXOS™ TESTS, GMOD

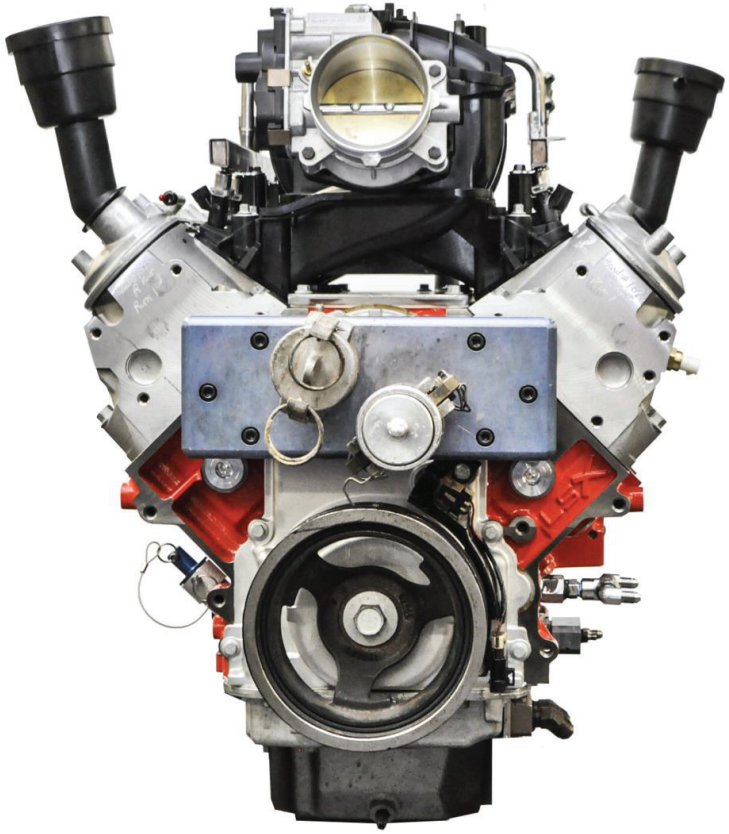
**Objective**– This test was developed to evaluate an oil's resistance to oxidation during high temperature operation. GMOD is a part of GM's dexos™ engine oil specification.

**Specifications**

- GM's dexos ™ 1 Gen III

**Engine –** GM 5.7L LSX, V8 Engine

**Operating Conditions–** The test runs for a total of 100 hours at a constant speed and load with elevated temperatures to accelerate oil oxidation.

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