IVB Precision Matrix Follow-Up | MINUTES

Revision Date *5/21/2017 6:32:00 PM*

Relevant Test:	Sequence IVB
Note Taker:	Chris Mileti
Meeting Date:	05-17-2017
Lubrizol Attendees:	Mileti, Brys, Matasic and O'Malley
Comments:	This meeting was scheduled to discuss the investigations that have taken place since the Precision Matrix was temporarily halted.

1. DISCUSSION:

a) Emails and Files Provided Prior to this Meeting:

i) Intertek and Southwest distributed this data during the afternoon of 05-16-2017.

ii) ***Files discussed during this meeting:***

Haltermann KA24E Green Fuel Sulfur Content Investigation	5/17/2017 8:09 AM	Outlook Item	223 KB
IVB Dipstick Calibration - IAR Stand 102	5/17/2017 8:09 AM	Microsoft Excel W...	24 KB
IVB Dipstick Calibration - IAR Stand 165	5/17/2017 8:09 AM	Microsoft Excel W...	24 KB
IVB Dipstick Calibration - SwRI Stand 18	5/17/2017 8:09 AM	Microsoft Excel W...	24 KB
IVB Dipstick Calibration - SwRI Stand 20	5/17/2017 8:09 AM	Microsoft Excel W...	24 KB
IVB Dipstick Calibration Procedure v1	5/17/2017 8:09 AM	Microsoft Word D...	20 KB
IVB Dipstick Calibration Procedure v2	5/17/2017 8:09 AM	Microsoft Word D...	20 KB
IVB Dipstick Calibration Worksheets	5/17/2017 8:09 AM	Foxit Reader PDF ...	184 KB
IVB Exhaust Orifice Experiment	5/17/2017 8:09 AM	Foxit Reader PDF ...	38 KB
IVB Oil Level and Oil Consumption Investigation	5/17/2017 8:09 AM	Outlook Item	558 KB
IVB Precision Matrix Database for Operational Review v4	5/17/2017 8:10 AM	Microsoft Excel W...	85 KB
IVB Precision Matrix Database for Surveillance Panel Review v4	5/17/2017 8:10 AM	Microsoft Excel W...	157 KB
IVB Stage 1 Exhaust Backpressure Experiement	5/17/2017 8:09 AM	Foxit Reader PDF ...	108 KB
Sequence IVB Precision Matrix Operational Review Follow-up	5/17/2017 8:09 AM	Outlook Item	252 KB
Sulfur in KA24E Green Fuel Batches 2014 - Present v2	5/17/2017 8:09 AM	Microsoft Excel W...	31 KB

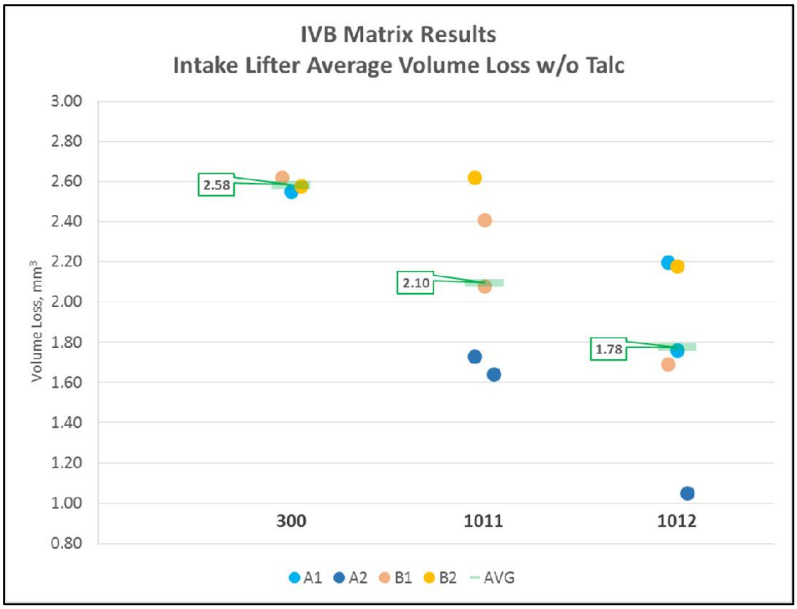
b) IVB Precision Matrix Database for Surveillance Panel Review v4:

i) ***Intertek Comments:***

(1) The results for REO300 are tightly clustered.

(2) There originally appeared to be a significant amount of variability with REO1011.

(a) However, this "variability" may actually be the result of bias with one stand (Stand A2 in the chart below).



(b) The last two runs yet to be completed on Stand A2 are with REO300.

c) IVB Precision Matrix Database for Operational Review v4:

i) *Exhaust Backpressure:*

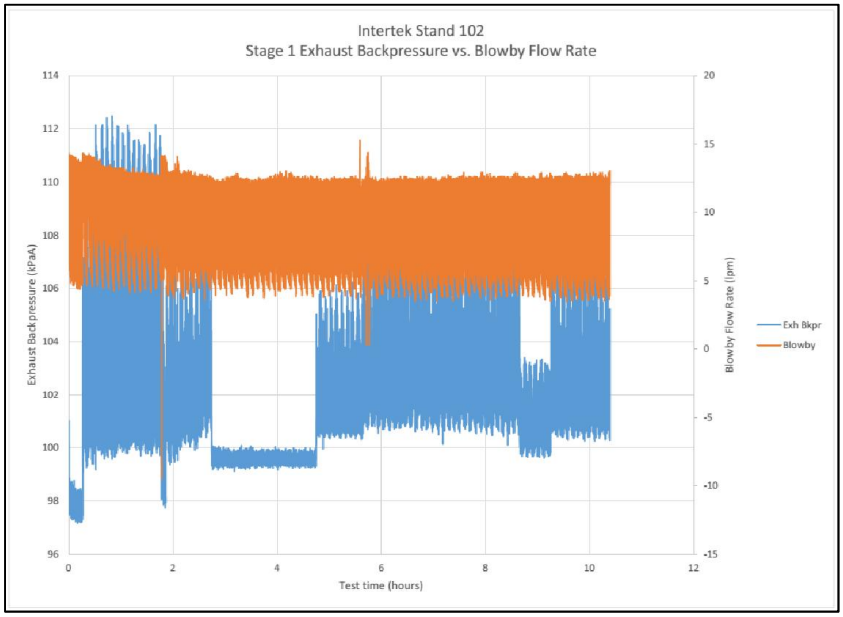
(1) Prior to the Precision Matrix, the IVB Development Task Force made a decision to lock the exhaust backpressure valve at the end of Stage 2.
   (a) The original strategy used an exhaust backpressure set point of 103.5kPa during Stage 1.

(2) The Stage 1 exhaust backpressure is now very different at Intertek and Southwest with this new strategy of locking the valve.
   (a) *Typical Stage 1 Exhaust Backpressure at Intertek* = barometric pressure
   (b) *Typical Stage 1 Exhaust Backpressure at SWRI* = 103kPa (approximate)

(3) As a result, Intertek conducted two separate exhaust backpressure experiments:
   (a) *Experiment #1* – Evaluate impact of exhaust backpressure on ring seal and blowby
   (b) *Experiment #2* – Evaluate the impact of a restrictor in the exhaust system

ii) *Exhaust Backpressure Experiment #1:*

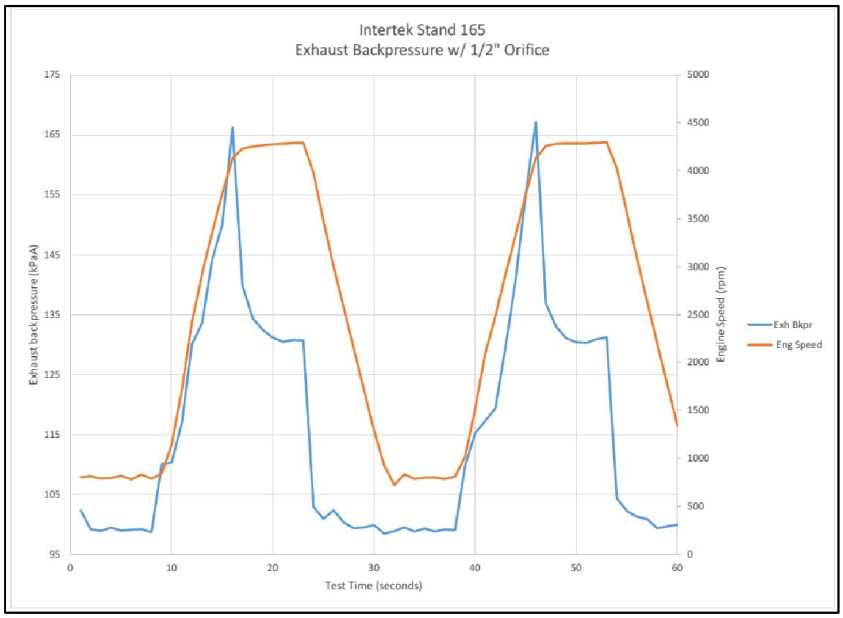
(1) Intertek did not find a correlation between exhaust backpressure and blowby flow.



iii) *Exhaust Backpressure Experiment #2:*

(1) The restrictor in the exhaust system did not help Stage 1 backpressure control.
   (a) The orifice could not build enough pressure.

(2) The restrictor actually made the Stage 2 backpressure control worse.



iv) Intertek believes that the group should reconsider using a set point for the Stage 1 exhaust backpressure.

(1) This will need to be discussed after the Precision Matrix is complete.

d) Discussion about Completing the Precision Matrix:

i) *Toyota's Comments:*

(1) There is lab-to-lab variation with this test.

(2) They feel that it is better to complete the Precision Matrix, analyze the data, and then fine-tune the test procedure and set points.

ii) *Afton's Comments:*

(1) One of the test stands in the Precision Matrix has completely different oil consumption than the other stands.

(2) As a result, this stand is running a completely different test than the other stands.

iii) *Lubrizol's Comments:*

(1) Lubrizol has several concerns with the Precision Matrix.
   (a) The high frequency of camshaft lobe failures with candidate oils is concerning.
   (b) There was not a lot of time to review the data and information sent by Intertek and Southwest prior to this conference call.
   (c) Several Surveillance Panel members were not aware that the Precision Matrix was placed on hold.

(2) It is in the best interest of the Industry to thoroughly look through this data to determine what is happening with this test.
   (a) It is not ideal to restart the Precision Matrix without solutions in place for some of the outstanding issues.

iv) *Toyota's Comments:*

(1) Recent candidate chemistry is having a higher camshaft failure rate than the reference oil chemistry.

(2) This is an indication that chemistry is impacting the lobe failures.

(3) The operational data that was distributed by Intertek has been publicly available since April.

v) *Lubrizol's Comments:*

(1) Camshaft lobe failures are not caused by traditional wear.
   (a) When a camshaft lobe failure occurs, it is common for the remaining lobes to exhibit little to no wear.

(2) A formal statistical study is needed to correlate lobe failures to chemistry.

vi) *Afton's Comments:*

(1) Afton is concerned that some important details regarding this test, such as the highly variable oil consumption measurements, were not revealed until last night.

vii) *Toyota's Comments:*

(1) The two recent camshaft lobe failures at Lubrizol may be related to oil aeration.

(2) Lubrizol appears to have a more significant problem with aeration and timing chain rattle than the other two labs.

viii) *Afton's Comments:*

(1) Individual camshaft lobe failures cannot be attributed to chemistry.

(2) Many of the oils that have experienced lobe failures were expected to pass.

(3) Also, Afton frequently runs the same oil twice.
   (a) They have seen camshaft lobe failures occur with one of these repeat tests but not the other.

ix) *Lubrizol's Comments:*

(1) The AOAP and Class Panel will need to approve this test.
   (a) Many of the companies that are experiencing these camshaft lobe failures are the voting members on these panels.

(2) Lubrizol is not suggesting that the Surveillance Panel redesign the test.
   (a) Instead, it wants the Surveillance Panel to continue investigating some of the issues being discussed (i.e. camshaft lobe failures, aeration, etc.).

(3) *What is the camshaft lobe failure rate under the "Precision Matrix" test conditions?*

x) *Toyota's Comments:*

(1) Toyota cannot develop a test to satisfy the latest chemistry strategies.

(2) Toyota has not heard that there have been high camshaft lobe failure rates (~40%) with candidate oils under the latest test conditions.

(3) The AOAP panel has been briefed on camshaft lobe failure rates throughout the development of this test.

xi) *Exxon's Comments:*

(1) Exxon agrees that the camshaft lobe failure phenomenon is a concern.

xii) *Intertek's Comments:*

(1) Most of the Sequence IVB candidate testing was done on the original test conditions.

(2) Candidate testing with the latest procedure did not begin until the start of the Precision Matrix.

(3) The camshaft lobe failure rate has been 9.92% since the start of test development.

(4) There has been one camshaft lobe failure during the Precision Matrix.
   (a) This engine was near the end of its useful life.

xiii) *Lubrizol's Comments:*

(1) *What is the camshaft lobe failure rate with the <u>latest</u> test conditions?*

(2) Intertek replied that their failure rate with the latest conditions is 42%.

(3) Southwest replied that their failure rate with the latest conditions is 50%.

xiv) *Exxon's Comments:*

(1) They reiterated that failure rates this high cannot be strictly attributed to chemistry issues.

(2) *Could variations in the initial oil charge be playing a role?*

xv) *Intertek's Comments:*

(1) Many of the recent candidate formulations have been of a lower viscosity than the reference oils.

(2) Engine life may be dependent on candidate chemistry.
(a) They are concerned about using an engine for more than 6-runs.

xvi) Lubrizol and Southwest both confirmed that they are not using engines for more than 6-runs.

e) Discussion about Fuel Sulfur Content:

i) *Toyota's Comments:*

(1) An engine in the field that is using a 50ppm sulfur fuel will perform differently than the same engine using a 100ppm sulfur fuel.
(2) The iron content (and thus the wear rate) increases after the TAN-TBN cross-over.
(3) The sulfur content could be impacting the TAN-TBN cross-over.
(a) As a result, the sulfur content of the fuel must be controlled in order to keep the overall wear rate of the test consistent.

ii) The "Precision Matrix" fuel batch has an 180ppm sulfur content

(1) There appears to have been a severity shift between the Precision Matrix and the Prove-Out matrix.
(2) The Precision Matrix is also showing less oil discrimination than originally expected.
(3) *Could either of these phenomenon be the result of the fuel's sulfur content?*

iii) *Intertek's Comments:*

(1) There appears to have been a 0.5mm^3 increase in average intake lifter volume loss between the Prove-Out Matrix and Precision Matrix.
(2) *Could this be due to the difference in fuel batch?*

iv) *Lubrizol's Comments:*

(1) Lubrizol noted a significant increase in test severity when it switched to the EJ1821GP01 fuel batch (small batch delivered to Lubrizol with extremely high sulfur content) during the 4th quarter of 2016.
(a) Lubrizol also encountered three consecutive invalidated tests with the EJ-batch.
(2) Lubrizol's severity aligned with the severity of the two San Antonio labs when it switched to the EL3021LT10 "Precision Matrix" fuel batch on 01/30/2017.
(3) Lubrizol will provide the statisticians with data from its two valid prove-out tests shown in the table below.
(4) ***NOTE:*** All tests in the table below were run with the Precision Matrix test conditions.

Test Name	Fuel Batch	Oil	Average Intake Lifter Volume Loss (mm^3)	Comments
TRNT388PB	EJ1821GP01	REO3	NA	Aborted due to low oil pressure and contact between the timing chain and interior of engine. The lifters were measured and found to be far more "severe" than expected.
TRNKVVM3B	EJ1821GP01	REO3	NA	Camshaft lobe failure.
TRNGGD8BB	EJ1821GP01	REO300	NA	Camshaft lobe failure.
TRNQPCV3B	EL3021LT10	REO300	2.696	Severity similar to Precision Matrix.
TRN8DFBTB	EL3021LT10	REO3	1.949	Severity similar to Precision Matrix REO1012 runs.

v) *Toyota's Comments:*

(1) A high sulfur content in the fuel could increase cylinder bore wear.
(a) High cylinder bore wear can lead to higher oil consumption.

(2) Lubrizol's experience with its two recent "high sulfur" fuel batches support the theory that the fuel is impacting test severity and oil consumption.

vi) *Intertek's Comments:*

(1) The KA24E fuel spec has been in place for about 19-years.
(2) The sulfur specification is currently 100-400ppm.
  (a) The last two batches have been on the higher end of this specification.
(3) Haltermann has stated that they are willing to implement a tighter sulfur specification in the future (140 ± X ppm).

vii) *Haltermann's Comments:*

(1) They agree that the current sulfur specification for the KA24E "green" fuel is probably too high.
(2) They are willing to "touch up" the current "Precision Matrix" fuel batch if needed.
(3) The KA24E "green" fuel has the highest sulfur level of any of the test fuels that it supplies to the Industry.
  (a) The KA24E sulfur specification is very old and dates back to the early days of Sequence V testing.
(4) Intertek speculates that the high level of sulfur was required to generate sludge for the Sequence V test.

viii) *Fuel batches used for final prove-out testing at San Antonio labs:*

(1) *IAR fuel batch:* 124ppm
(2) *SWRI fuel batch:* 146ppm
(3) *Precision Matrix fuel batch:* 185ppm
  (a) SWRI tested the fuel using their internal lab and found the sulfur to be closer to 202ppm.

ix) *Intertek's Comments:*

(1) High-level assessment of severity shift between various prove-out fuel batches and Precision Matrix fuel batch:

Reference Oil	Average Intake Lifter Wear (mm^3), Prove-Out Testing	Average Intake Lifter Wear (mm^3), Precision Matrix Testing
Intertek, REO300	1.65	2.60
SWRI, REO300	2.05	2.40
Lubrizol, REO300	Lobe Failure	2.696
Intertek, REO1012	1.30	1.95
SWRI, REO1012	1.0	1.70

x) *Comments from Afton and Lubrizol:*

(1) The statisticians need to review all of the available data before a revised specification is issued for the fuel.
(2) Also, the shift in severity between the prove-out testing and the Precision Matrix testing needs to be analyzed on a "per stand" basis and not a "per lab" basis.

f) Potential Scenarios for Moving Forward (Part 1):

i) *Toyota's Comments:*

(1) *Scenario #1:*

(a) Complete the Precision Matrix with the current fuel so that there is more data to review.

(2) *Scenario #2:*

(a) Switch to a lower sulfur fuel batch for the remaining Precision Matrix tests.

(b) The statisticians will need to provide input as to whether they will have enough data to recommend fuel correction factors.

ii) *Lubrizol's Comments:*

(1) It would be uncommon to apply correction factors to correct Precision Matrix data back to prove-out data.

(a) The Precision Matrix results are used to set the targets for the test.

(2) The critical question to ask at this point is, "*Are the data at this [elevated] sulfur level acceptable?*"

iii) *Afton's Comments:*

(1) They will need more time to review all of this new data and information before they can comment on Lubrizol's question.

iv) *Toyota's Comments:*

(1) Toyota agrees that there have been important developments since the last conference call.

(2) The group should be given more time to review this information before any decisions are made.

g) Oil Pan Dipstick Trials at Intertek:

i) The oil level during a test was never a major concern with the Sequence IVA.

ii) The oil level during a test is a concern for the Sequence IVB.

iii) OHT recently redesigned the oil pan.

(1) The OHT oil pan has a second drain plug to reduce the volume of retained oil during engine drains.

(2) It also has a dipstick.

iv) The dipstick measurements are somewhat subjective.

(1) This subjectivity could lead to dipstick readings that vary by as much as ±5mm.

v) *Beakers:*

(1) The San Antonio labs use plastic beakers to establish the volume of the initial oil charge.

(2) These plastic beakers have some inherent variability.

(a) As a result, the initial oil charge is almost never exactly 2400mL.

(3) They found that this variation can be reduced by using smaller beakers to fill the larger beakers.

vi) Intertek is recommending that all Sequence IVB laboratories use a common, calibrated beaker or flask for setting the initial oil charge.

vii) *Trial to Reduce 3000mL Oil Charge to 0mL:*

(1) Intertek performed a trial using a small 100mL cup (with 20mL markings) to add 3000mL of oil to one of their engines.

(a) This oil charge was also weighed.

(2) Oil was the incrementally removed from the engine.

(3) *Intertek learned several things during this trial:*

(a) The dipstick calibration can have an inherent error of up to 8mL.

(b) The OHT oil pan is extremely effective at draining almost all of the oil from the engine.

(c) There was a clear increase in the amount of aeration in the oil as the drain amount exceeded 400mL.

(d) This aeration eventually resulted in timing chain rattle.

viii) *Lubrizol's Comments:*

(1) *Lubrizol currently has three working theories to explain how the aeration is developing:*

(a) The lack of a windage tray in the engine is causing the oil in the sump to foam.
(b) The warped OHT front covers are preventing an adequate seal between the oil pump and the engine block.
(c) The oil level in the sump is dropping below the top of the oil pick-up tube (so the oil pump is ingesting air).

(2) The latest Intertek findings support Lubrizol's third theory (that the top of the oil pick-up tube is being exposed to air).
(3) *Could the installation angle of the engine be modified to keep the pick-up tube immersed?*

ix) *Intertek's Comments:*

(1) The engine is already angled so that the oil in the pan will cover the pick-up tube.
(2) A shield could be added to cover the top of the tube.
(3) Intertek has used Prussian Blue to confirm that the oil pump is, in fact, sealing against the engine block.
(4) The volume of the initial oil charge could be increased, but that might change the entire test.
(5) Aeration could be contributing to the camshaft lobe failures.
(a) Intake lobes #2 and #8 have the highest frequency of failures.
(b) In fact, some recent tests have had more than one lobe fail.
(6) The IVB Development Task Force did make a commitment to the AOAP to continue investigating this phenomenon.

h) Potential Scenarios for Moving Forward (Part 2):

i) Intertek plans to resume candidate testing on its Precision Matrix stands while the matrix is on hold.
(1) Lubrizol is not sure that this decision can be made without consulting the Surveillance Panel.
(2) Afton agreed that this decision needs a Surveillance Panel vote.
(3) Exxon stated that this is not a precedent that should be set within the Industry.

ii) Lubrizol and Afton both recommended that the full Sequence IV Surveillance Panel be invited to all future Sequence IVB conference calls.

iii) The attendees agreed to convene again at the end of the week after everyone has time to review these new developments.

Action Items	Person responsible	Completion Date

Follow-up Notes/Updates:	Initials	Date Added