Sequence IV Surveillance Panel | MINUTES

Revision Date 6/20/2017 10:26:00 AM

Relevant Test:	Sequence IVA and IVB
Note Taker:	Chris Mileti
Meeting Date:	June 6th through June 8th, 2017
Comments:	Three day Sequence IV Surveillance Panel Meeting hosted by Intertek. The goal of this meeting was to develop a forward action plan for the Sequence IVB Test.

1. JUNE 6, 2017:

a) Opening Comments from Intertek:

i) The original intent of this meeting was to address the following items:
   (1) Review the test procedure.
   (2) Inspect the four Precision Matrix test stands at Intertek and SWRI.
      (a) Last week, Lubrizol provided a stand audit checklist that could be used to facilitate the inspections.
      (b) Intertek has been running coolant flow direction trials on their stands, so they have not yet started the Lubrizol checklist.
      (c) SWRI has started (but not completed) the Lubrizol checklist.
      (d) In an effort to save time, Intertek and SWRI will initially focus on their Precision Matrix test stands.

ii) However, the agenda for this meeting has recently shifted.
   (1) ***Note:*** Reference the documents distributed by Bill Buscher via email on 06-06-2017.

IVB Coolant Flow Direction Database with ASTM REO 1012.xlsx (54 KB)
IVB102-0-57 ASTM REO 1012 Keyence Results.pdf (31 KB)
IVB165-0-23 ASTM REO 1012 Keyence Results.pdf (31 KB)
IVB102-0-57 Oil Analysis.xlsx (77 KB)

IV Agenda 6-6-17 to 6-8-17.doc (29 KB)
Toyota Propsal for Seq IVB Improvement 20170606.pptx (81 KB)

   (2) The discussion by the Surveillance Panel this week will eventually result in a report to the AOAP that outlines a plan for continuing the Precision Matrix.
   (3) Conference call on Thursday, June 1st:
      (a) *Participants:* Toyota, Intertek, SWRI, and OHT
      (b) Hirano-san reviewed a presentation with these participants that summarized his forward action plan.
      (c) There have been some developments over the last 24-hours that have not yet been reviewed with Hirano-san.
      (d) So it is possible that Hirano-san may choose to revise his forward action plan.

iii) Motion to approve minutes from last Sequence IV Surveillance Panel meeting:
   (1) This motion was proposed by Intertek and seconded by OHT.
   (2) It was unanimously approved.

b) Engine Coolant Flow Direction:

i) Lab-to-lab differences in the direction of engine coolant flow were identified during the last Surveillance Panel conference call.

ii) History:

(1) The production version of the 2NR-FE engine is configured so that the coolant enters through the water pump's inlet tube and exits through the back of the cylinder head.

(2) This test was originally developed at Oronite's Omaezaki laboratory in Japan.

(a) Archived photographs confirm that the Oronite laboratory used the production coolant configuration.

(3) Early test development at the SWRI facility maintained the production coolant configuration and controlled the temperature to a set-point at the cylinder head outlet.

(4) April to August 2014:

(a) The test engineer at SWRI changed the coolant temperature set-point to the inlet of the engine instead of the outlet.

(b) Intertek was building their initial Golden Stands at this time.

(c) These new Intertek stands were configured with the coolant entering the back of the cylinder head.

(i) The reason for this was not documented.

(5) August 2014:

(a) SWRI inspected the Intertek stands during this time.

(b) The difference in flow direction was not identified.

iii) Engineers at Toyota do not believe that the difference in flow direction will have a major impact on test severity.

iv) Intertek Scoping Tests:

(1) The difference in coolant flow direction was identified when Afton questioned why the labs have different coolant temperature differentials.

(2) The cylinder head temperature and temperature differential of the coolant ($\Delta T = \Delta T_{OUTLET}-\Delta T_{INLET}$) are obviously impacted by the coolant flow direction.

(3) Intertek recently completed two scoping tests to evaluate the impact of flow direction on test results.

(a) They changed the plumbing on their stand to match that of SWRI and Lubrizol.

(b) The coolant temperature differentials at Intertek and SWRI became more aligned after Intertek changed their flow direction.

(4) Changing the flow direction did not have an apparent impact on secondary parameters such as AFR, oil sump temperature, etc.

(5) TAN-TBN Crossover:

(a) Changing the flow direction did have a small impact on the TAN-TBN crossover.

(b) The production flow direction appears to have caused the crossover to occur 25HRS later than the reverse flow direction.

(c) This shift further aligned the Intertek and SWRI stands.

(6) End of Test Iron:

(a) Changing the coolant flow direction helped align IAR102 with the SWRI stands.

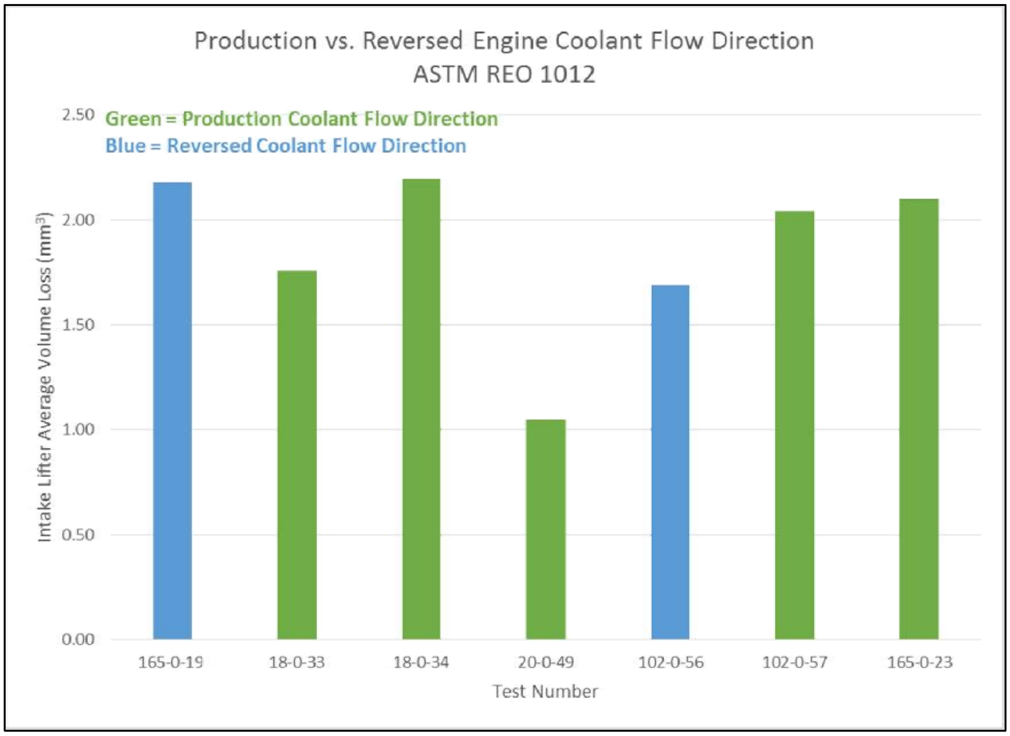
(b) IAR165 had an unexpectedly low iron concentration during the scoping trials.

(i) The average intake lifter wear was very similar between IAR102 and IAR165 even though the iron levels were very different.

(ii) The difference in iron between the two stands appears to have been due to differences in exhaust lifter wear.

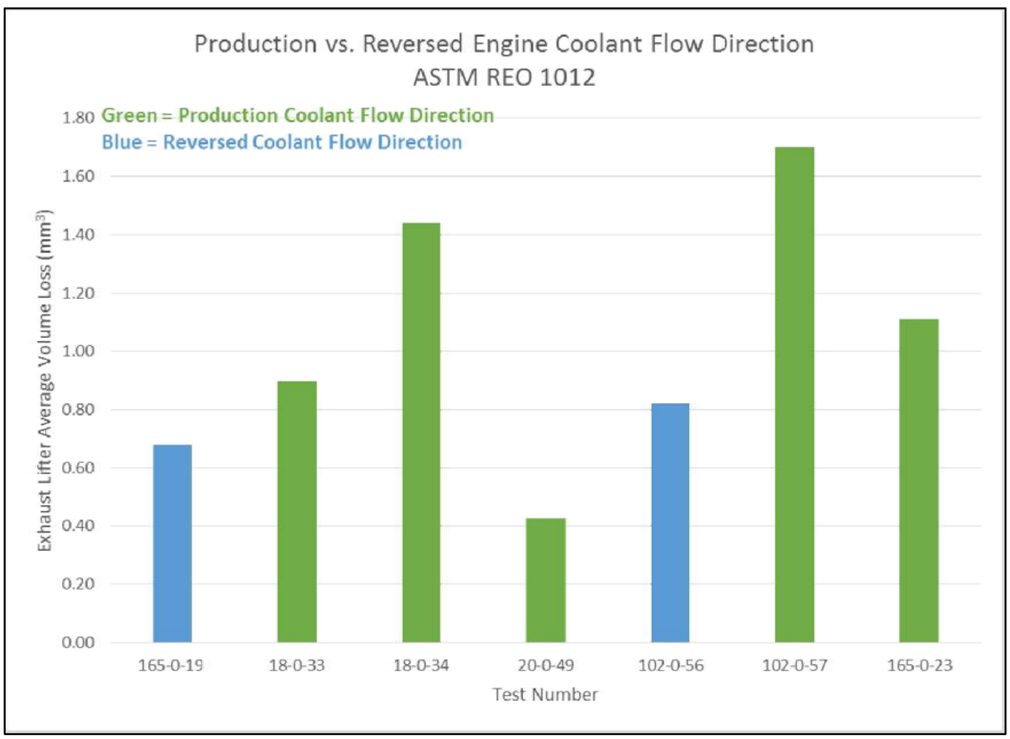
v) IVB Coolant Flow Direction Database with ASTM REO 1012.xlsx:

(1) Chart 1:



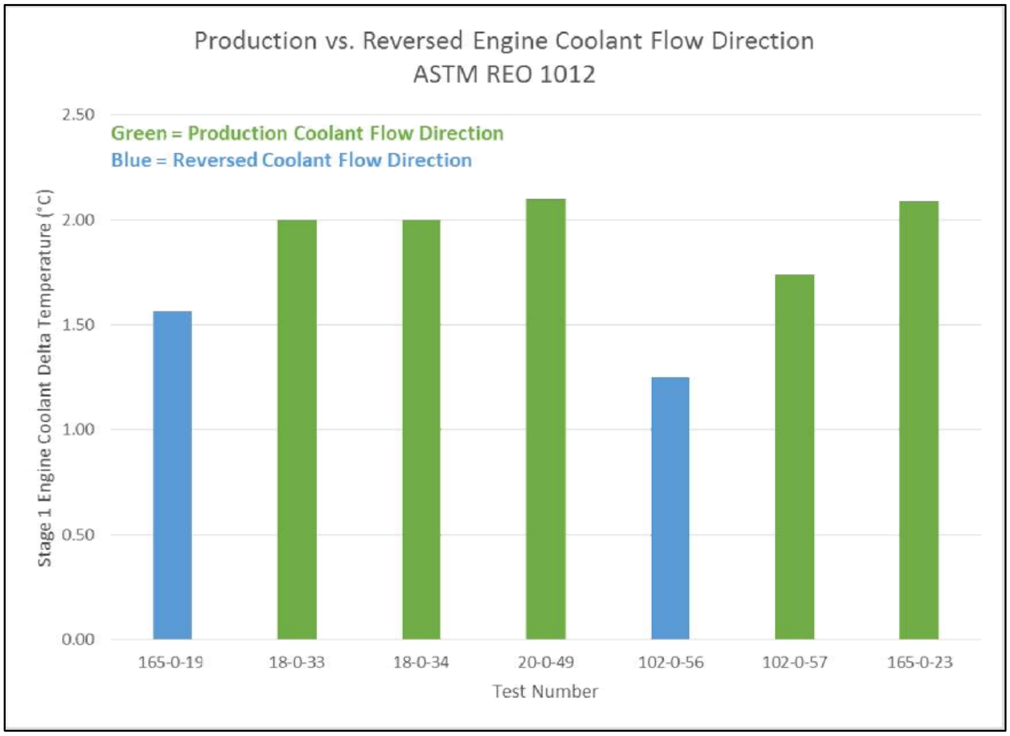
(a) All of the REO1012 results are around 2.0mm^3 with the exception of SWRI20.

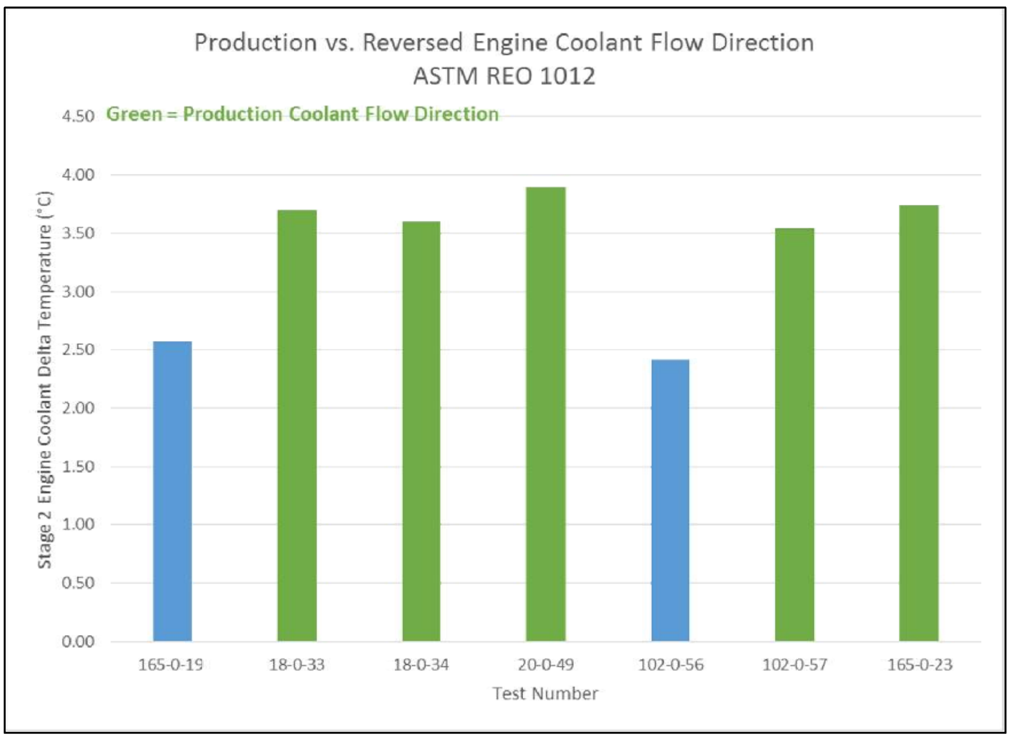
(2) Chart 2:



(a) Exhaust lifter wear continues to be highly variable.

(3) Chart 4 and Chart 5:





(a) The coolant temperature differential is clearly different between the two flow directions.

vi) Toyota wants to use the flow direction that offers the best precision and oil separation.

vii) Intertek's statistician performed an analysis on the available data, but the results were inconclusive and no recommendation regarding the flow direction could be made.

viii) Controlling Coolant Flow Temperature:

(1) There is some concern with controlling the coolant temperature at the water pump inlet pipe.

(2) Intertek noted that the radiant heat from the exhaust manifold and downpipe could influence the coolant inlet thermocouple.

(a) They feel that the thermocouple may need to be moved if the test continues to control to the coolant inlet temperature.

(3) Afton's comments:

(a) The test should be modified to control to the coolant outlet temperature.
(b) The outlet set-point can be established by averaging the Stage 1 and Stage 2 outlet temperatures at SWRI.
(c) Controlling the outlet temperature will yield the most consistent cylinder head operating conditions.
(d) The cylinder head is the most critical part of the engine for this test.
(e) It is probably not very useful to review recent data when making a decision [about the coolant flow or temperature controls] because it is impossible to separate coolant flow effects from lab effects.

(4) Lubrizol's comments:

(a) Lubrizol supports Afton's recommendation.
(b) Calculate the coolant outlet temperature set-point using SWRI's Precision Matrix data.
(c) Prove-out data should not be used because there were minor but potentially significant operational changes made before the Precision Matrix was started.

ix) Review of SWRI Coolant Outlet Temperature:

(1) Coolant inlet temperature:

Stage	Average, °C	Standard Deviation, °C
Stage 1	49.30	0.02
Stage 2	48.64	0.22

(a) It is very difficult to control to the actual coolant inlet temperature set-point because the conditions are so dynamic.

(2) Coolant outlet temperature:

Stage	Average, °C	Standard Deviation, °C
Stage 1	51.31	0.13
Stage 2	52.46	0.09

(a) The obvious coolant outlet temperature set-point would be 52°C.

x) Formal Motion Regarding Coolant Flow and Temperature Control:

(1) Intertek drafted the following motion, "Revise the Sequence IVB test procedure to standardize the coolant flow direction into the coolant inlet pipe and out of the rear of the cylinder head (as is the production flow direction for the Toyota 2NR-FE engine), with the coolant temperature set-point at the coolant outlet and set to 52°C for both stages."
(2) Afton made the motion and it was seconded by Shell.
(3) The group agreed that quality index limits and the ASTM report form will both need to be modified as a result of this motion.
(4) The motion passed unanimously.

c) Sulfur Content of Test Fuel:

i) Toyota has provided very clear instructions on how they would like this issue handled.

ii) Toyota's Comments (as Relayed by Intertek):

(1) Toyota feels that any change in the fuel's sulfur content greater than 50ppm is significant.

(2) REO300 and REO1012 have both shifted "severe" between the prove-out testing and the Precision Matrix.
(3) High sulfur content in the fuel will result in a high sulfuric acid content in both the oil and emulsion.
(4) The historic sulfur content of the KA24E green fuel is around 130ppm.
(5) As a result, Toyota would like Haltermann to establish a sulfur target of 130±10ppm for this fuel.

iii) Customers at both Intertek and SWRI have reported similar shifts in severity with their candidate tests at around the same time.

iv) The high sulfur content of the recent batches of fuel (Lubrizol batch and Precision Matrix batch) may be aggravating camshaft lobe failures and engine wear.
(1) Lubrizol ran its Golden Stand for most of 2015 and 2016 without a camshaft lobe failure.
(2) However, Lubrizol had to abort three consecutive tests (one for excessive oil consumption and two for camshaft lobe failures) after it switched to the high sulfur fuel.

v) Haltermann believes that it can control to a range of ±10ppm around the target.
(1) Haltermann noted that the KA24E fuel is unusual because its sulfur level is so high.
(2) This fuel is doped to get the sulfur content as high as it is.

vi) SWRI did receive a 181ppm [sulfur concentration] batch of fuel several years ago, but it did not appear to cause any problems with Sequence IVB severity.

vii) Lubrizol's comments:
(1) The high sulfur level of Lubrizol's recent fuel batch did not appear to impact its Sequence IVA testing.
(2) The Surveillance Panel may want to reduce the sulfur content as low as possible in order to shift the test away from corrosive wear and back towards mechanical wear.
(3) Counterpoint from Exxon and Shell:
(a) The only problem with doing this is that no one knows what will happen to test severity if the sulfur content is lowered too far.
(b) For example, the test lost all ability to discriminate between oils when it was run on EEE fuel early in development.

viii) Afton suggested that Haltermann blend larger batches of KA24E fuel if the sulfur target is revised.

ix) What type of wear is the Sequence IVB trying to simulate?
(1) The Sequence IVB may not necessarily protect against traditional wear in the field if is shifted too far towards being a "corrosive" test.
(2) Intertek's comments:
(a) Toyota does want a corrosive aspect to this test.
(b) The Industry is moving towards hybrid vehicles.
(c) Hybrid engines generate more emulsion, water and fuel dilution than traditional engines.

x) Formal motion regarding fuel sulfur:
(1) Formal motion: "Revise the sulfur content fuel specification for Haltermann KA24E "green" test fuel from a 100-400ppm range to a 130±10ppm target."
(2) Intertek made the motion and it was seconded by Lubrizol.
(3) This motion passed unanimously.
(4) The TMC requested that the Sequence IV Surveillance Panel formally notify the Sequence VIII Surveillance Panel of this fuel revision.

xi) Returning high sulfur fuel to Haltermann:
(1) The Surveillance Panel finds it acceptable for a lab to return their Precision Matrix fuel if they so choose.
(2) It will take Haltermann 7-10 business days to re-blend this fuel and adjust its sulfur content.

(3) Each lab is to report to Haltermann the volume of KA24E fuel that they plan to return for re-blending.
    (a) Haltermann can handle a maximum of 5,000-gallons returned from the labs.

xii) Exxon's fuel restrictions:

(1) Exxon originally purchased 20,000-gallons of KA24E fuel because they were concerned about impending New Jersey regulations.
(2) So they have a 2-year supply of 140ppm (sulfur) fuel.
(3) This fuel does meet the revised sulfur specification (but is on the high side of the target).
(4) Haltermann will contact Exxon outside of this Surveillance Panel meeting to discuss their fuel situation.

xiii) Haltermann does not currently have the storage capacity for large batches (~100,000 gallons) of KA24E fuel.

xiv) A typical Sequence IVB test consumes 200-gallons of fuel.

xv) Several members of the group questioned how future KA24E fuel batches will be released.

(1) One option would be for each lab to run a reference test when they switch to a new fuel batch.
(2) Another option would be for the Industry to run fuel release matrices (similar to what is done with the Sequence V test).
(3) The Surveillance Panel decided to delay making a decision about this issue until a later time.

d) Camshaft Lobe Failures:

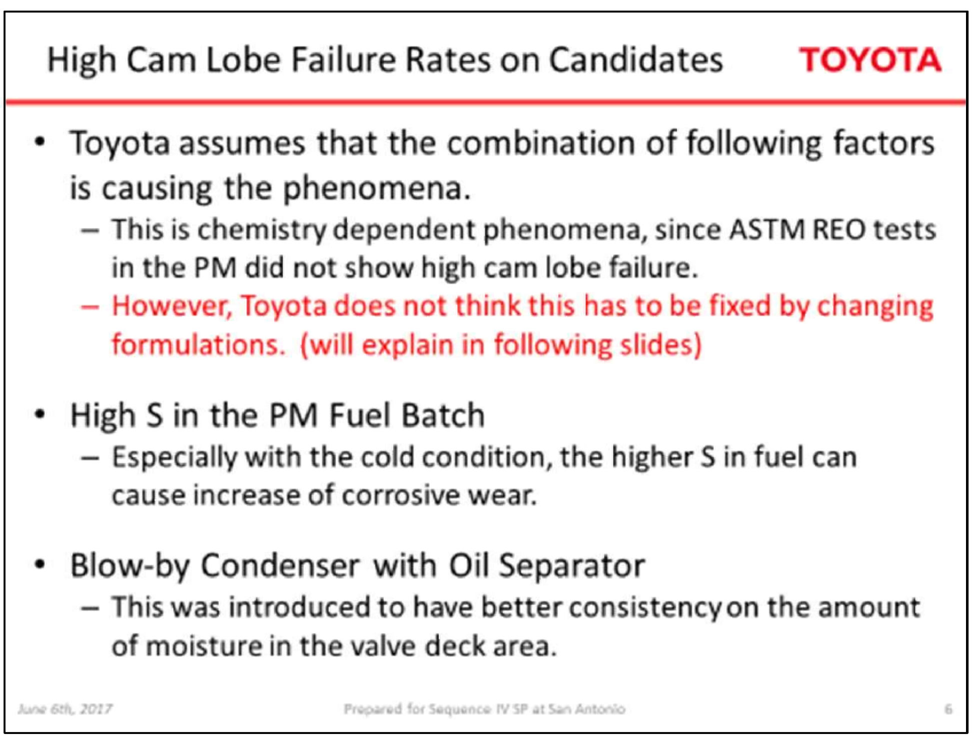
i) All three development labs (Intertek, SWRI and Lubrizol) have experienced camshaft lobe failures with candidate oils.

ii) Intertek and SWRI are both experiencing a 40%-50% camshaft failure rate with candidate oils and the latest test conditions.

iii) These two labs experienced a 5%-10% camshaft failure rate with previous batches of [low sulfur] fuel.

iv) The AOAP instructed the Sequence IVB Development Team that the camshaft lobe failure rate must remain below 10%.

v) Slide #6 from Toyota presentation dated June 6th:



(1) Toyota believes that the camshaft lobe failures are dependent on chemistry and not hardware since there has only been one camshaft lobe failure during the Precision Matrix.
   (a) However, Toyota has still identified camshaft lobe failures as a problem that needs to be resolved.
(2) Exxon and Lubrizol comments:
   (a) Camshaft lobe failures do not appear to be traditional wear.
   (b) In most cases, the remaining lobes on the failed camshaft exhibit no wear at all.
(3) Intertek comments:
   (a) One of their additive company customers has not experienced any lobe failures.
   (b) One of their oil marketer customers has also not experienced a lobe failure.
   (c) Intake lobes #2, #6, #7 and #8 exhibit the highest frequency of lobe failures.
(4) Exxon comments:
   (a) These lobes are probably more susceptible to failures because of the shape of the bottom of the rocker arm cover.
   (b) The coolant inlet on the rocker arm cover is directly above intake lobe #2.
   (c) The blowby return is close to intake lobe #8.
(5) Exxon and Lubrizol comments:
   (a) Exxon's blowby heat exchanger is becoming clogged with emulsion in less than 200HRS.
   (b) Lubrizol's oil separator is becoming clogged with emulsion in less than 200HRS.
   (c) Intertek and SWRI have not seen the excessive clogging that Exxon and Lubrizol have experienced.
(6) A lot of recent GF-6 candidate oils have transitioned from calcium to magnesium.
   (a) Calcium does a much better job at neutralizing acid than magnesium.

vi) Camshaft Chamfers:

(1) Edges on the exhaust camshafts are chamfered.
(2) The intake camshaft edges have an edge break but not a chamfer.
   (a) As a result, parting lines in the casting can result in a sharp edge.
(3) Intertek does have an inventory of intake camshafts that were mistakenly chamfered.
   (a) Unfortunately, Toyota's vendor has difficulty creating a consistent chamfer around the revised lobe profile.
   (b) OHT is trying to find a vendor that can provide consistent chamfering.

vii) Camshaft and Lifter Hardness:

(1) Lubrizol recently repeated a hardness study that was originally conducted by Oronite and later SWRI.
   (a) The lifters (62 RC) are significantly harder than the intake camshafts (37 RC).
   (b) The hardness of the intake camshafts also drops off precipitously below the outer surface.
   (c) It is not ideal to have a critical part (i.e. lifter) with a significantly harder surface finish than the hardware that is supposed to generate the wear (i.e. intake camshaft).
(2) Lubrizol would like to work with OHT's vendor to evaluate different surface hardening.
(3) Intertek comments:
   (a) The intake camshaft is hardened to a production hardness, then annealed to reduce the hardness.
   (b) This process is an artifact from when the camshaft was the critical wear component early in test development.
   (c) Toyota does not want to change the profile or the surface hardness of the intake camshafts.
   (d) In 2015, Intertek did evaluate a low entrainment angle intake camshaft that had a production surface hardness.
      (i) The second test that used this camshaft had a lobe failure.

(ii) The higher surface hardness definitely increased the amount of lifter wear.
(e) Around this time, Intertek also evaluated production intake valve springs.
(i) The lower tension of these springs lowered the amount of lifter wear.
(ii) The wear was so low that the production intake valve springs were no longer considered as an option.

viii) Lifter Rotation:

(1) This engine is designed to utilize a flat camshaft lobe on a flat intake lifter.
(2) Two design factors initiate lifter rotation:
(a) An offset in the centerline of the lobe versus the centerline of the lifter.
(b) The design of the valve spring.
(3) Tapered camshaft lobes cannot be used in conjunction with the flat lifter profile.
(a) This combination would result in potentially damaging edge loading.
(4) Lubrizol has seen square patterns on the surfaces of lifters associated with lobe failures.
(a) It has also seen deep wear grooves on the associated lifter shims.
(b) Both of these observations indicate that the lifter periodically stopped rotating.
(5) Toyota stated that consistent lifter spin is not necessary with this engine.
(a) Lubrizol then speculated that maybe lifter rotation is not the key variable.
(b) Instead, maybe it is the amount of force necessary to displace the lifter vertically?

e) Blowby Heat Exchanger Clogging at Exxon:

i) Exxon showed the Surveillance Panel several photographs of the inside of their blowby heat exchanger.
(1) The heat exchanger is becoming completely clogged with a yellow, foamy emulsion.
(2) This clogging occurs within 200-hours.
ii) The fact that Exxon is using a 12-run engine may be contributing to this clogging.
(1) This engine is generating Stage 2 blowby levels that are higher than at Intertek or SWRI (~22LPM).
(2) The engine may be "used up".
iii) Intertek and SWRI have need seen any clogging of their heat exchangers or oil separators.

iv) Lubrizol Comments:

(1) Lubrizol has seen similar clogging in its oil separator (but not necessarily the heat exchanger).
(2) This clogging is concerning because it frequently leads to a large slug of emulsion sliding down onto the valve deck.
(3) Lubrizol also expressed concern regarding whether there is a steady flow of blowby out of the engine and into the surge chamber.
(a) Is it possible that there is a backflow of gas from the surge chamber and into the crankcase?
(b) The Sierra meter may not be able to differentiate the direction of the flow that it is measuring.

v) Exxon Comments:

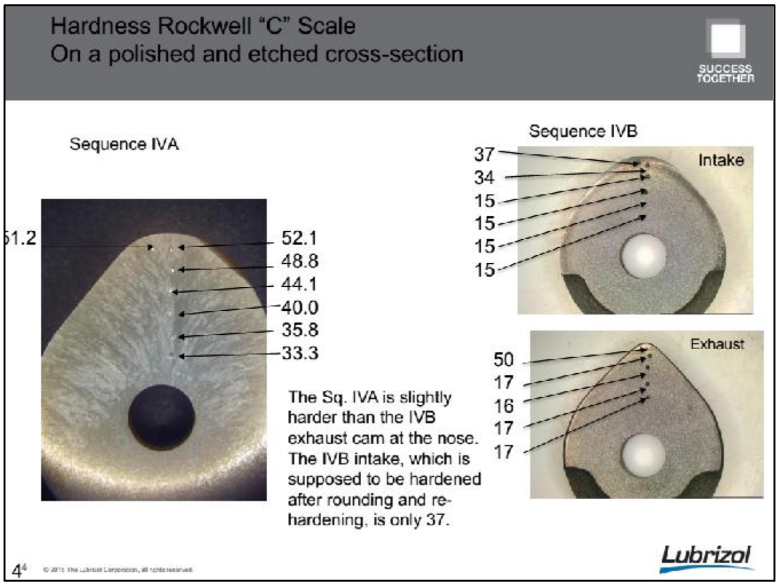
(1) The Sequence IVB stand uses an elaborate blowby system that is only altering the temperature of the blowby gas by 3-degrees.
(2) Is this necessary?
(3) Is the Surveillance Panel confident that this temperature control is actually driving severity?

vi) Intertek Comments:

(1) They feel that different blowby temperature set-points do impact test severity.
(2) There was a correlation between a higher blowby temperature set-point and a lower water content.
(3) They feel that the external blowby system, with its current blowby temperature set-point, is returning the same amount of water to the crankcase as the original test conditions.

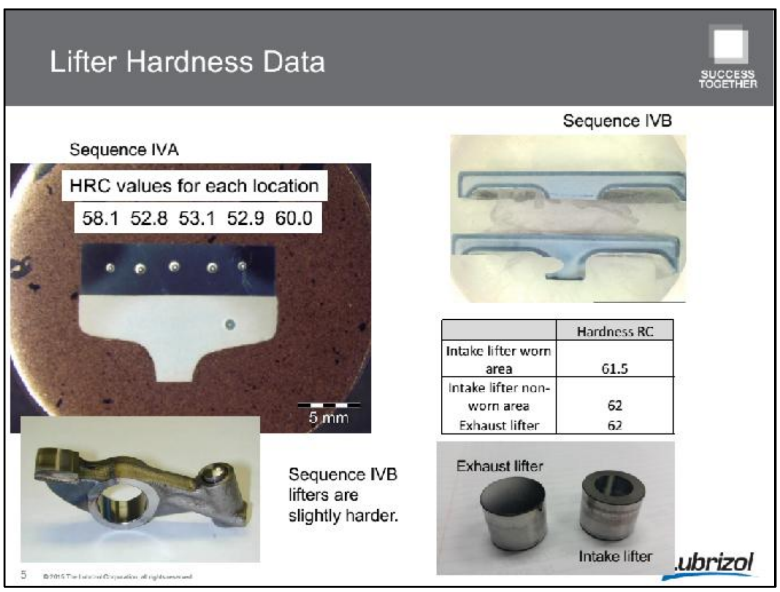
f) Review of Lubrizol Presentation on Surface Hardness of IVB Camshafts and Lifters:

i) Slide #4:



(1) The surface of the IVB intake camshafts have a Rockwell hardness of 37.
(2) The surface of the IVB exhaust camshafts have a Rockwell hardness of 50.
 (a) This is similar to the surface hardness of the IVA camshafts.
(3) Shell suggested that Lubrizol repeat this surface hardness study with used camshafts.

ii) Slide #5:



(1) The IVB lifters have a typical Rockwell hardness of 62.
(2) The surface hardness of the lifters is almost twice as high as the surface hardness of the intake camshafts.

iii) Intertek Comments:

(1) The typical wear scar depth on an intake camshaft lobe is 1-2μm.
(2) Normally, camshaft lobe failures occur between 150 and 200-hours.
(3) None of the labs have every encountered an <u>exhaust</u> camshaft lobe failure.

iv) Exxon Comments:

(1) Previous testing at Intertek has shown that the surface hardness of the intake camshaft is a lever that can be used to control the magnitude of lifter wear.

(2) Why don't we increase this surface hardness to increase lifter wear and improve oil differentiation?

v) Why have there not been any exhaust camshaft lobe failures?

(1) Lubrizol noted that the exhaust lifters have a higher operating temperature, and this probably reduces the amount of emulsion on that side of the valve deck.

(2) Exxon noted that the topography of the inside of the rocker arm cover allows emulsion to drip directly on the intake lifters but not the exhaust lifters.

g) Return Emulsion to Crankcase and Not Valve Deck:

i) Several members of the group suggested that camshaft lobe failures can be mitigated by returning the blowby condensate to the sump and not the valve deck.

ii) Afton suggested installing an electrically driven OMS unit to the engine in place of the external blowby system heat exchanger and oil separator.

(1) The OMS would return the condensate directly to the sump.

(2) An OMS unit would be relatively insensitive to differences in ambient temperatures.

iii) Shell suggested channeling the blowby gas back into the intake manifold.

h) "Lobe Failure" Oil:

i) The group agreed that there is a need for a high-event "lobe failure" oil to use during the upcoming test development.

ii) This "lobe failure" oil would be a candidate oil that has experienced more than one camshaft lobe failure.

iii) This oil should represent current GF-6 technology.

(1) The reference oils used during IVB test development (REO3/REO1012, REO1011, REO300 and REO1006-2) definitely do not represent GF-6 technology.

iv) Ideally, there will be Sequence IVA data available for this "lobe failure" oil.

v) Toyota will ask each of the additive and oil companies if they are willing to provide such an oil for test development.

i) Oil Aeration:

i) Lubrizol has been aware of a potential oil aeration problem with this test for almost a year.

(1) It sent out a report on this topic early in 2017.

ii) Lubrizol originally speculated that the aeration could be generated in three ways:

(1) The warped front covers are preventing the oil pump from sealing against the engine block.

(2) The lack of a windage tray is causing the oil in the sump to generate an excessive amount of foam.

(3) The oil level in the sump is becoming so low that the top of the pick-up tube is being exposed to air.

iii) Lubrizol is of the opinion that this aeration could be contributing to the timing chain rattle, excessive engine wear and camshaft lobe failures.

iv) Recent work at Intertek supports the theory that the oil pick up tube is being exposed to air.

v) Exxon recommended that the group consider using a ratcheting timing chain tensioner on the IVB engine.

(1) This will make the timing chain more resistant to air bubbles in the oil.

vi) Afton suggested that 5-hour oil samples be eliminated from the procedure.

(1) That will leave more oil in the sump during the last half of the test.

(2) Intertek replied that many of its customers have requested that the 5-hour oil samples remain in place.

j) Keyence Software:

i) Intertek, SWRI, Afton and Lubrizol are all using the Generation-1 Keyence software.
ii) Exxon is using the Generation-2 Keyence software.
   (1) As a result, they cannot use the current IVB leveling ring and templates.
iii) Lubrizol would like all of the labs to update to the Generation-2 software.
   (1) It has developed templates for the new software that may improve lab-to-lab reproducibility.
   (2) An Industry metrology workshop should then be held after all labs perform the upgrade.
iv) Variation in Keyence Units:
   (1) Previous Keyence round-robin trials have shown a measurable difference in the Keyence measurements at each lab.
   (2) Intertek recently had a problem that helped confirm that there are, in fact, differences between the Keyence units.
      (a) The light shudders on their original Keyence unit began malfunctioning.
      (b) This unit was sent back to Japan for repairs.
      (c) The measurements from their original Keyence unit were greatly affected by the presence of talc.
      (d) The measurements from their loaner Keyence unit have shown almost no sensitivity to the presence of talc (much like Lubrizol's Keyence unit).
v) Most of the Surveillance Panel members agreed that now would be a good time to perform the software upgrade.
vi) Afton: *Will the new software shift the wear results?*
   (1) Lubrizol: *Most likely. There will need to be a round-robin once all of the labs complete the upgrade.*
vii) Formal Motion Regarding the Keyence Software:
   (1) Formal Motion: "Upgrade the Keyence VR-3000 3D Measurement System software to version G2 [Generation-2] prior to the restart of the Sequence IVB Precision Matrix. Once the Keyence VR-3000 software is updated to version G2 at all labs, a workshop and round-robin will be performed"
   (2) This motion was made by Lubrizol and seconded by Intertek.
   (3) It passed unanimously.
   (4) Lubrizol offered to represent the remaining four labs in negotiations with Keyence regarding a lower cost for the software.
   (5) There will be no vote to discontinue the PDI measurements until the statisticians can review the data from the (13) Precision Matrix tests and make a formal recommendation regarding this decision.
   (6) The mass loss data can probably be dropped at this time.

k) Exhaust Backpressure:

i) There was a Stage 1 backpressure set-point earlier in the development of this test.
ii) The test procedure was changed to lock the exhaust backpressure valve in place at the end of Stage 2 and keep it locked through Stage 1.
   (1) This was done because Intertek and Lubrizol were having difficulty controlling to the original Stage 1 exhaust backpressure set-point.
iii) During the Precision Matrix, Intertek and SWRI discovered that their Stage 1 exhaust backpressures were very different when the valve was locked open.
   (1) The Intertek stands had Stage 1 exhaust backpressures that were close to the barometric pressure.
   (2) The SWRI stands had Stage 1 exhaust backpressures that were between 102-103kPa.
iv) Intertek ran several experiments to align their Stage 1 backpressure with that of SWRI, but none of them were successful.
   (1) Intertek suggested that a Stage 1 set-point may need to be reintroduced.

v) Lubrizol and Exxon both stressed that any new Stage 1 backpressure set-point will need wide QI limits.
   (1) The labs in the Midwest and on the East Coast will be subject to larger swings in barometric pressure than the San Antonio labs.
   (2) Also, there is no direct evidence suggesting that the exhaust backpressure impacts test severity.

vi) The Surveillance Panel may need to specify an exhaust valve design for all of the Golden Stands.

l) Blowby System Oil Separator:

i) Does the oil separator have more of an impact on test severity than the heat exchanger?

ii) The oil separator was originally installed above the heat exchanger.
   (1) It was moved below the heat exchanger to address concerns from Lubrizol about the main Tygon hose becoming clogged with emulsion.
   (2) This change was made when the blowby temperature set-point was at 24°C instead of the current 29°C.

iii) It is possible that the oil separator is contributing more to the emulsion on the valve deck than the heat exchanger.
   (1) This emulsion could be impacting overall engine wear.
   (2) Intertek noted that iron levels increased significantly after the oil separator was introduced.

iv) As a counterpoint, removing the heat exchanger could exacerbate the oil consumption problem.

v) The group again talked about the use of an OMS system in place of the current external blowby system.
   (1) OHT suggested that any "blowby" scoping tests should evaluate a <u>major</u> change to the blowby system and not an incremental change.
   (2) Lubrizol feels that an OMS unit would make the Golden Stand a lot simpler.

vi) Alfdex OMS:
   (1) Afton suggested evaluating an Alfdex system.
   (2) One version is driven by a 24V power supply instead of oil pressure.
   (3) The internal cartridge would need to be replaced after every test.

vii) Another option would be to remove the oil separator and route the existing blowby hose back into the crankcase.

viii) The Precision Matrix data (which was obviously generated with the oil separator in place) has shown relatively consistent water levels (as shown by Karl Fischer testing).

ix) Exxon questioned whether the heat exchanger is actually "chilling" condensate out of the blowby gas.
   (1) Instead, the surface area of the heat exchanger may be creating the condensate.

m) Initial Discussion about Design of Experiment:

i) There is a broad consensus among the Surveillance Panel members that the Sequence IVB test needs another DOE matrix.

ii) Lubrizol Comments on Engine Wear:
   (1) The upcoming DOE matrix will need to identify what is damaging these engines.
   (2) Prior to 2015, the IVB Development Task Force was discussing the possibility of using engines for more than (12) tests.
      (a) Lubrizol disassembled and inspected an 11-run engine during this time, and the bearings and cylinder walls looked almost new.
   (3) Now, the labs are nervous about using an engine for (6) or more runs.

iii) Available Hardware for DOE:

(1) OHT has approximately 20-30 Batch-C camshafts remaining that could be used for this DOE testing.
(2) They have a similar number of runs available with Batch-1 engines.
(3) This hardware will not be needed when the Precision Matrix is restarted.
    (a) The decision has already been made to use Batch-D camshafts and Batch-2 engines for the second Precision Matrix.
(4) OHT does not think that the Batch-D camshafts will be in place by July.
    (a) OHT is looking into having these new camshafts chamfered.
(b) All of the hardware also needs to be inspected and repackaged.

2. JUNE 7, 2017:

a) Opening Comments from Intertek:

i) The Sequence IVB test worked well when there were only the original six Golden Stands.
   (1) About (200) candidate tests were run at Intertek and SWRI during this time.
ii) The test was redeveloped in 2016 to address stand-to-stand reproducibility problems.
   (1) It was during this time that the severity of the test began to deviate from ideal conditions.
   (2) However, these changes did help align all of the stands in the Industry.
iii) Toyota's fundamental goal is to get back to where the test was operating prior to the 2016 changes.
   (1) They feel that current test conditions have shifted too far away from mechanical wear and too far towards corrosive wear.

b) Initial DOE Brainstorming (Things to Evaluate):

i) Chamfer the lobe edges of the test-specific intake camshafts.
   (1) Toyota has instructed OHT to pursue this enhancement with one of their suppliers.
ii) Introduce a taper on the intake camshaft lobes to promote lifter rotation.
   (1) Toyota warned that a tapered camshaft may require a test-specific tapered intake lifter.
   (2) A tapered camshaft cannot be used in conjunction with the current flat intake lifter (the edge loading would be too high).
iii) Increase the hardness of the intake camshaft lobes.
   (1) In 2015, Intertek ran a trial with production harness intake camshafts.
   (2) These production hardness intake camshafts increased lifter wear by approximately 80%.
   (3) Unfortunately, one these production hardness intake camshafts still experienced a lobe failure.
iv) Remove the oil separator from the external blowby system.
v) Evaluate an OMS in place of the current oil separator and heat exchanger.
vi) Use the current external blowby system, but drain the condensate back into the sump instead of the valve deck.
vii) Change the temperature set-point of the rocker arm cover coolant.
   (1) The current set-point has been at 20°C for most of the development of this test.
   (2) The origin of this 20°C set-point is not entirely clear.
   (3) It is well below the dew point of the crankcase gas.
   (4) It would be interesting to evaluate a higher temperature set-point (~29°C).
   (5) Sequence VG Rocker Arm Cover Temperature Set-Point:
      (a) Leverett contacted Gordon Farnsworth, who is considered to be the "father of the Sequence V test".

(b) The rocker arm cover coolant temperature of the Sequence VG test was set to match the approximate dew point of that engine's blowby gas.
(c) Farnsworth noted that the VG test became too corrosive if the rocker cover temperature was set too far below the dew point.
(6) The Sequence IVB test adopted the current OHT rocker arm cover design in August 2013.
(7) Lubrizol noted that the Sequence VG engine has rocker arm cover baffles that prevent the blowby condensate/emulsion from dripping directly on the valvetrain hardware.
(a) OHT stated that there is not enough clearance under the IVB rocker arm cover to install a similar baffle.

c) Discussion about Camshaft Lobe Failures:

i) Lubrizol has enough high sulfur (>300ppm) fuel in its inventory to run 4-6 Sequence IVB tests.
(1) This fuel could be used by Lubrizol or one of the other labs to evaluate any changes designed to eliminate camshaft lobe failures.
(2) This fuel is definitely "severe" in terms of engine wear.
(3) Lubrizol only had one lobe failure during its 2015-2016 testing.
(4) It then experienced three consecutive engine failures immediately after switching to this fuel.
(a) One failure was due to excessive bore polishing and oil consumption.
(b) Two failures were for camshaft lobe failures.
ii) Intertek, SWRI and Lubrizol all agree that there is not a clear or consistent sequence of events prior to a camshaft lobe failure.
(1) There is also no correlation between lobe failures and unscheduled downtime.
iii) The iron level in a typical test begins to increase exponentially within 25-hours of the TAN-TBN crossover.

d) Why is the Sequence IVB a "Low Temperature" Wear Test?

i) Lubrizol and Shell noted that the low temperatures prevent certain additive chemistry from being activated.
ii) Toyota noted that low temperatures promote condensation.
iii) The 2NR-FE engine would not generate valvetrain wear when it was run under steady-state Sequence IVA conditions.
(1) A corrosive element was required to generate wear.

e) Test Length:

i) Shell noted that the engine is allowed to generate extremely high levels of corrosion during the current 200-hour test length.
(1) The excessive wear is proof that the engine and/or oil cannot handle this acid.
(2) One option would be to shorten the test so that it ends closer to the TAN-TBN crossover.
ii) Intertek would like to get the opinions of Toyota and the other OEM's on this issue.

f) Discussion with Toyota (Hirano-san):

i) Toyota agrees with the Surveillance Panel decision to utilize the production coolant flow direction.
ii) Toyota agrees with the motion to revise the sulfur specification for the KA24E fuel.
iii) Toyota agrees with the motion to update the Keyence software before the Precision Matrix is restarted.
(1) They are hopeful that the new software will eliminate the need the need for talc on the end-of-test hardware.

(2) Toyota is amenable to eliminating the PDI and mass loss measurements if the statistical analysis supports this decision.
(3) Intertek noted that eliminating the PDI and mass loss measurements will significantly simplify the Sequence IVB test reports.

iv) Toyota supports the decision to evaluate chamfered edges on the intake camshafts.
(1) OHT has a vendor that can chamfer the lobe edges of the Batch-D camshafts.

v) Toyota does not think that evaluating tapered intake lobes would be successful.
(1) This type of engine is not designed for tapered camshafts.

vi) Toyota would like to return the Sequence IVB test to its 2015 severity level.
(1) Lubrizol cautioned that the test still had a 10% camshaft lobe failure rate in 2015.
(2) Both Lubrizol and Toyota agreed that the addition of the oil separator and blowby heat exchanger significantly increased the frequency of lobe failures.

vii) Causes of Camshaft Lobe Failures:
(1) Toyota's opinion is that the lobe failures are not entirely the result of chemistry.
(2) Exxon speculated about three possible drivers of these lobe failures:
(a) Chemistry
(i) The fact that the reference oils have a lower frequency of lobe failures than the candidate oils is evidence that chemistry is playing a role.
(b) Hardware
(i) Intertek noted that hardware must be playing a role because there has never been an exhaust lobe failure.
(c) Test Conditions
(i) Test conditions are playing a role in this problem because the frequency of lobe failures increased after the external blowby system was added to the Golden Stand.
(3) Intertek added the fuel as a fourth possible driver of lobe failures.
(a) Lubrizol's experience indicates that there may be a correlation between fuel sulfur and lobe failures.

viii) Summary of Four Possible Drivers of Camshaft Lobe Failures:
(1) Chemistry
(2) Hardware
(3) Test Conditions
(4) Sulfur Content of Fuel

ix) There was a broad consensus among the Surveillance Panel that each of these four drivers is contributing to these lobe failures to some degree.
(1) The balance between these four drivers may change from failure-to-failure.

x) Afton's Comments:
(1) A poor performing oil should generate high wear without failing hardware.
(2) This test might need a drastic change to eliminate this problem.
(a) One such change would be to dump the blowby condensate into the sump instead of the valve deck.

g) Review of Sequence IVB DOE "Wish List":

i) Obtain a candidate oil that has experienced intake camshaft lobe failures in at least two Sequence IVB tests.
(1) It would be nice to have Sequence IVA data for this oil as well (although this is not a requirement).
(2) Exxon suggested that another option would be to have an oil or additive company formulate a specific high-event oil for camshaft lobe failures.

ii) Run an experiment (or experiments) to evaluate how the fuel's sulfur content effects test severity.
(1) The camshaft lobe failure high-event oil would be incorporated into these experiments.

(2) Exxon warned that the group thinks that water and sulfur are severity "knobs" for this test, but that the group is not sure of this.
(3) Intertek has a spreadsheet that the statisticians can use to analyze the correlation between sulfur and test severity.
(a) Lubrizol still needs to add its data to this spreadsheet.

iii) Evaluate the impact of removing the oil separator.
(1) This trial would use REO1012 and a 130ppm (sulfur) fuel batch.

iv) Evaluate replacing the current external blowby system with an OMS unit and route the condensate back to the oil sump instead of the valve deck.

v) Evaluate the current external blowby system but route the condensate back to the oil sump instead of the valve deck.
(1) Intertek is willing to run preliminary scoping trials in which they route the blowby condensate back to different locations of the engine.
(2) The blowby return line will need to be lengthened in order to reach the crankcase.
(a) As a result, it should be insulated to reduce the effect of ambient conditions.
(3) Intertek will try lowering the heat exchanger directly over the rocker arm cover during these scoping trials.

vi) Evaluate a higher rocker arm cover coolant temperature.
(1) One option would be to increase the set-point from 20°C to 29°C.

vii) Evaluate a shorter test length.
(1) One option would be to decrease the test length from 200-hours to 150-hours.
(2) It is rare for a camshaft lobe failure to occur prior to 150-hours.

viii) Evaluate the use of an active PCV system.
(1) The external blowby system can be connected to the intake manifold (via a PCV valve) instead of the current surge tank.

ix) Evaluate whether oil aeration is contributing to the lobe failures and excessive engine wear.
(1) It is possible that the aeration is being caused by the top of the oil pick-up tube being exposed to air.
(2) Lubrizol has fabricated an oil pan with a large sight glass.
(3) Lubrizol will take the lead on evaluating this possibility.
(4) There are two possible modifications to the oil pan if Lubrizol confirms that the pick-up tube is ingesting air:
(a) A displacement block can be added to the oil pan.
(b) The shape of the pick-up tube can be modified.

x) Evaluate chamfered edges on the camshaft lobes.

xi) Evaluate production hardness intake camshaft lobes.

xii) Evaluate an increased initial oil charge.
(1) This proposal should be the main priority for the group if Lubrizol confirms that the oil pick-up tube is ingesting air.

xiii) Discussion about Potential Outcomes:
(1) SWRI posed the question: *What does the group do if the high-event camshaft failure oil does not repeat a camshaft lobe failure with low sulfur fuel?*
(2) Toyota would like to continue any of the proposed trials that could potentially increase oil separation.

xiv) Discussion about Priorities:
(1) *Priority #1:* Any trials related to the initial oil charge volume need to take priority if Lubrizol confirms that the pick-up tube is becoming exposed to air.
(2) *Priority #2:* Any trials related to fuel sulfur content.
(3) *Priority #3:* Any trials related to the blowby system.
(a) Prioritization of blowby trials (in the order listed):
(i) Remove oil separator.

(ii) Modify current external blowby configuration with active PCV system.
(iii) Evaluate an OMS unit.
(iv) Maintain current external blowby system but route condensate back into crankcase.

xv) Test Stand Assignments:

(1) Lubrizol will provide its stand for the oil level trials.
(a) Lubrizol will need to discuss its participation in the DOE matrix internally and then get back to the Surveillance Panel.
(2) SWRI will need to discuss its participation in the DOE matrix internally and then get back to the Surveillance Panel.
(a) They would probably use Stand #18 to run DOE tests.
(b) They still need to investigate why Stand #20 is generating mild results.

h) Oil Pan Screen:

i) All three development labs have experienced excessive debris in this screen.
ii) The labs are currently removing this screen to clean it.
iii) OHT is trying to get more screens so that they can be replaced.
iv) OHT does not currently double-impregnate the oil pan (to reduce porosity) because they do not have replacement screens.
(1) They will begin doing this once additional screens are available.

i) Hardware Inventories:

i) Lubrizol:

(1) Lubrizol has a full inventory of lifters.
(2) Lubrizol has approximately (3) Batch-C intake camshafts and approximately (3) Batch-A intake camshafts.
(3) Lubrizol only has one new Batch-1 engine remaining.

ii) Intertek:

(1) Intertek is out of Batch-1 engines.
(2) They have (8) Batch-A intake camshafts.
(3) They have (5) Batch-C intake camshafts.

iii) OHT:

(1) OHT has already started adding Batch-D exhaust camshafts to new test kits.
(2) OHT will donate Batch-2 engines for the upcoming DOE tests.

iv) SWRI:

(1) They have (5) runs remaining on Precision Matrix engines.
(2) They have both Batch-A and Batch-C intake camshafts remaining.

Action Items	Person responsible	Completion Date
Complete the Lubrizol stand audit checklist for all Golden Stands (with priority given to stands that are currently in the Precision Matrix).	All Labs	
Establish quality index limits for the new coolant outlet temperature set point.	Statisticians	
Labs to update their coolant temperature control strategy.	All labs	
Schedule meeting or conference call to discuss necessary revisions to ASTM test report and LTMS fields.	All Labs	
Notify the Sequence VIII Surveillance Panel of the revision to the KA24E sulfur specification.	Buscher, Lang	

Action Items	Person responsible	Completion Date
Each lab is to report to Haltermann the volume of KA24E fuel that they plan to return for re-blending. Haltermann will adjust existing KA24E fuel batch to meet newly accepted sulfur specifications.	All Labs, Haltermann	
Repeat surface hardness study with used camshafts.	Lubrizol	
Negotiate with Keyence for a lower cost for the G2 software.	Lubrizol	
Review the data from the (13) Precision Matrix tests and make a recommendation about discontinuing the PDI measurements.	Statisticians	
Establish timetable for the availability of Batch-D camshafts with chamfered edges.	OHT, Toyota	
Lubrizol needs to add its recent prove-out test data to Intertek's spreadsheet so that the statisticians can analyze the correlation between sulfur and test severity.	Lubrizol	
Run preliminary scoping trials that route the blowby condensate back to different locations of the engine.	Intertek	
Evaluate color-coding the Golden Stand coolant hoses (Red = Outlet, Blue = Inlet).	TEI	
Haltermann requested that the Sequence IV Surveillance Panel revisit and amend the 10% volume acceptance with respect to mixing new and old fuel batches. Haltermann recommends that the tanks be de-inventoried prior to receiving the newly adjusted batch of KA24E fuel.	Surveillance Panel	
Lubrizol to run oil level trials and work with OHT on potential oil pan design changes.	Lubrizol, OHT	
OHT to design and supply a clutch alignment tool.	OHT	
OHT to design and supply a tool or wedge to secure the timing chain.	OHT	
OHT to add "IN" and "OUT" stamping to OHT coolant adaptor plates.	OHT	
OHT to design and supply an engine rotation locking tool.	OHT	
SWRI and Intertek to draft Section 4 of the Sequence IVB Engine Assembly Manual.	Intertek, SWRI	

Follow-up Notes/Updates:	Initials	Date Added

Attendees:	Company