Caterpillar engine Oil Aeration Test (COAT)

NCDT Meeting Telecon

March 26, 2015

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Test Update

- All remaining requirements have been addressed by the Task Force.
  - Weekly TF meetings to discuss matrix data (operational data and statistical analysis of aeration).
  - Most recent face to face to (March) finalized matrix data analysis and established test readiness for PC-11.
  - Detailed evaluation of operational data and their impact on aeration have enabled significant improvement of the test (procedure, referencing, calibration).

- The C13 Aeration Task Force has voted and recommends to NCDT that the C13 Aeration test is now ready for use in PC-11.

Critical Test Parameters

- A pass criterion has been determined based on matrix data: 40 to 50 hours average aeration (%)
  - “Report only” parameter: Slope of 40 to 50 hour Aeration (%)
- No shut-downs allowed during last 20 hours of the test
- Density measurement
  - Procedure defined
- Controlled operational conditions

Reference oils Selection and Timing

- Reference oils were selected by the task force for stand calibration:
  - **PC-11K** (Tech 2, BS2) Higher Aeration
  - **PC-11G** (Tech 1, BS1) Lower Aeration

- TMC is working on supply

Stand Calibration, Referencing and Status

- Task Force has defined Stand Calibration and Referencing process.
  - Refer to appendix for details.

- All Stands participating in the matrix have satisfied calibration requirements

Targets and Standard Deviation

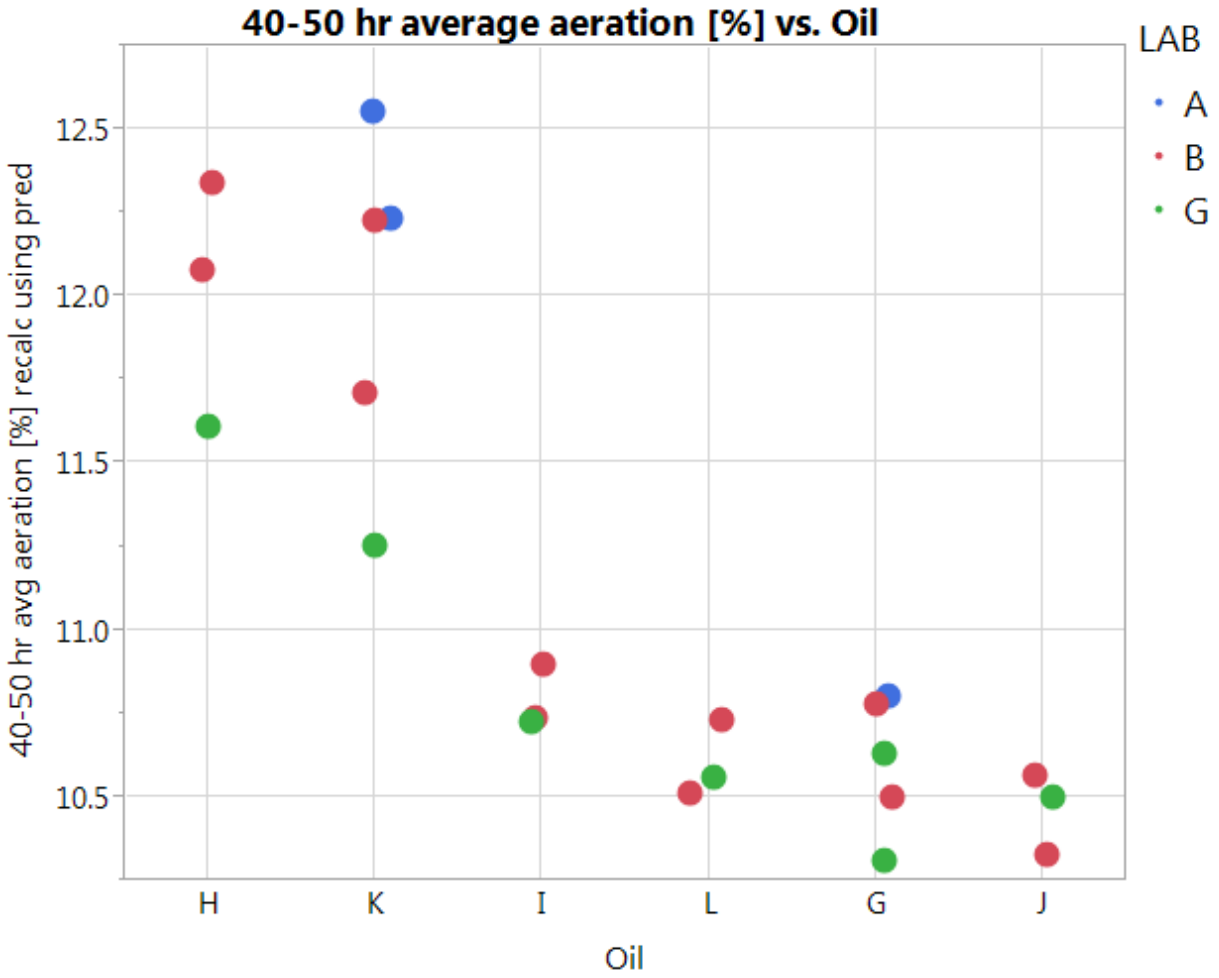
- Targets and Standard deviations presented below were generated by the matrix data analysis

Avg. Aeration 40 to 50 hours, %		
Reference Oil	Target	Standard Deviation
PC-11G	10.67	0.2026
PC-11H	12.14	0.2846
PC-11I	10.92	0.1387
PC-11J	10.60	0.2026
PC-11K	11.94	0.2846
PC-11L	10.73	0.1387

Matrix Data: Update Since Last NCDT Meeting

- Background: Because Lab A made improvements to the test Stand right before test A15, Task Force wanted to confirm level which lab is running, before calculating targets and standard deviation. Task Force requested Lab A to run additional tests.
- The analysis of the three recent tests from Lab A uncovered that there was a restriction in the external oil circuit since the beginning of the matrix. The restricted line was replaced.
  - Tests after repair in Lab A:
    - Two tests in oil K (higher aeration when compared to other matrix oils)
    - One in oil G (low aeration)
- After detailed review of operational data from all matrix tests and their impact on average 40 to 50 hours aeration (%), the Task Force decided to select a subset of tests that most represent current and future test operation.
  - All twelve tests from Lab B
  - Seven tests from Lab G
  - Three tests from Lab A

40-50 hr. avg. aeration [%] using predicted baseline density vs. Oil by Lab: ordered from highest to lowest oil mean



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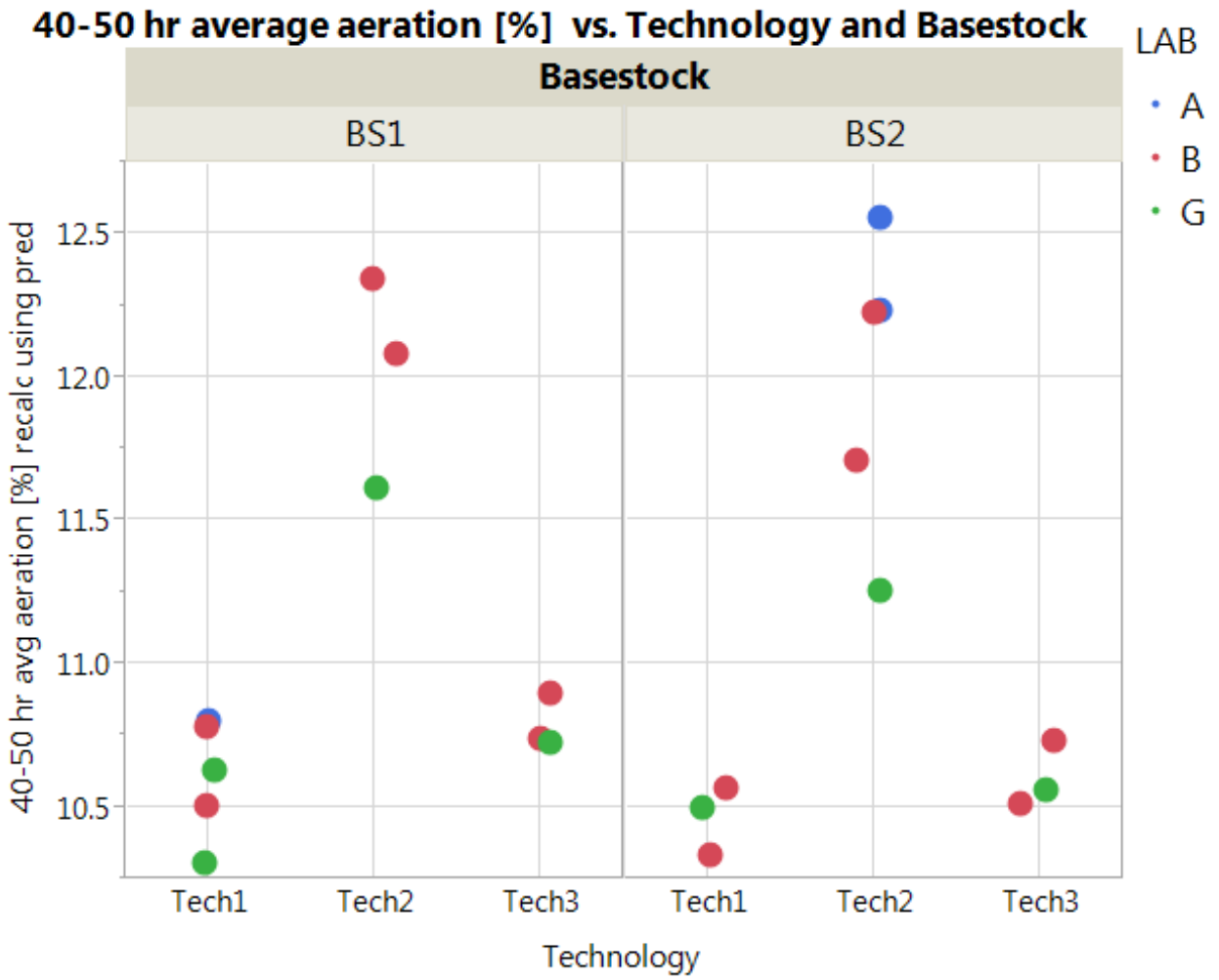
40-50 hr. avg. aeration [%] using predicted baseline density vs. Technology and Basestock type by Lab



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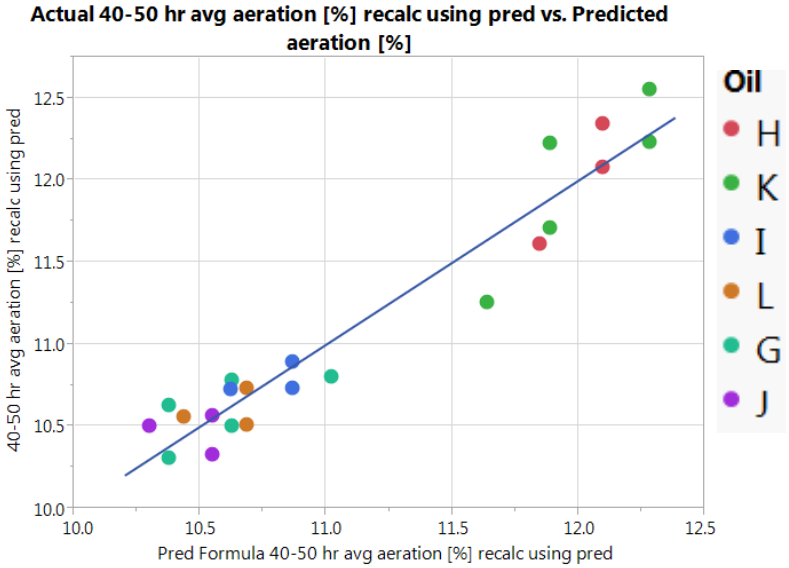
Model

- Model used to derive targets by oil and standard deviation:
  - Lab
  - Basestock
  - Technology
  - Basestock*Technology

Summary of Fit	
RSquare	0.93
RSquare Adj	0.89
Root Mean Square Error	0.24
Mean of Response	11.1
Observations (or Sum Wgts)	22

Actual Avg. Aeration vs. Predicted Avg. Aeration



- The “Engine Hours” effect was not statistically significant and not included in the final model
  - Engine Hours effects will continue to be monitored through future reference data as part of Caterpillar Surveillance Panel work

Main Conclusions

Oil comparisons: Note that the Targets are the Least Sq Mean

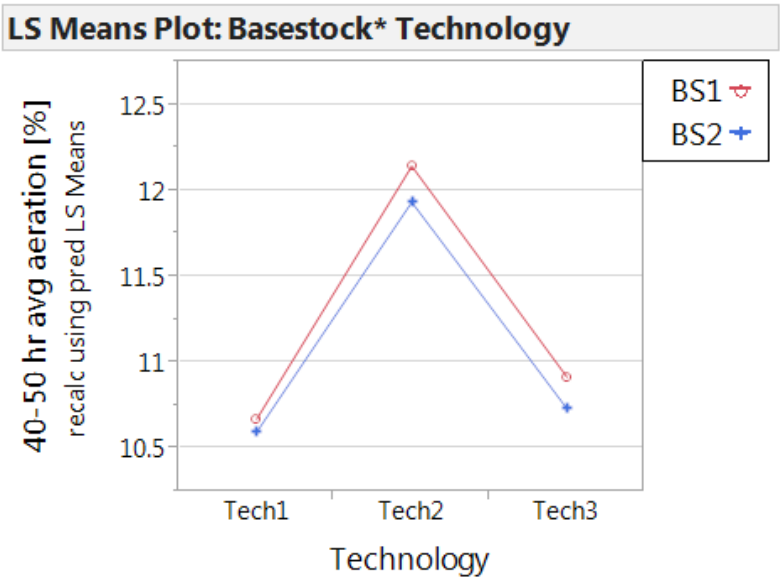
Oil	BS,Tech		Least Sq Mean
H	BS1,Tech2	A	12.14
K	BS2,Tech2	A	11.94
I	BS1,Tech3	B	10.92
L	BS2,Tech3	B	10.73
G	BS1,Tech1	B	10.67
J	BS2,Tech1	B	10.60

Lab A significantly higher than Lab G

Lab			Least Sq Mean
A	A		11.52
B	A	B	11.12
G		B	10.87

For the two basestocks selected, there is no evidence that Basetocks within Technology are different with respect to aeration

Technology 2 significantly higher than Technology 3 and 1



Levels not connected by same letter are significantly different.

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Lubricant Test Monitoring System (LTMS) and Quality Index Values

- All required LTMS elements are in place:
  - Targets and standard deviations have been determined
  - The standard deviation used for establishing lab severity adjustments has been determined
  - The constants used for the construction of the control charts were selected

- QI values for the engine operational parameters were reviewed and set (refer Appendix, page 25)

Appendix K

- Appendix K was reviewed by the Task Force, updated and provided to ACC

Test Method

- The Test method was reviewed and updated by the Task Force
- The most current version is publicly available for use on the TMC website:

Link:
ftp://ftp.astmtmc.cmu.edu/docs/diesel/coat/procedure_and_ils/

Task Force Recommendation

- The C13 Aeration Task Force has voted and recommends to NCDT that the C13 Aeration test is now ready for use in PC-11.

APPENDIX

Stand Calibration and Referencing Process

- Calibration periods: The preferred ratio of the two oils K:G is 2:1.
  - 1st period = 2 candidate tests
  - 2nd period = 4 candidate tests
  - 3rd period = 6 candidate tests
  - 4th period and subsequent = 9 candidate tests
- Brand New Stand (3 tests to begin)
  - Reference oils K, G, K
- Rebuilt or new engine with existing stand (2 tests to begin)
  - Reference oils K, G
- Critical components replaced
  - Terminate current calibration period. Run Reference oil K and restart the calibration period.
    - Example: if a component is changed in the 4th period after 3 tests. Run the reference oil K then go back to the beginning of Period 4.
  - Critical components: Included in the procedure.
    - Examples: micromotion, research valve (regulator), heated line

Matrix Data Selection

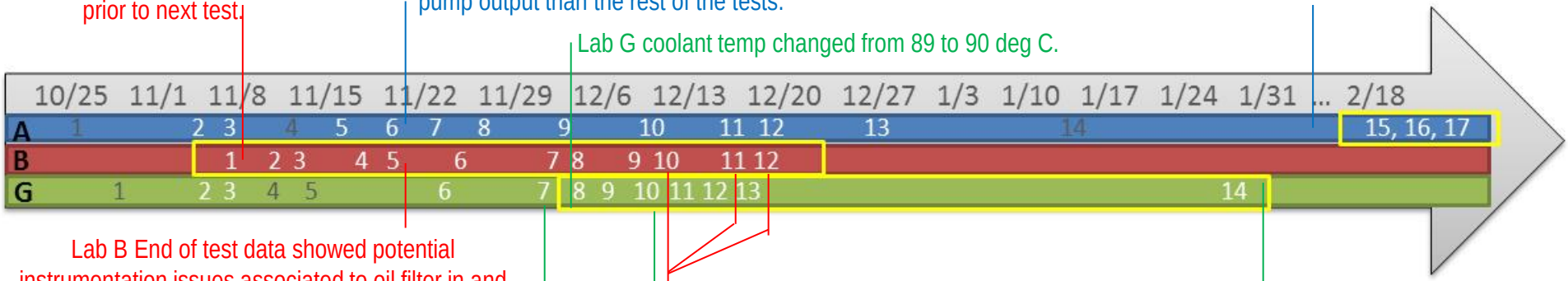
TF selected the results highlighted in yellow boxes below to be included in setting targets and calculate variability

Lab B Exhaust restriction valve appears to have difficulty holding position. Replacement was made prior to next test.

Lab A to review the enclosure box insulation to reduce temperature swings. Lab A will look into Pump control to reduce variability. Test one of oil K showed different level for pump output than the rest of the tests.

Lab A: Heated line replaced, additional wall insulation to heated box, regulator replaced, MM remounted and reinsulated, water control valve size reduced for intake manifold, manual adjustment value installed to control chilled water inlet pressure, JTEC unit replaced.

Lab G coolant temp changed from 89 to 90 deg C.



Lab B End of test data showed potential instrumentation issues associated to oil filter in and out pressure and temperature. At the completion of this test, the instruments we investigated and an instrument failure was found for oil filter in and out pressures. Transducers were replaced and Test 6 was started.

Lab G added additional Cummins Day tank upstream of Fuel Micro Motion signal to eliminate fueling spikes to engine tank.

Lab B noted small oil leak at the fuel pump front cover located at he front of the engine. (Test 11: Leak amounted to roughly 2 oz. Test 12: Leak was monitored through test duration. Amount of roughly 2 oz was returned to the oil pan with the 25 hr sample purge. Approximate oil leak amounted to roughly 5 oz)

Lab G made improvements to the controls for Gallery and Coolant Temperature by changing controllers from SSR Pulse to Process (0-10V). Noise in the signal is very low at +/- 0.02 C. Added a process trim valve to the Compressor Inlet Air Pressure which controls to 96 kPaa +/- 0.2. By adding voltage resolution to the speed control setting, RPMs now at 1800 +/- 1. Added a process controller to the Crank Case Pressure and it controls on average to 103.0 with a tolerance of 0.2 kPaa which is similar to the tolerance of a fixed ball valve.

Lab G replaced 2 short sections of engine coolant hose since they appeared weak (swollen). A coolant bypass valve was unfortunately pushed open during the hose replacement. The first 17 hours of the test had a low coolant temp of 84 C. The alarm limit had only been set for High. It is now set for Low and High. The remainder of the test was run at 90 C.

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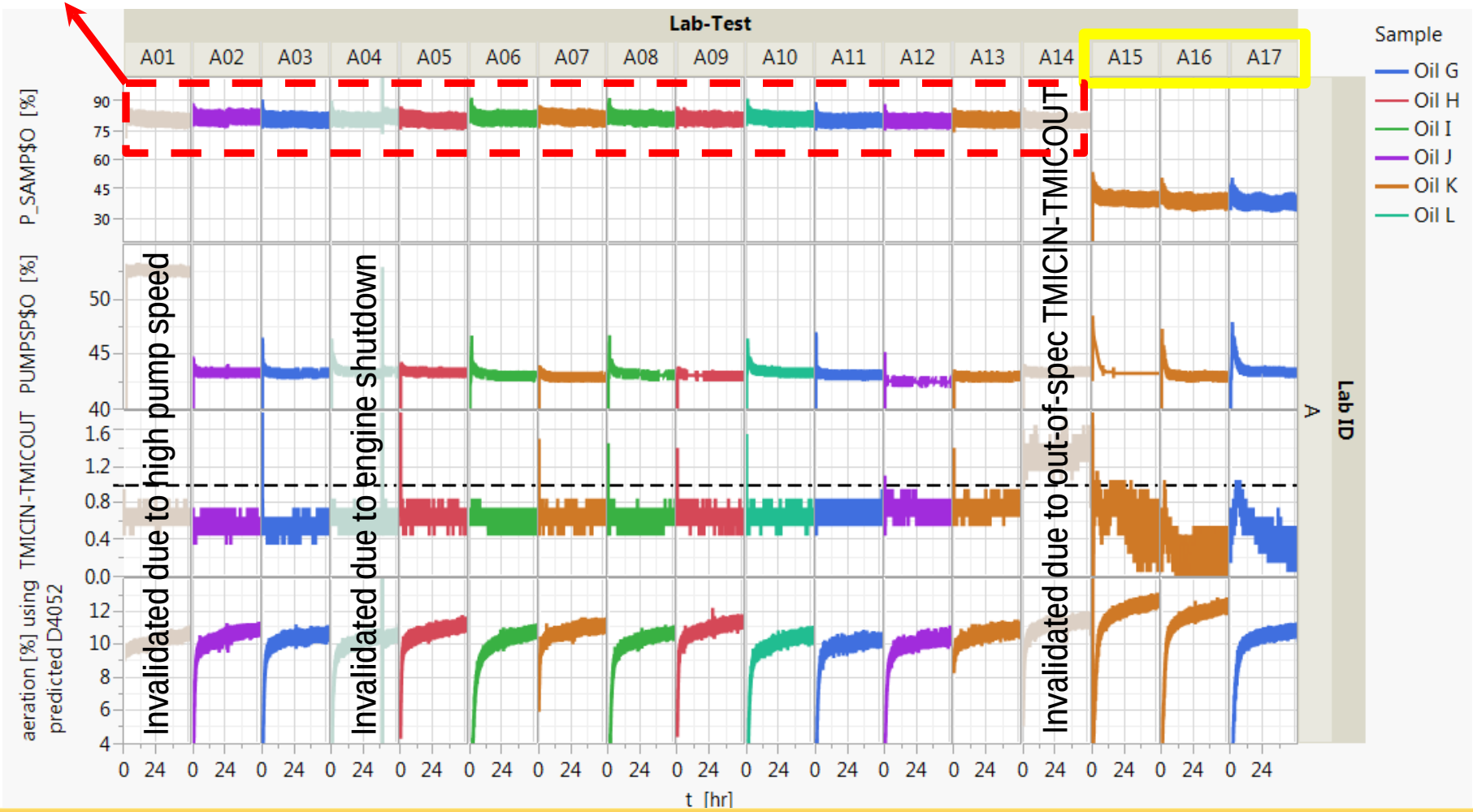
Selection of tests from Lab A

Selected data

It was discovered late in matrix testing that there was a restriction in the external oil circuit.
The heated line was replaced to achieve a valve position more aligned with other labs.



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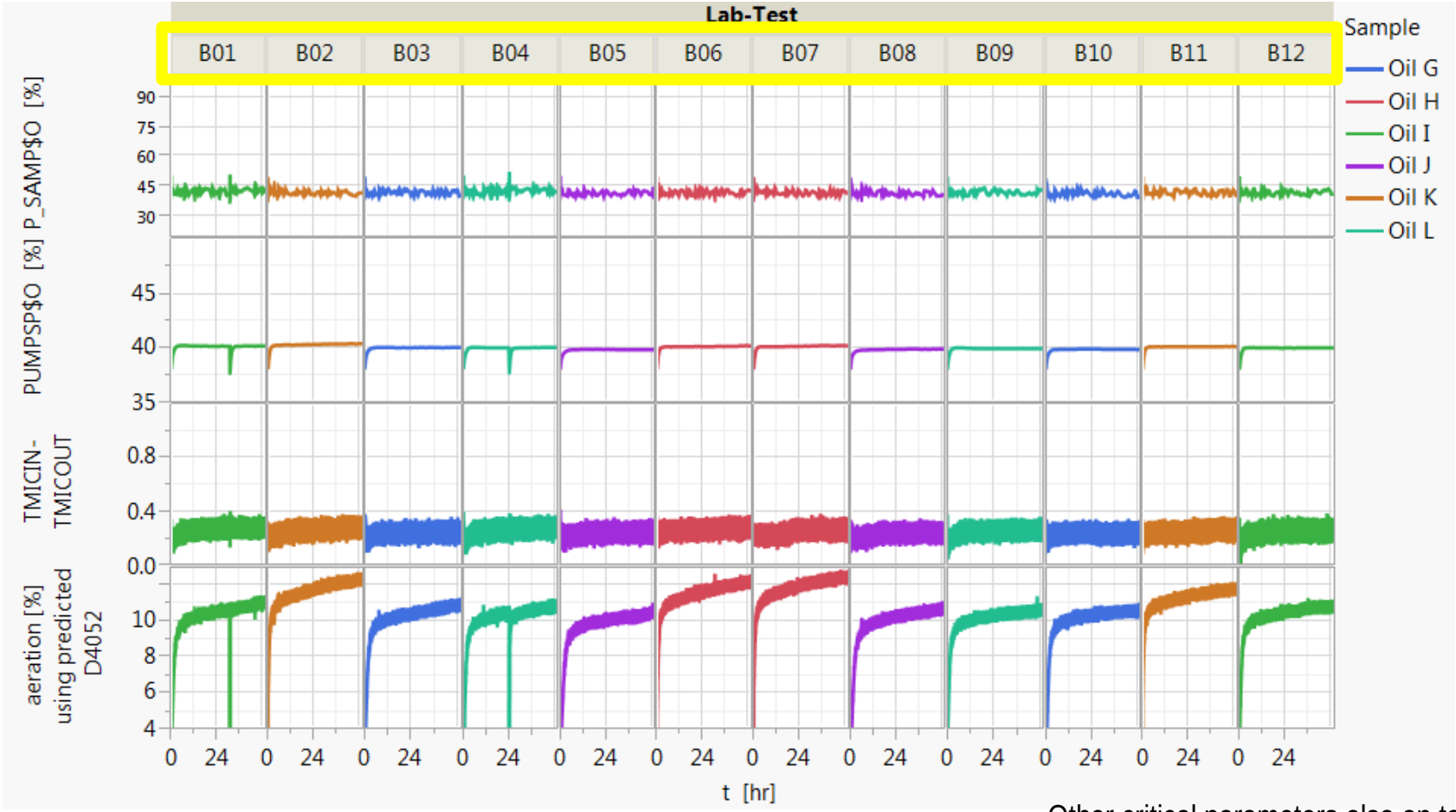
Selection of tests from Lab B

Selected data

All runs from Lab B were selected



Other critical parameters also on target.

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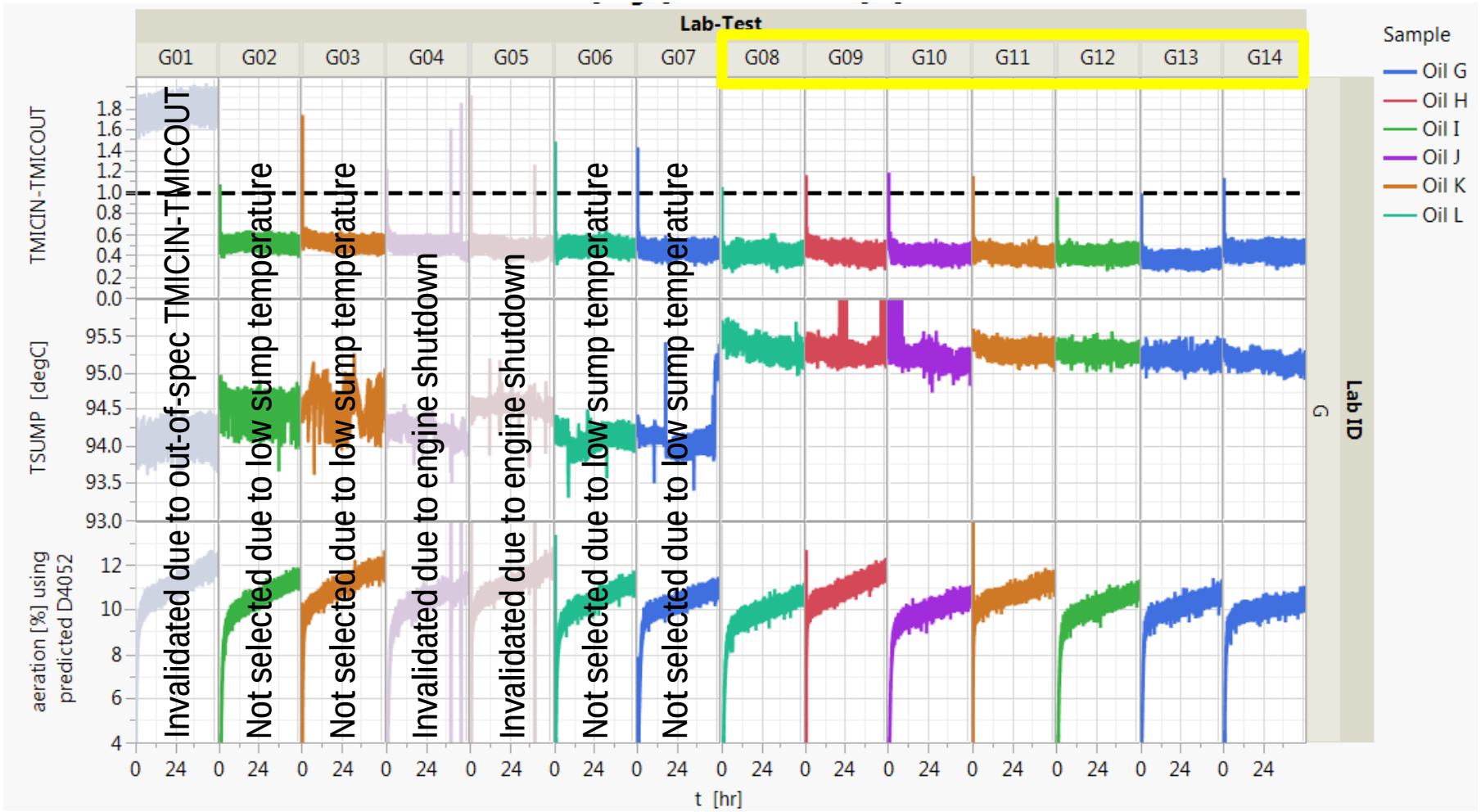
Selection of tests from Lab G

Selected data



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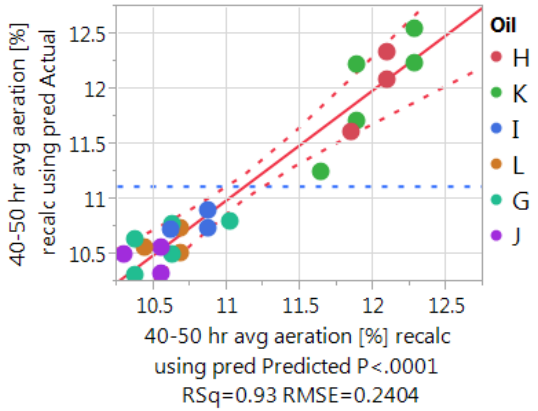
Model Details

Actual by Predicted Plot



Summary of Fit

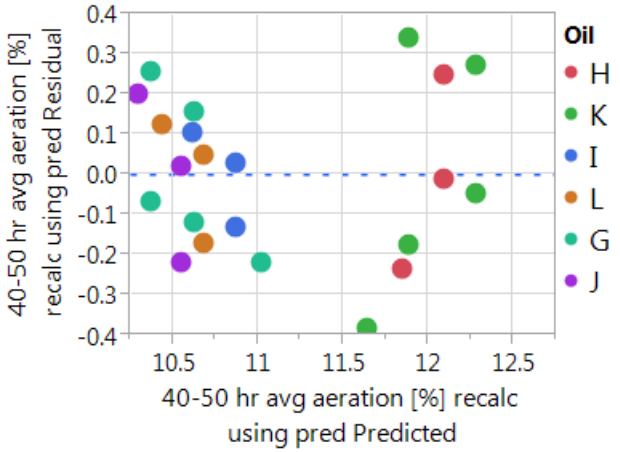
RSquare	0.92992
RSquare Adj	0.89488
Root Mean Square Error	0.240401
Mean of Response	11.11768
Observations (or Sum Wgts)	22

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	10.736244	1.53375	26.5389
Error	14	0.809095	0.05779	Prob > F
C. Total	21	11.545339		<.0001*

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	11.167368	0.067089	166.46	<.0001*
LAB[A]	0.3482845	0.113586	3.07	0.0084*
LAB[B]	-0.049839	0.078142	-0.64	0.5339
Basestock[BS1]	0.0781581	0.053104	1.47	0.1632
Technology[Tech1]	-0.531276	0.073331	-7.24	<.0001*
Technology[Tech2]	0.8726192	0.075122	11.62	<.0001*
Basestock[BS1]*Technology[Tech1]	-0.040228	0.076829	-0.52	0.6087
Basestock[BS1]*Technology[Tech2]	0.0265143	0.07854	0.34	0.7407

Residual by Predicted Plot



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Discrimination Previously Established

- Statistically significant differences between oils
  - HA from OS, LAD-1
  - TMC1005 from OS, LAD-1
  - All four oils from LAD1
- Lab not included in the model because of confounding with Si delta

Oil Comparison at Avg Si delta

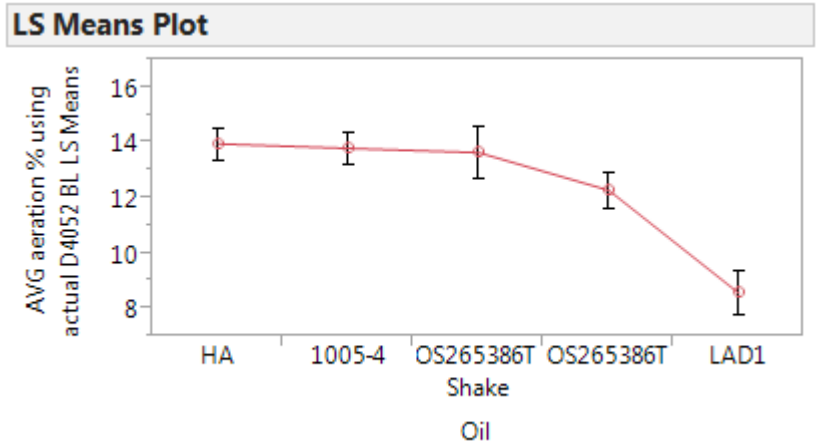
Level			Least Sq Mean
HA	A		13.983147
1005-4	A		13.818996
OS265386T Shake	A	B	13.663651
OS265386T		B	12.301463
LAD1		C	8.578476

Levels not connected by same letter are significantly different.

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|	VIF
Intercept	11.679907	0.242772	48.11	<.0001*	.
Oil[HA]	1.5140003	0.25377	5.97	<.0001*	1.3859806
Oil[1005-4]	1.3498497	0.252916	5.34	0.0001*	1.376671
Oil[OS265386T Shake]	1.1945042	0.411237	2.90	0.0115*	2.7997462
Oil[OS265386T]	-0.167684	0.280186	-0.60	0.5591	1.5054262
Si delta (EOT-1hr)	0.1135596	0.027062	4.20	0.0009*	1.8690264

Oil Ranking by Estimated Aeration %



Summary of Fit

RSquare	0.950648
RSquare Adj	0.933022
Root Mean Square Error	0.602017
Mean of Response	12.74715
Observations (or Sum Wgts)	20

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	5	97.73737	19.5475	53.9354
Error	14	5.07393	0.3624	Prob > F
C. Total	19	102.81131		<.0001*

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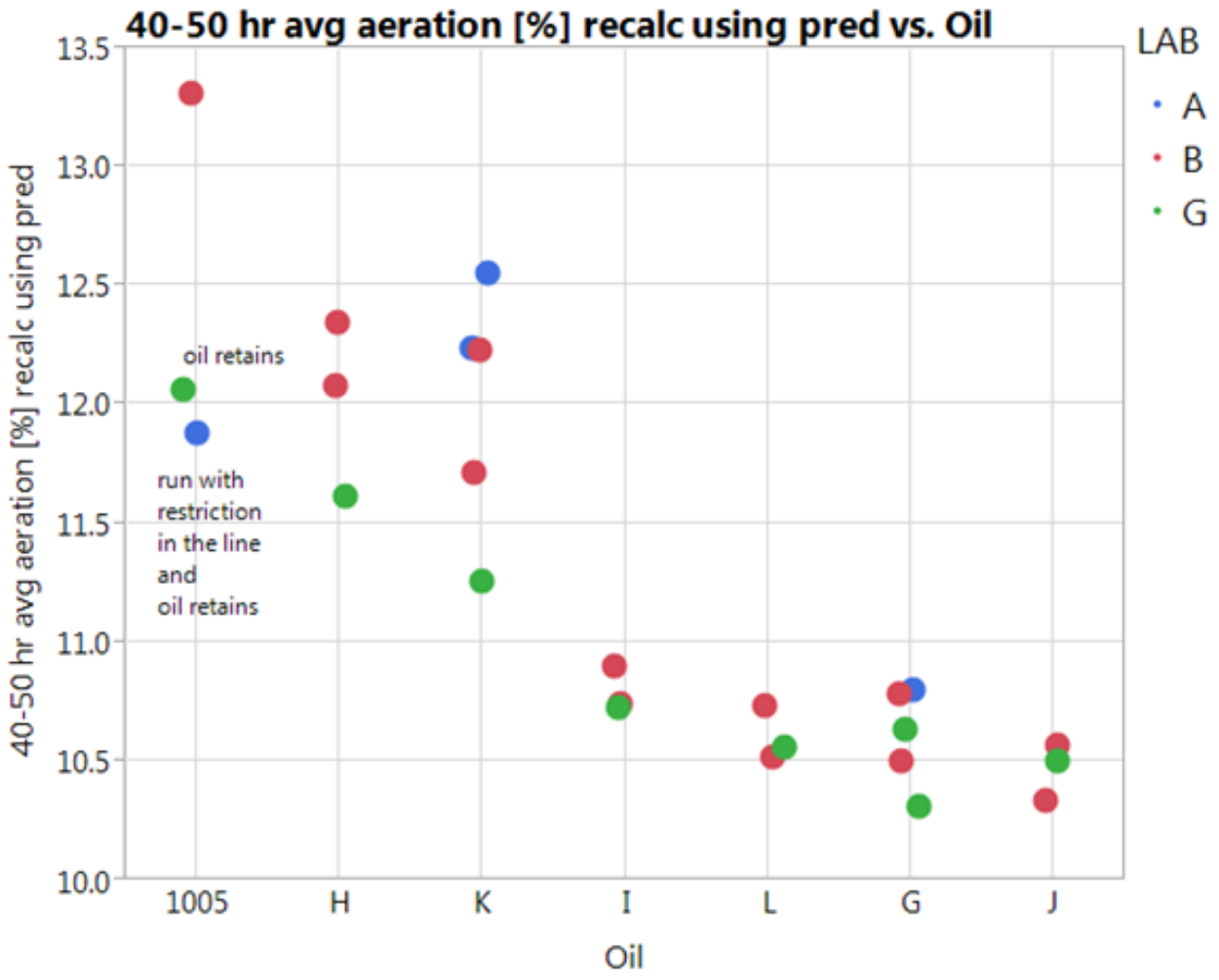
Setting Quality Index Values

- Qi Values were reviewed and set at:
  - Engine Speed set to 1800 +/- 2.5 RPM
  - Inlet Air Temp set to 25 +/- ? deg C *design point decided on, TMC will calculate based on setting test A6 as Qi = zero.*
  - Inlet Man Temp set to 40 +/- 0.5 deg C
  - Fuel Temp set to 40 +/- 0.4 deg C
  - Coolant Out Temp set to 90 +/- 0.4 deg C
  - Oil Gal Temp set to 90 +/- 0.2 deg C
  - Exhaust Back Press set to 104 +/- 0.3 kPa
  - Crankcase Press set to 103 +/- 0.25 kPa
  - Sample Oil Temp set to 90 +/- 0.2 deg C
  - Sample Oil Flow set to 1.5 +/- 0.03 L/min
  - Sample Oil Press set to 84 +/- 0.35 kPa
- Qi calculations starts 10 minutes after each start-up.

Aeration Test of 1005 Ref Oil

Tests conducted after the Matrix: latest procedure



Based on test conditions, data point from Lab A may be actually higher than current value. Potentially close to value from Lab B .

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