

CAT AERATION ANALYSIS OF THE 2ND PROVE OUT RUNS

September 10th, 2014

Performance you can rely on.



Outline



- Data collection and visualization
- Modeling the data
- Si correction
- Visualization of Before and After correction is applied to Aeration %
- Summary
- Appendix

Data available from 2nd prove out runs



Test plan update, 27 Aug 2014

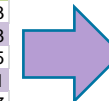
Lab	Test 0	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
A	LZ oil (OS)	HA	1005	HA	1005	LZ oil start Thurs	LAD1	1005/1004?
B	LZ oil (OS)	HA	1005	HA – Start Friday	LZ oil	LAD1	Obtain info on insulation box - validate	
C	LZ oil (OS) Hi Si	1005	HA	1005-start Thurs	LZ oil	LZ oil*	LAD1	

Done

* = LZ oil Test 5 Lab C, different batch , test completed but data not on TMC yet

- 2nd prove out tests ONLY (Table below organized by Kevin O'Malley). 18 test results

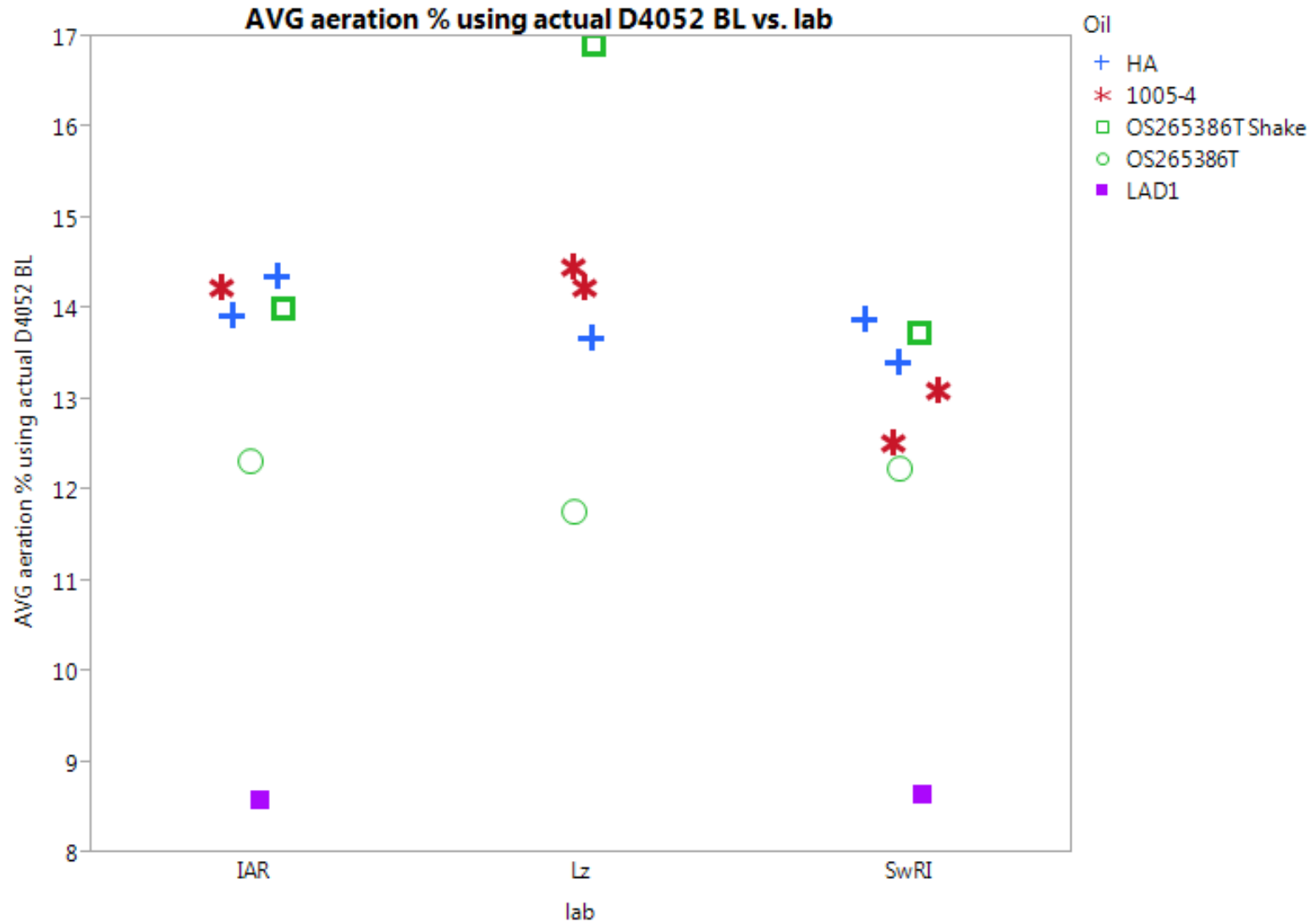
Additional Prove Out Testing (Finished Tests and Planned Tests)												
Prove Out Phase	Phase Label	Lab	Oil	Start of test engine hours	Si 0hr	Si 1hr	Si 5hrs	Si 25hrs	Si 50hrs	Actual D4052 @90C	% Aeration (using Actual D4052 baseline density)	DvT slope
2	103 kPa Plus	LZ	OS265386T	88	7	18	27	37	52	0.82545	16.91	-0.00062554
2	103 kPa Plus	LZ	1005-4	142	6	5	7	12	15	0.83594	14.2283	-0.00062896
2	103 kPa Plus	LZ	HA	194	6	4	4	10	12	0.82822	13.6702	-0.00062436
2	103 kPa Plus	LZ	1005-4	247	7	5	6	10	15	0.83598	14.4685	-0.00062946
2	103 kPa Plus	LZ	OS265386T	299	7	4	6	7	10	0.82559	11.7516	-0.00062546
2	103 kPa Plus	LZ	OS265386S									
2	103 kPa Plus	LZ	LA									
2	103 kPa Plus	ICES	OS265386T	94.8	5	4	5	10	14	0.8257	14.0018	-0.00062
2	103 kPa Plus	ICES	HA	147.4	5	3	4	7	10	0.8279	14.3628	-0.00062
2	103 kPa Plus	ICES	1005-4	200.1	6	4	5	6	8	0.8360	14.2367	-0.00063
2	103 kPa Plus	ICES	HA	254.19	5	3	4	6	8	0.8279	13.9304	-0.00062393
2	103 kPa Plus	ICES	OS265386T	307.7	5	2	3	4	6	0.8257	12.2949	-0.00062268
2	103 kPa Plus	ICES	LA	362.4	14	10	10	11	12	0.8310	8.5732	-0.000615
2	103 kPa Plus	SwRI	OS265386T	87	5	6	8	12	15	0.8257	13.7206	-0.00062321
2	103 kPa Plus	SwRI	HA	129	5	3	4	6	9	0.8278	13.8787	-0.00062357
2	103 kPa Plus	SwRI	1005-4	180	5	3	4	5	7	0.835	13.1022	-0.00062714
2	103 kPa Plus	SwRI	HA	280	5	3	3	5	6	0.8278	13.4166	-0.00062357
2	103 kPa Plus	SwRI	1005-4	330	6	3	3	4	5	0.835	12.5167	-0.00062714
2	103 kPa Plus	SwRI	OS265386T	380	8		3	4	5	0.8257	12.2329	-0.00062321
2	103 kPa Plus	SwRI	LA	430	14	9	9	10	10	0.8305	8.65	-0.000625



The two highlighted % Aeration values differ by 0.01 from the values used in this analysis. The small discrepancies are being investigated but will not impact the conclusions

- Aeration %: AVG aeration % using actual D4052 BL
- SwRI OS at 380 hours tests is missing the Si at 1 hr. To be able to use this data in the model assumed that Si 1 hour = 3. The other two OS runs are, respectively, IAR OS Si 1 hr = 2 and Lz OS Si 1 hr = 4. Si 1 hour = 2 or 3 does lead to similar conclusions.
- Definition: Si delta= Si EOT – Si 1hr
- Confounding: LZ Lab and high Si delta

2nd Prove out phase after operation conditions were controlled: Avg aeration % using actual D4052 BL

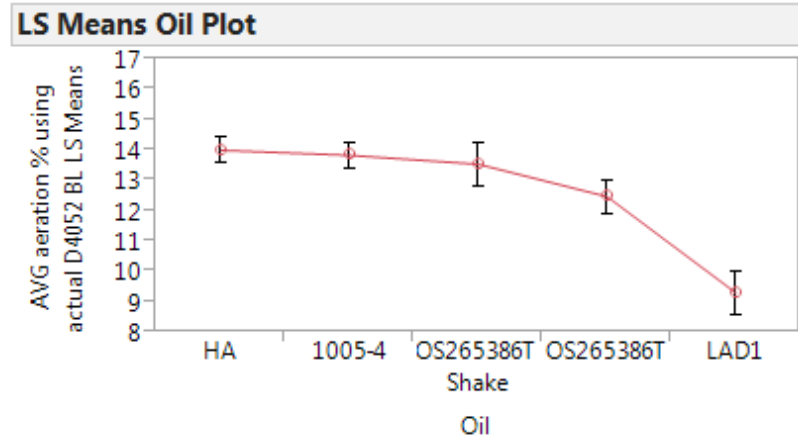


Model 1 and corresponding statistically significant differences between oils



- Avg aeration % using actual D4052 BL = f(Oil, Si delta (EOT – 1hr))
- Lab not included in the model because of confounding with Si delta
- Statistically significant differences between oils
 - HA from OS, LAD-1
 - TMC1005 from OS, LAD-1
 - All four oils from LAD1

Oil Ranking by Estimated Aeration %



Summary of Fit

RSquare	0.966662
RSquare Adj	0.952771
Root Mean Square Error	0.432459
Mean of Response	13.10995
Observations (or Sum Wgts)	18

→ Variability

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	5	65.073205	13.0146	69.5891
Error	12	2.244254	0.1870	Prob > F
C. Total	17	67.317459		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob> t	VIF
Intercept	11.752912	0.175433	66.99	<.0001*	.
Oil[HA]	1.3714731	0.186326	7.36	<.0001*	1.2066186
Oil[1005-4]	1.2049252	0.185868	6.48	<.0001*	1.200696
Oil[OS265386T Shake]	0.9097356	0.3058	2.97	0.0116*	2.4723042
Oil[OS265386T]	-0.156589	0.229381	-0.68	0.5078	1.3910439
Si delta (EOT-1hr)	0.1255463	0.01974	6.36	<.0001*	1.9187675

Oil Comparison at Avg Si delta

Level	Least Sq Mean
HA	14.010184
1005-4	13.843636
OS265386T Shake	13.548446
OS265386T	12.482121
LAD1	9.309166

Levels not connected by same letter are significantly different.

Correction for excess Si delta (EOT -1 hr)

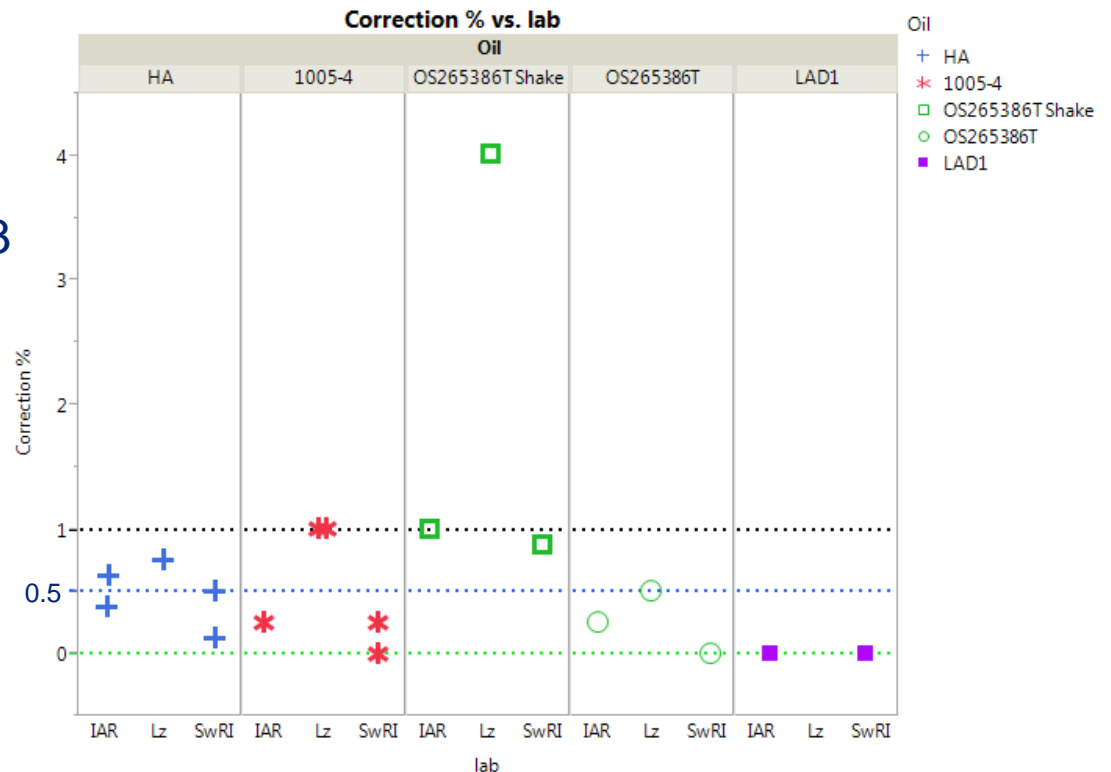


- Goal: Remove from the observed % aeration, the estimated portion of aeration due to Si delta (EOT -1hr) >2, so that the data can be visualized simulating Si passivation
- Corrected Aeration = Avg aeration % using actual D4052 BL – beta (Si delta EOT – 1 hr) - 2),

where beta is the regression coefficient for Si delta (EOT – 1hr) in the model.

For model 1, beta =0.1255463 (see page 6, under Parameters Estimates.

Total: 18 tests
 4 tests – no correction
 7 tests – correction <= 0.5%
 3 tests – correction < 1%
 3 tests – correction = 1%
 1 test – correction = 4%



Correction for Si delta (EOT – 1 hr.) < 3

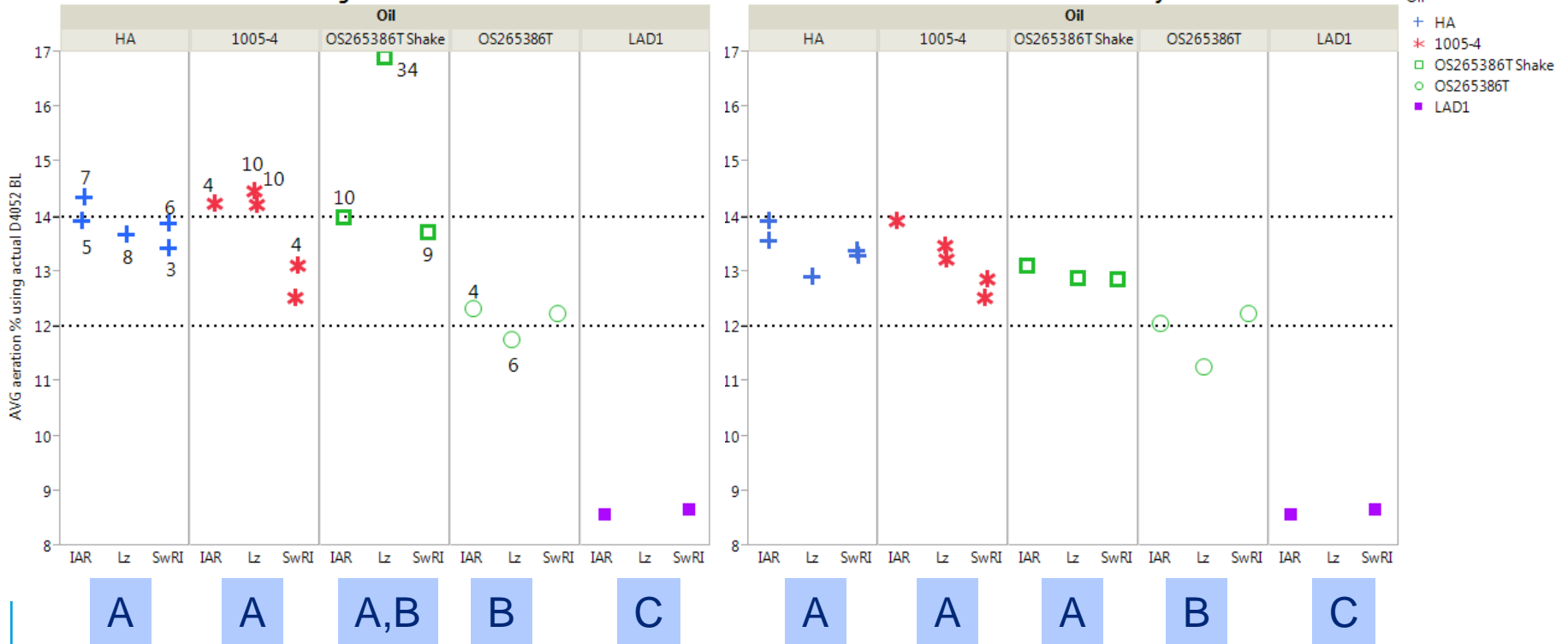


Before

After

AVG aeration % using actual D4052 BL vs. lab

Corrected Aeration % vs. lab by Oil

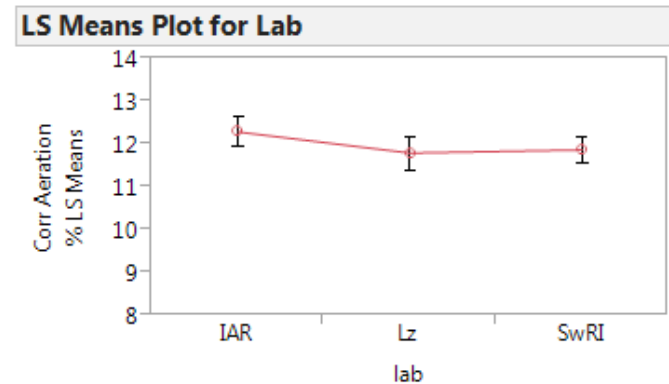
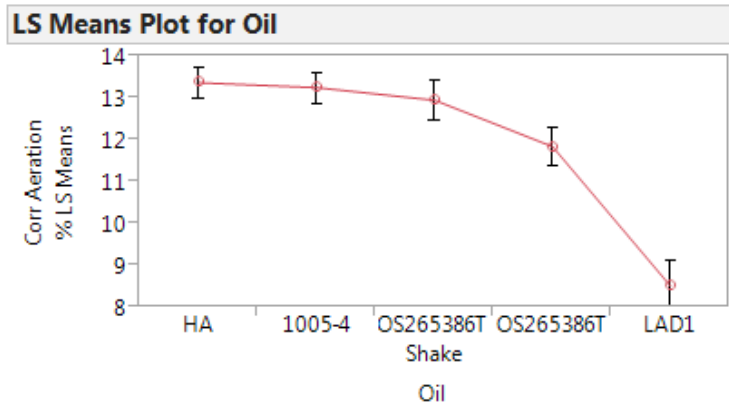


Test labels represent the Si delta (EOT – 1 hr.)
 Tests without a number are considered passivated (<3)
 Capital letters at the bottom of the plot show the oil ranking wrt aeration
 Different letters represent statistically significant different oils wrt aeration

Models 2 and 3



- Model 2, in the appendix, for n=17 after excluding OS Shakedown run from Lz lab show similar separation between oils when compared to model 1
- Model 3: Fits the Corrected Aeration % by Lab and Oil
 - Oil Ranking by Estimated Aeration % is similar to the ranking obtained for model 2, but now there is a statistically significant difference between OS and all the other oils
 - There is no evidence that the labs are different



Oil Ranking by
Estimated Aeration %

Level		Least Sq Mean
HA	A	13.373347
1005-4	A	13.255691
OS265386T Shake	A	12.953818
OS265386T	B	11.845902
LAD1	C	8.514596

Levels not connected by same letter are significantly different.

Summary



- According to model 1 (and model 2 in the appendix), the statistically significant differences between oils are the following
 - HA from OS, LAD-1
 - TMC1005 from OS, LAD-1
 - All four oils from LAD1
- Based on the analysis of Si delta (EOT -1hr) corrected data (model 3),
 - There is no evidence that labs are different.
 - Oil Ranking by Estimated Aeration % is similar to the ranking obtained for models 1 and 2, but now there is a statistically significant difference between OS and all the other oils
 - The repeats within labs are somewhat closer after the correction is applied (see table 1 below)

Table 1: 2nd prove out repeats

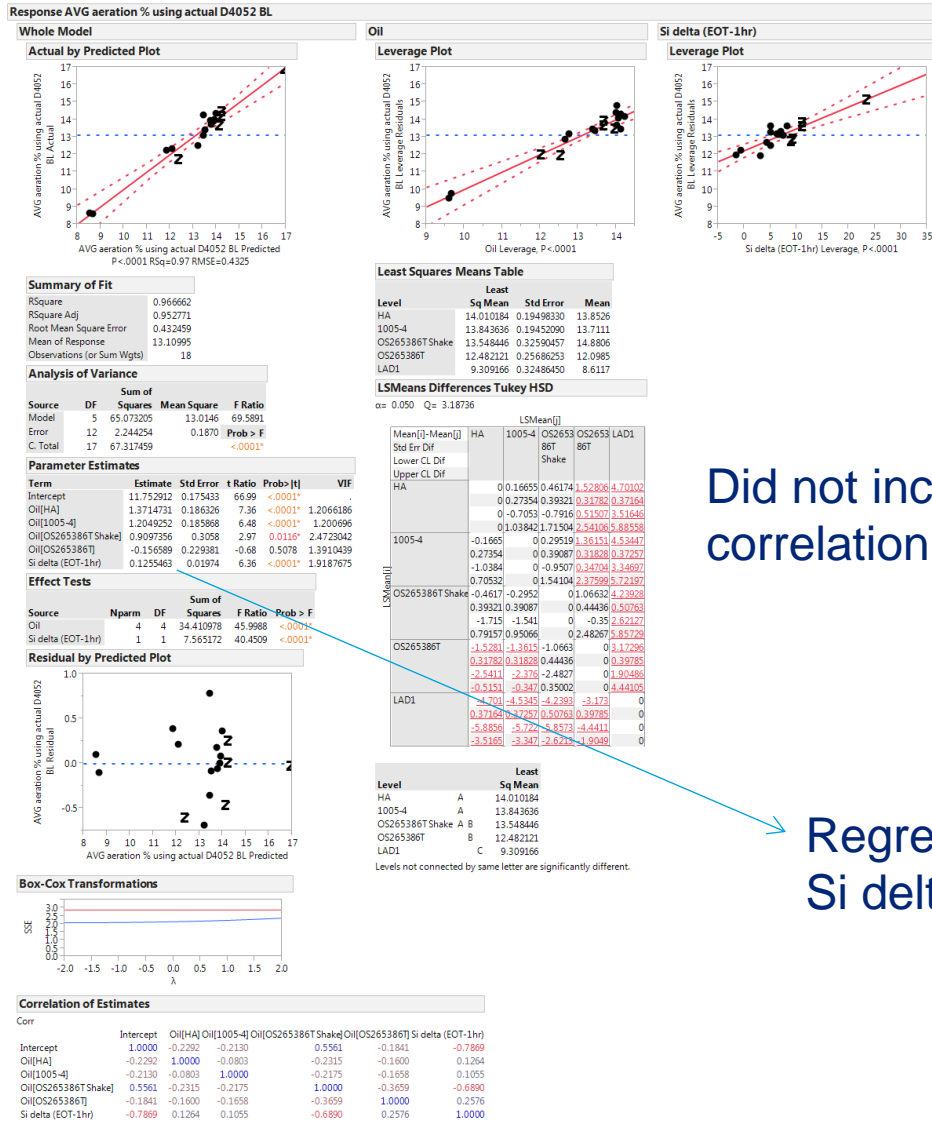
avg	Oil	lab	AVG aeration % using actual D4052 BL	SOT engine hours	Si delta (EOT-1hr)	Corr Aeration %
30-50	HA	IAR	14.3644665	147.4	7	13.91372269
30-50	HA	IAR	13.93295566	254.19	5	13.55631676
30-50	HA	SwRI	13.87848895	129	6	13.37630375
30-50	HA	SwRI	13.41681099	280	3	13.29126469
30-50	1005-4	Lz	14.22813655	142	10	13.22376615
30-50	1005-4	Lz	14.46834609	247	10	13.46397569

APPENDIX

Performance you can rely on.



Model 1: Avg aeration % using actual D4052 BL by Oil and Si delta (EOT- 1hr.)



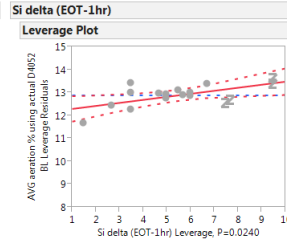
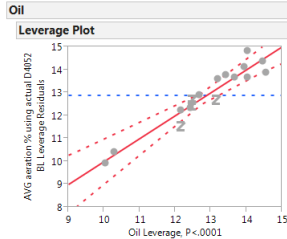
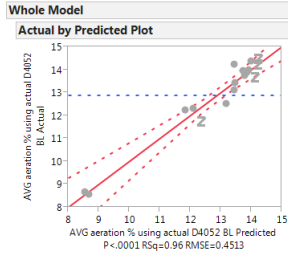
Did not include Lab in the model because of correlation with Si. Lz Lab correlated with High Si.

Regression coefficient for Si delta used in the Si delta correction

Model 2: n=17 after excluding OS Shakedown run from Lz lab



Response AVG aeration % using actual D4052 BL



Summary of Fit

RSquare	0.956944
RSquare Adj	0.937374
Root Mean Square Error	0.451275
Mean of Response	12.88643
Observations (or Sum Wgts)	17

Analysis of Variance

Source	DF	Squares	Mean Square	F Ratio
Model	5	49.788660	9.95773	48.8966
Error	11	2.240137	0.20365	Prob > F
C. Total	16	52.028796		<.0001*

Lack Of Fit

Source	DF	Squares	Mean Square	F Ratio
Lack Of Fit	9	1.5644855	0.173832	0.5146
Pure Error	2	0.6756511	0.337826	Prob > F
Total Error	11	2.2401366		0.8012

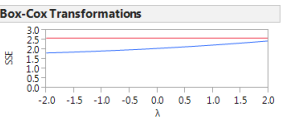
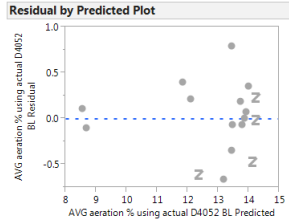
Max RSq: 0.9870

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob > t	VIF
Intercept	11.719894	0.295988	39.63	<.0001*	
Oil[HA]	1.3664511	0.197615	6.91	<.0001*	1.2407961
Oil[1005-4]	1.1985914	0.199005	6.02	<.0001*	1.2583105
Oil[OS265386T Shake]	0.8911278	0.344898	2.58	0.0254*	2.3364612
Oil[OS265386T]	-0.149806	0.244069	-0.61	0.5518	1.4453498
Si delta (EOT-1hr)	0.1321049	0.050517	2.62	0.0240*	1.9077105

Effect Tests

Source	Nparm	DF	Squares	F Ratio	Prob > F
Oil	4	4	26.429325	32.4447	<.0001*
Si delta (EOT-1hr)	1	1	1.392646	6.8385	0.0240*



Least Squares Means Table

Level	Sq Mean	Std Error	Mean
HA	13.809036	0.20250106	13.8536
1005-4	13.641177	0.20358050	13.7111
OS265386T Shake	13.333713	0.37849558	13.8660
OS265386T	12.292780	0.27092792	12.0985
LAD1	9.136220	0.37690578	8.6117

LSMeans Differences Tukey HSD
alpha = 0.050 Q = 3.233999

Mean[j]-Mean[i]	HA	1005-4	OS265386T Shake	OS265386T	LAD1
HA					
Std Err Dif					
Lower CL Dif					
Upper CL Dif					
HA		0.0.16786	0.47532	1.51636	4.67282
		0.0.28599	0.4213	0.34188	0.43599
		0.0.7557	-0.8871	0.41062	3.26411
		0.1.09146	1.83779	2.62189	6.08152
1005-4	-0.1679	0.0.30746	1.3484	4.50496	
	0.28599	0.0.41691	0.3447	0.44072	
	-1.0915	0.0.1.0408	0.23352	0.37968	
	0.75574	0.1.69576	2.66313	5.93029	
OS265386T Shake	-0.4753	-0.3075	0.1.04099	4.19749	
	0.4213	0.41691	0.0.4969	6.05729	
	-1.8378	-1.6558	0.0.566	2.23839	
	0.88715	1.04083	0.2.64789	6.1566	
OS265386T	-1.5163	-1.3484	-1.0409	0.1.15656	
	0.34188	0.3447	0.4969	0.83988	
	-1.6319	-2.4631	-2.6479	0.1.7631	
	-0.4106	-0.2336	0.56602	0.4.55002	
LAD1	-4.6728	-4.505	-4.1975	-3.1566	0
	0.43599	0.44072	0.60579	0.43088	0
	-6.0815	-5.9302	-6.1566	-4.55	0
	-3.2641	-3.0797	-2.2384	-1.7631	0

Least Squares Means Table

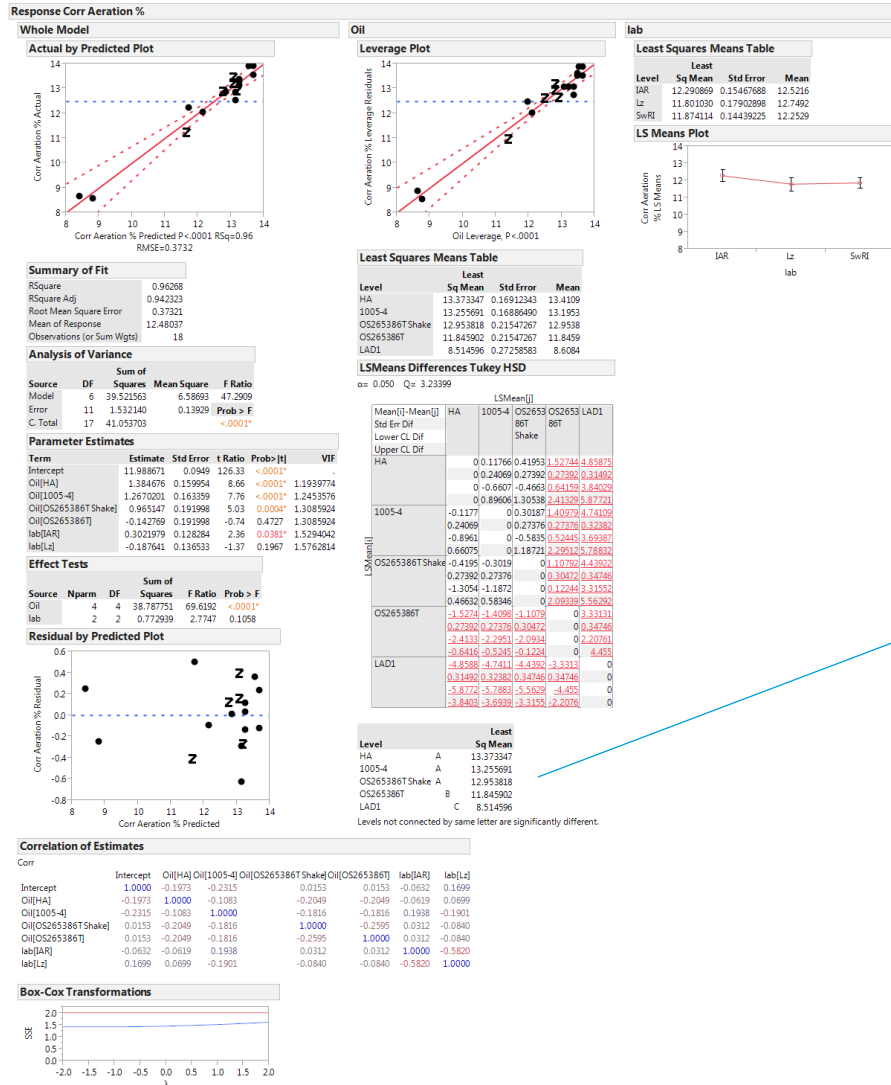
Level	Sq Mean
HA	13.809036
1005-4	13.641177
OS265386T Shake A B	13.333713
OS265386T B	12.292780
LAD1 C	9.136220

Levels not connected by same letter are significantly different.

Did not include Lab in the model because of correlation with Si. Lz Lab correlated with High Si.

Regression coefficient for Si delta close to original coefficient with full data set

Model 3: Corrected Aeration % by Lab and Oil



→ No evidence of difference among labs

Oil Comparisons

Level	Least	Sq Mean
HA	A	13.373347
1005-4	A	13.255691
OS265386T Shake	A	12.953818
OS265386T	B	11.845902
LAD1	C	8.514596

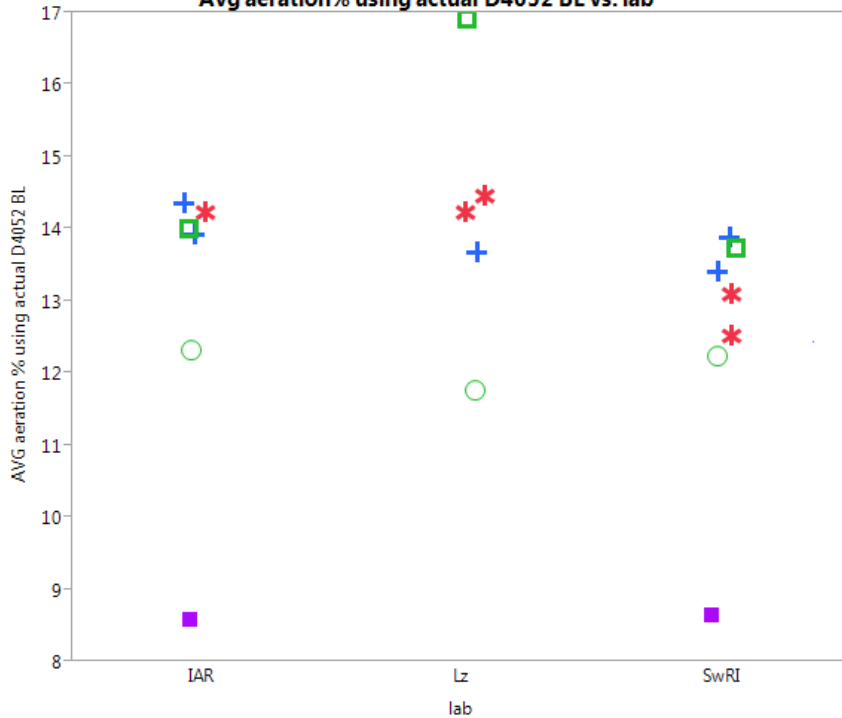
Levels not connected by same letter are significantly different.

2nd prove out runs: Before and After the correction



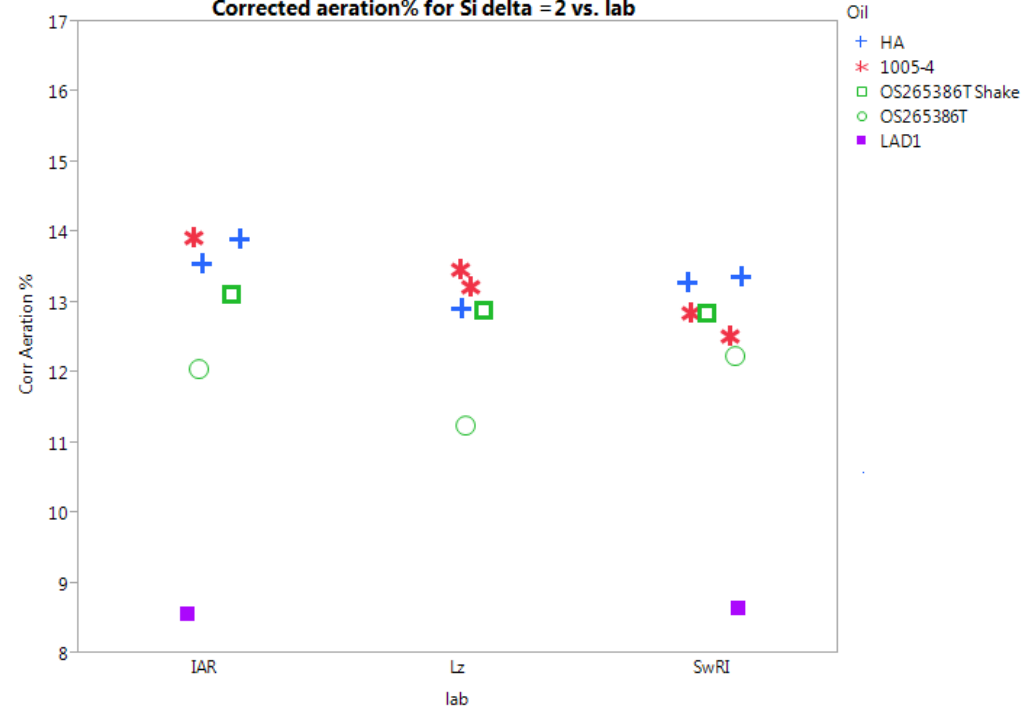
Before

Avg aeration% using actual D4052 BL vs. lab

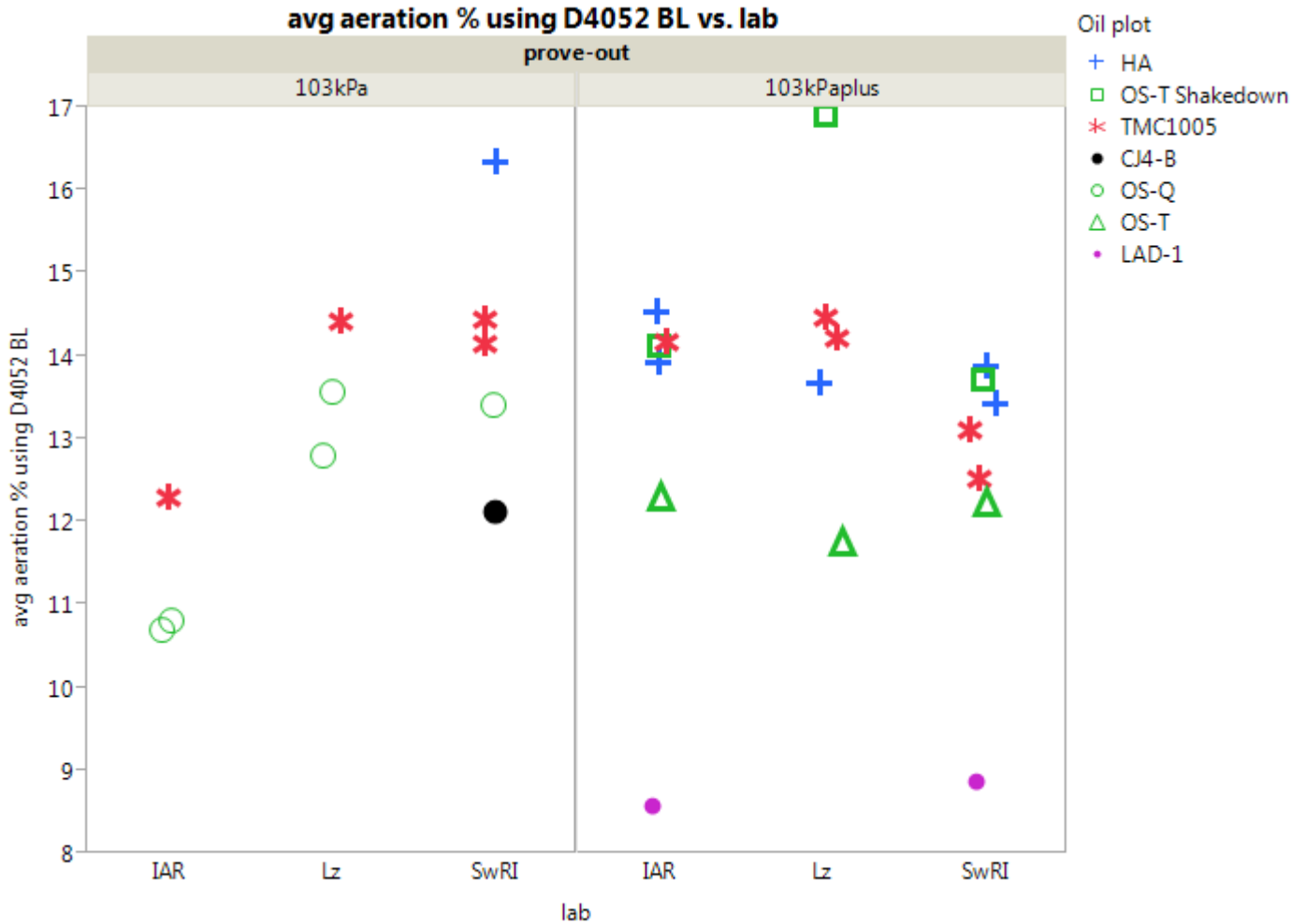


After

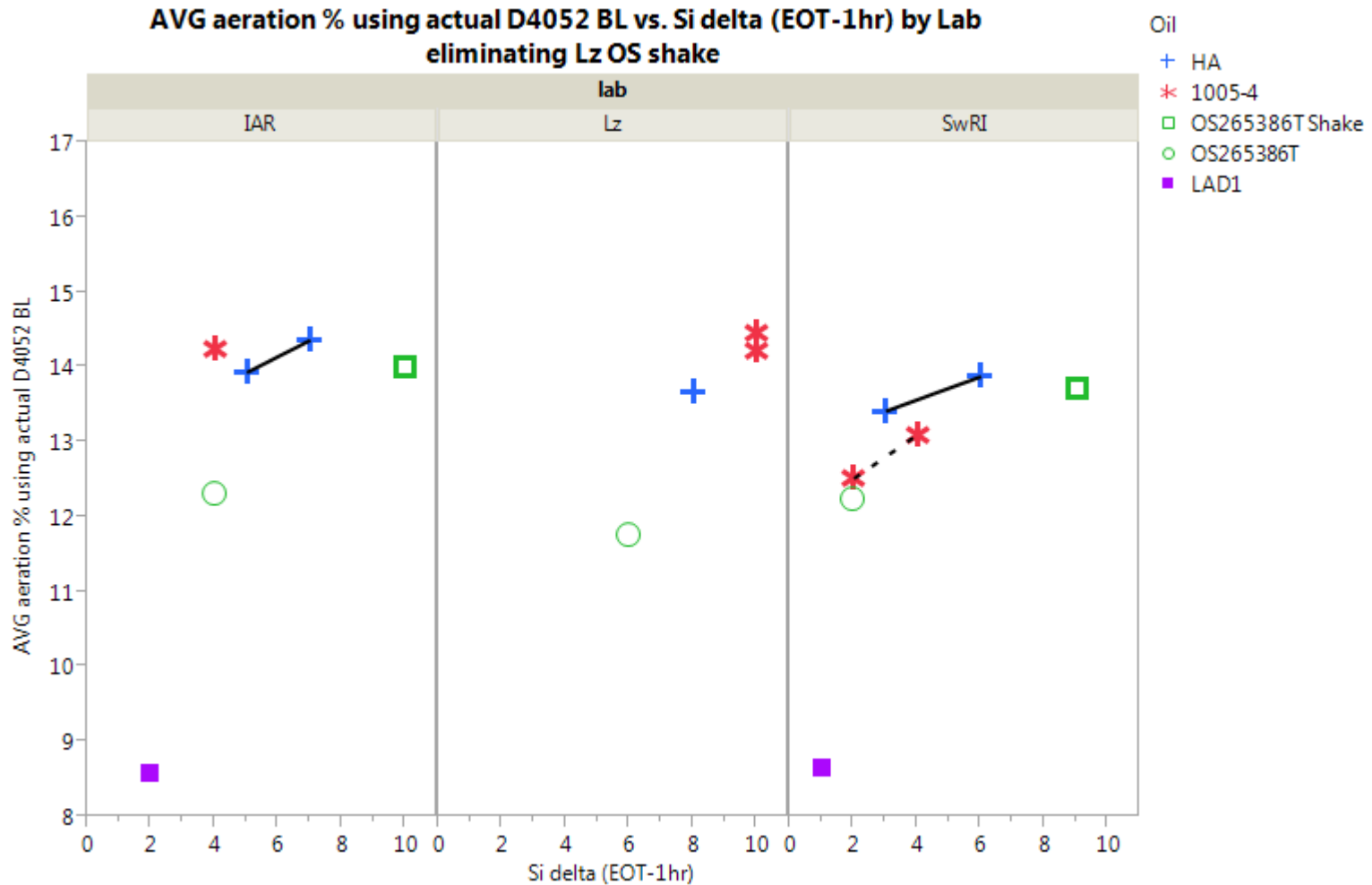
Corrected aeration% for Si delta = 2 vs. lab



Aeration % by Prove out phase and Lab



AVG aeration % using actual D4052 BL vs. Si delta by Lab



Another correction for Si delta (EOT – 1 hr.) < 3

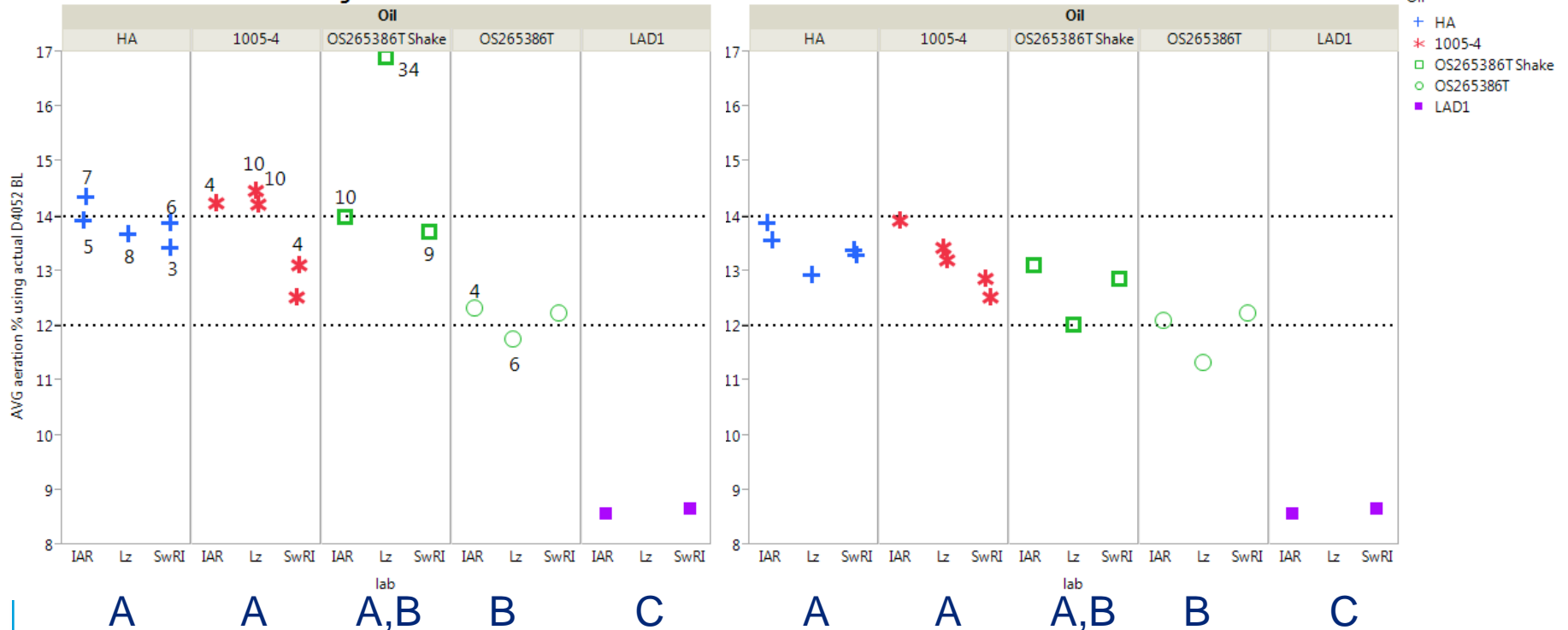


Before

After

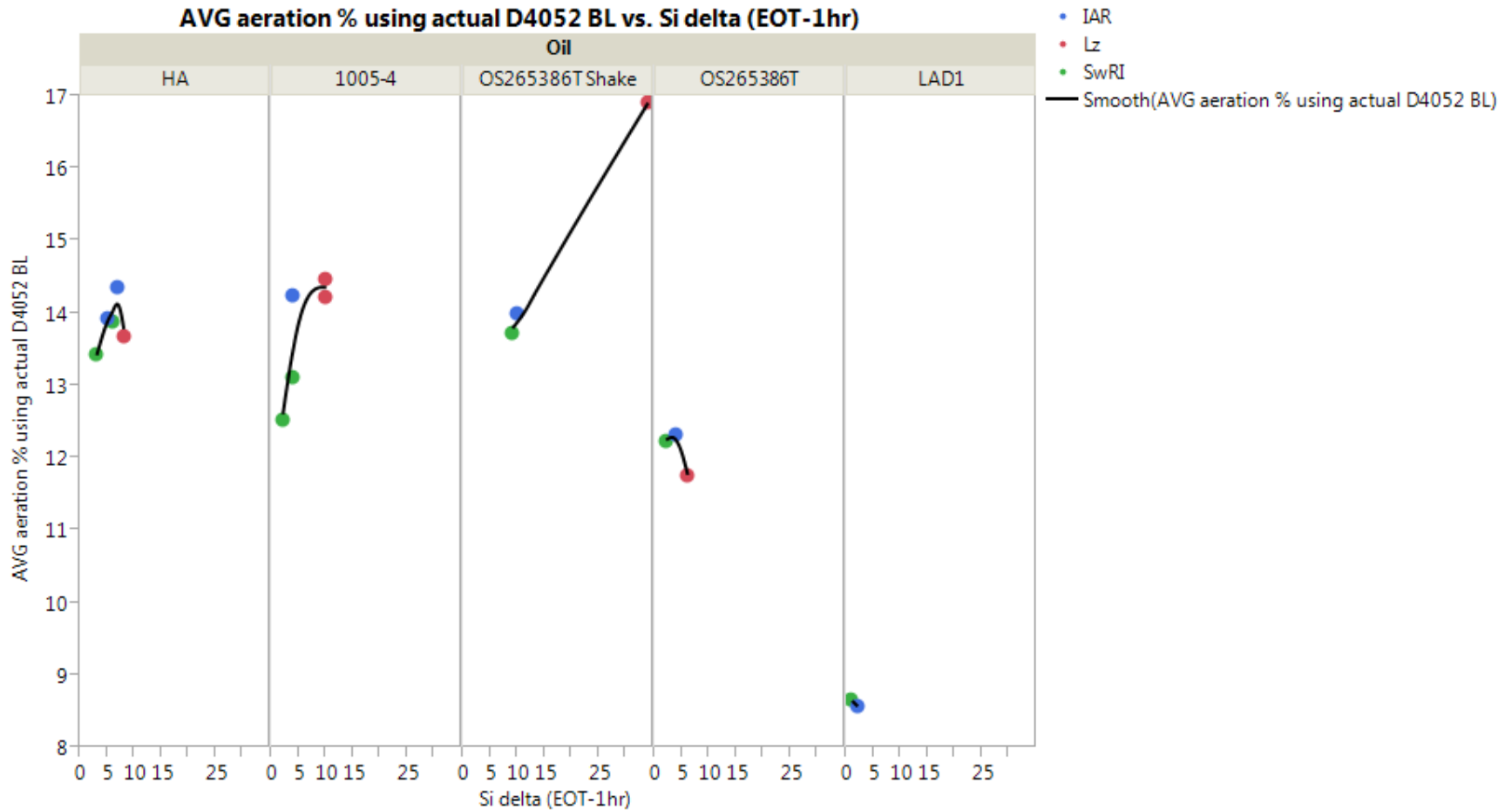
AVG aeration % using actual D4052 BL vs. lab

Corrected aeration% vs. lab



Test labels represent the Si delta (EOT – 1 hr.)
 Tests without a number are considered passivated (<3)
 Capital letters at the bottom of the plot represent the oil ranking wrt aeration
 Different letters represent statistically significant different oils wrt aeration

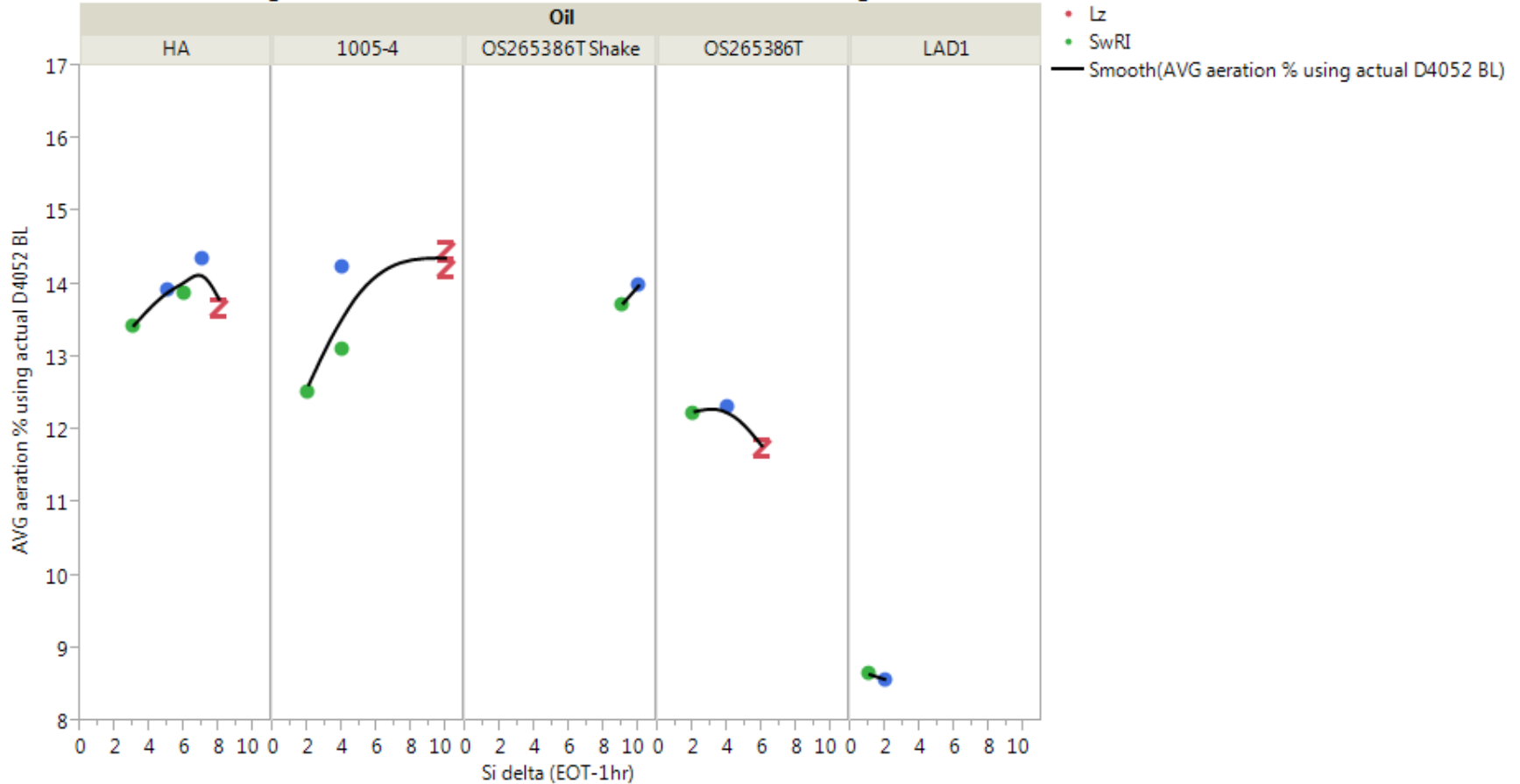
Including all 18 tests results



Eliminating the Lz OS shakedown test



AVG aeration % using actual D4052 BL vs. Si delta (EOT-1hr) - eliminating Lz OS shake



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