Sequence IV Surveillance Panel | MINUTES

REVISION DATE: 10/20/2017 8:35:00 PM

Relevant Test:	Sequence IVB
Note Taker:	Chris Mileti
Meeting Date:	10-16-2017
Comments:	This Surveillance Panel conference call was scheduled to review the agenda items that were not completed during the 10-12-2017 conference call.

1. DISCUSSION ABOUT 10-12-2017 OPERATIONAL DATA REVIEW:

1.1. Differences in Exhaust Temperature:

1.1.1. Lubrizol feels that the differences in exhaust temperature between labs and stands is significant.

1.1.2. Intertek's Comments:

1.1.2.1. Intertek replaced and calibrated the exhaust gas thermocouples on all four of their test stands.

1.1.2.1.1. The original thermocouples had heavy carbon deposits.

1.1.2.2. They have previously not calibrated exhaust thermocouples using a temperature bath.

1.1.2.3. They plan to use temperature baths for all future calibrations.

1.2. Laboratory Update from Exxon:

1.2.1. They will reprogram their intake air pressure parameter with the correct set-point.

1.2.2. They replaced the blowby flow meter on their stand.

1.2.3. They plan to install the correct blowby barrel check valve.

1.2.4. The work to collect OBD-II parameters is still in progress.

1.2.4.1. The Surveillance Panel gave Exxon permission to run their Precision Matrix tests without having the OBD-II channels in place.

1.2.5. A new test kit has been installed in their engine, so they are ready for the next prove-out test.

1.3. Laboratory Update from Lubrizol:

1.3.1. The REO1012 prove-out test is running.

1.3.1.1. Lubrizol plans to replace its exhaust thermocouple after the 150HR oil check.

1.3.1.2. The purpose of this replacement is to see if a new thermocouple results in a shift in the temperature measurements.

1.3.2. Intertek cautioned Lubrizol to check the male connector on the new thermocouple.

1.3.2.1. The screws have been loose on some of their new exhaust thermocouples.

1.3.3. Lubrizol is using its current REO1012 prove-out test to evaluate different oil temperature control strategies.

1.4. Laboratory Update from Southwest:

1.4.1. They adjusted the PID tuning on their engine coolant temperature parameters.

1.4.2. They are still investigating their exhaust backpressure control issues.

1.4.2.1. Intertek recommended that Southwest check the bulkhead fittings on their pressure transducers.

1.5. Oil Temperature Control:

1.5.1. Oil gallery temperature control is not as good as it should be.

1.5.2. Intertek's Comments:

1.5.2.1. They made modifications to their Golden Stands (1-2 years ago) to improve the control of this temperature.

1.5.2.2. This included installing an external fan on the oil heat exchanger.

1.5.2.3. They also increased the water pressure to the oil heat exchanger so that it is approximately 22psi at the outlet.

1.5.2.3.1. This was done by installing a booster pump.

1.5.2.3.2. They used the 3/4HP pump used on the rocker arm coolant system of the Sequence VG stand.

1.5.3. Lubrizol and Southwest both feel that the Intertek upgrades should be incorporated into the Golden Stand.

1.5.4. In fact, a recent statistical study at Southwest suggests that there may be a correlation between REO300 severity and the oil gallery temperature.

1.5.4.1. Higher oil gallery temperatures correlate to lower intake lifter wear.

1.6. Coolant Flow Schematic for Exxon's Golden Stand:

1.6.1. Exxon is experiencing a surge in their engine and rocker arm cover coolant flows late in the test cycle.

1.6.2. They believe that this surge may be related to their coolant plumbing.

1.6.2.1. The new Golden Stands at Exxon and Afton are not plumbed in the same way as the older stands at Intertek, Southwest and Lubrizol.

1.6.3. The key coolant system hardware (i.e. pumps, flow meters, valves, etc.) appear to be in the same location on both the new and old Golden Stands.

1.6.3.1. However, the plumbing lengths are likely very different on the new stands.

1.7. QI Limits for Coolant Outlet Temperature:

1.7.1. The Surveillance Panel decided to utilize a separate target and window for each stage.

1.7.2. Official Motion for Coolant Temperature QI Strategy:

1.7.2.1. "Set separate Stage 1 and Stage 2 targets and windows for the engine coolant (outlet) temperature QI calculation, with a target of 51.5°C and a window of ±0.75°C for Stage 1 and a target of 52.75°C and a window of ±0.75°C for Stage 2. Transition data will not be used in the engine coolant temperature (outlet) QI calculation."

1.7.2.2. Afton requested that a footnote be added to the procedure to specify how the control point and the QI targets are different.

1.7.3. Vote:

1.7.3.1. The motion was made by Lubrizol and seconded by Intertek.

1.7.3.2. *Approving votes:* Intertek, TMC, Shell, Toyota, Lubrizol, Afton, Southwest, Infineum, Exxon

1.7.3.3. *Waiving votes:* OHT, Chevron, TEI

1.7.3.4. This motion was approved (9-0-3).

1.7.4. The Surveillance Panel will eventually have to go through the same process for the oil temperature QI limits.

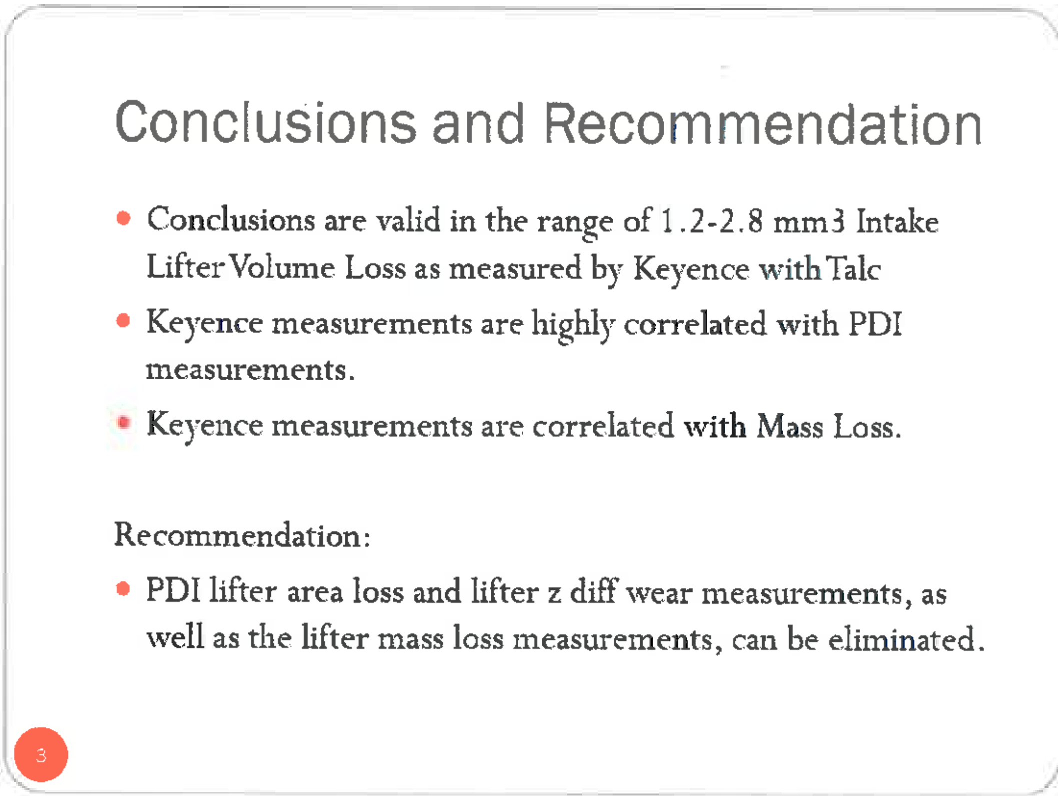
2. KEYENCE VERSUS PDI MEASUREMENTS:

2.1. Background:

2.1.1. This material was presented by J. Martinez.

2.1.2. **File name:** *"IVB Keyence and PDI Correlation Analysis 101017"*

2.2. Slide #3:



2.2.1. The statisticians analyzed Keyence measurements that were collected both with and without talc.

2.2.2. They identified a strong correlation between the Keyence volume loss measurements and the PDI area loss measurements.

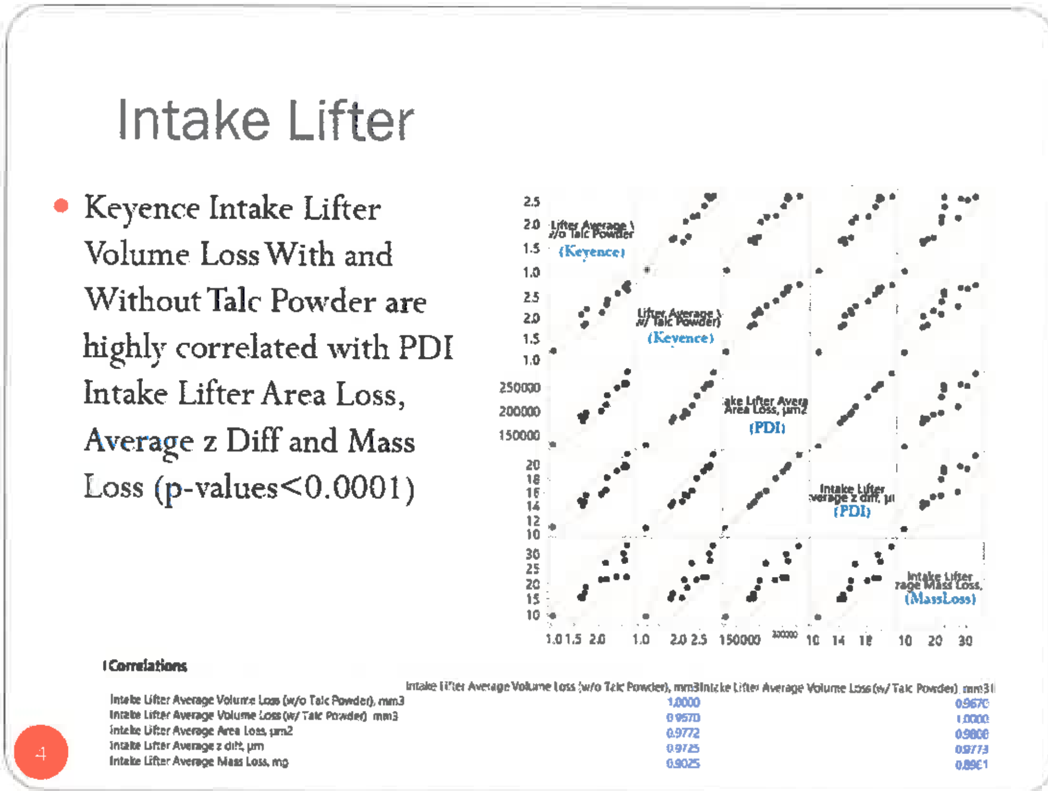
2.2.3. They also identified a correlation between the Keyence volume loss measurements and the mass loss measurements.

2.2.4. The statisticians did caution that their analysis was done using Keyence data that ranged between 1.2-2.8mm^3.

2.2.4.1. Their analysis may no longer be valid if the severity of the test shifts outside of this range in the future.

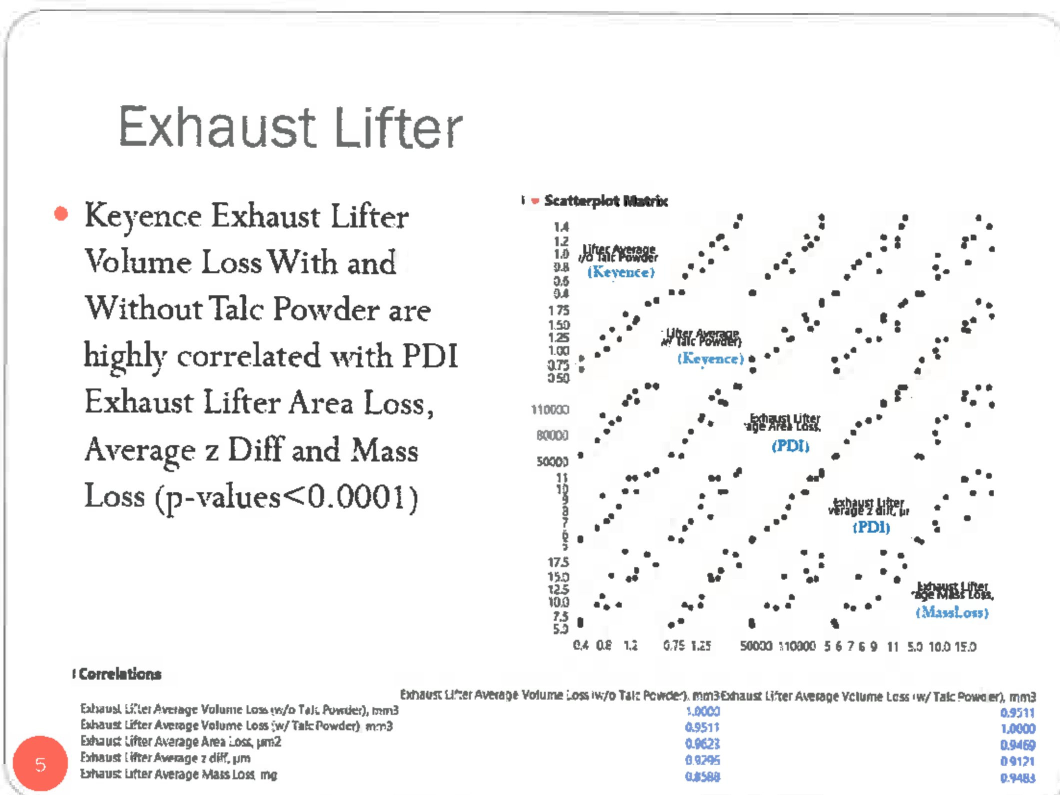
2.2.5. They recommend eliminating the PDI area loss and mass loss measurements.

2.3. Slide #4:



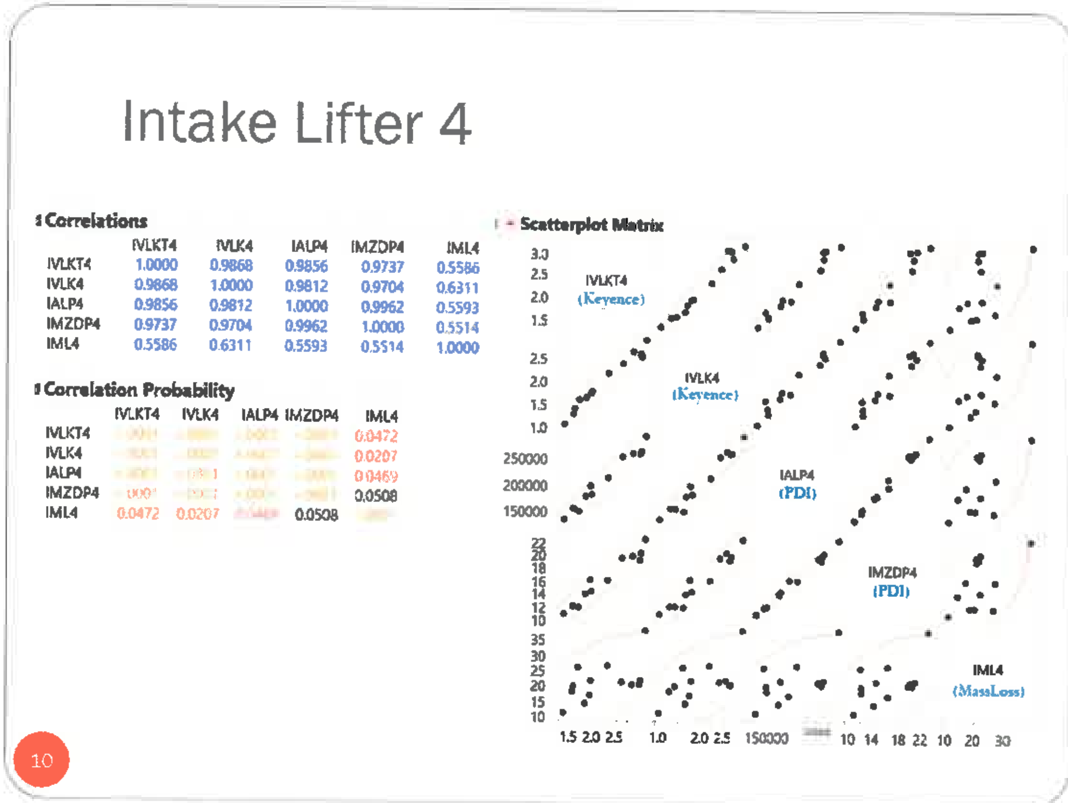
2.3.1. There is a "little bit of scatter" in the mass loss measurements, so the correlation between the Keyence and mass loss is not as strong as the correlation between the Keyence and the PDI.

2.4. Slide #5:



2.4.1. There is also a high correlation between the Keyence and PDI data for the exhaust lifters.

2.5. Slide #10:



2.5.1. The statisticians have identified wear trends with lifters from a given position in the engine.
2.5.2. For example, there is the most scatter in the mass loss data for lifter position #4.
2.5.3. This lifter position also has the lowest correlation between the Keyence and PDI measurements.
2.5.4. Afton asked whether the mass loss gives better discrimination than the volume loss.
  2.5.4.1. The statisticians will run this analysis.
2.5.5. Afton is comfortable with removing the PDI measurements, but they would like to wait to remove the mass loss measurements until the statisticians can review the data.

2.6. Motion to Remove PDI Data:

2.6.1. "The Surveillance Panel agrees to eliminate PDI area loss and z-diff as lifter wear measurement requirements for the Sequence IVB test procedure, based on the statistical correlation analysis between the Keyence volume loss and PDI area loss and z-diff wear measurement parameters. This will be effective on 10-16-2017."
2.6.2. Intertek made the motion and it was seconded by Lubrizol.
2.6.3. *Vote:*
  2.6.3.1. *Approving votes:* Intertek, TMC, Chevron, Toyota, Lubrizol, Afton, Southwest, Infineum, Exxon
  2.6.3.2. *Waive votes:* OHT, Shell, TEI
  2.6.3.3. The vote passed (9-0-3).
2.6.4. The TMC will not finalize the new IVB report forms until a decision is made on the mass loss measurements.

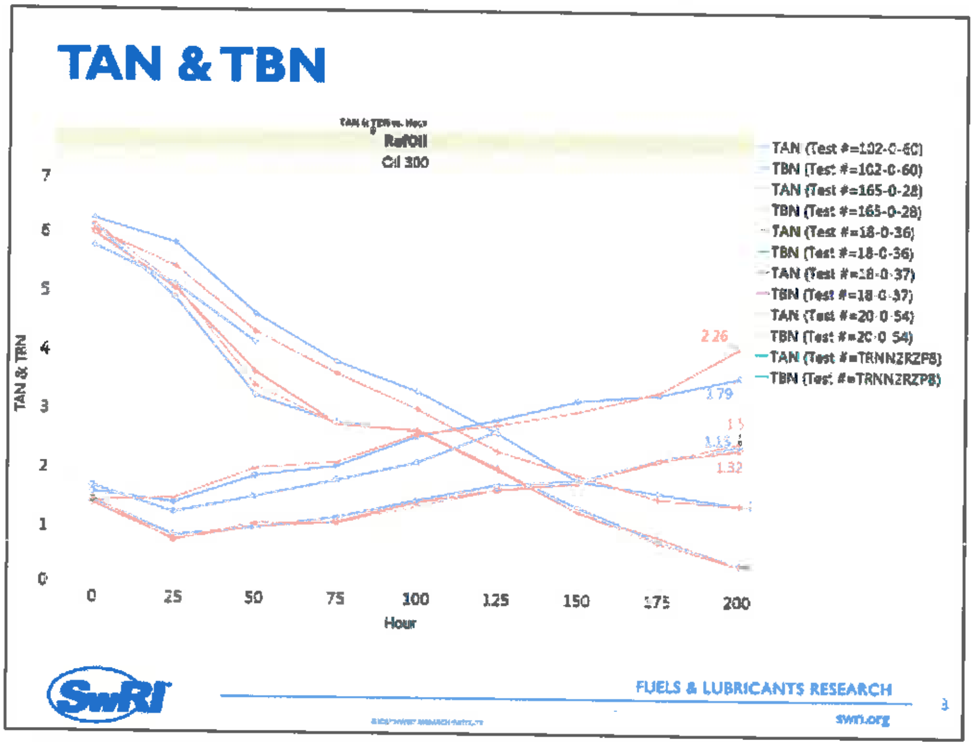
2.6.5. Intertek recommended removing all the summation fields (for the metrology measurements) from the test report.

2.6.5.1. There were no objections from the Surveillance Panel.

3. ADDITIONAL PLOTS FOR IVB DISCUSSION (SOUTHWEST):

3.1. This material was presented by Travis Kostan.

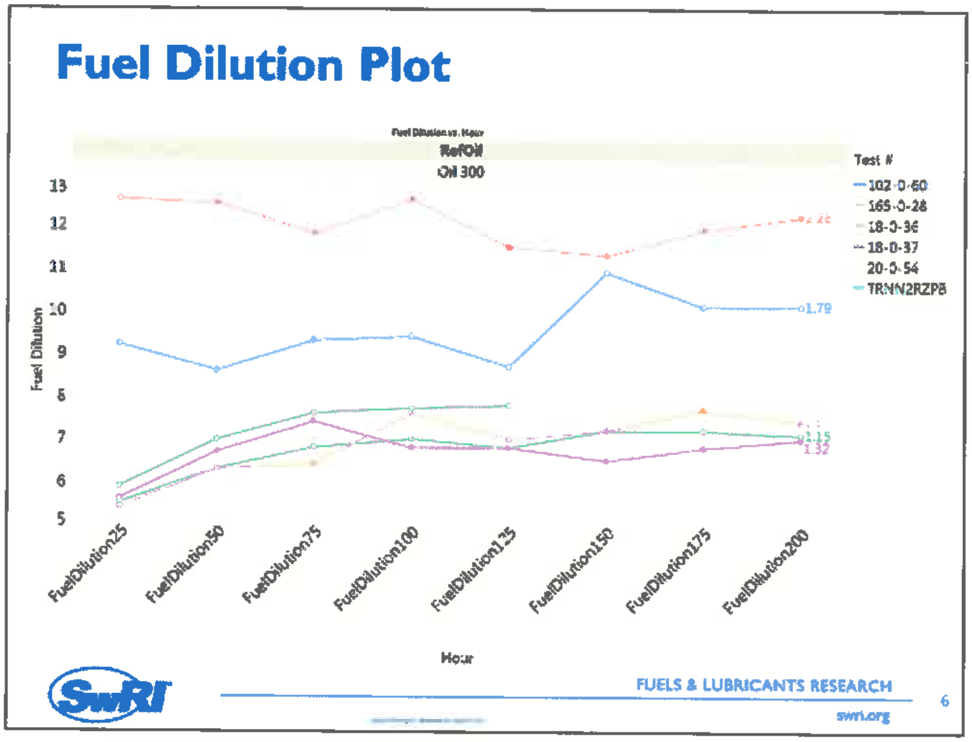
3.2. Slide #3:



3.2.1. The Lubrizol oil analysis data from their first (REO300) prove-out test is incomplete.

3.2.1.1. Lubrizol agreed to send out an update shortly.

3.3. Slide #6:



3.3.1. There are differences in fuel dilution between the tests.

3.3.1.1. The fuel dilution at Lubrizol and Southwest is similar.

3.3.2. There was a lot of discussion regarding whether these fuel dilution differences are real or an artifact of measurement technique.

3.3.3. Intertek and Southwest oil analysis round-robin:

3.3.3.1. Southwest and Intertek have already exchanged end-of-test oil samples to compare analysis results.

Fuel Dilution	Sample #1	Sample #2
Intertek	11.1%	10.1%
Southwest	7.9%	7.8%

3.3.3.2. This fuel dilution comparison indicates that measurement technique is contributing to lab-to-lab fuel dilution differences.

3.3.4. Shell asked whether there are any time limits on the fuel dilution measurements.

3.3.4.1. Intertek said that there are no time limits in the fuel dilution measurement procedure.

3.3.4.2. Shell believes that some of the light ends of the fuel may volatize out of the sample over time.

3.4. Oil Temperature vs. Volume Loss (Slides #7 and #8):

3.4.1. The R^2 between oil sump temperature and volume loss is 0.650.

3.4.2. The R^2 between oil gallery temperature and volume loss is 0.520.

3.4.3. Intertek, Southwest and Lubrizol agreed that all the test stands should be modified to improve oil temperature control before any more tests are run.

3.4.3.1. These modifications involve installing a blower and booster pump on the external oil system.

3.4.3.2. All four Intertek stands have had this improvement in place since 2014.

3.4.4. Toyota already suspected that the oil temperature could drive severity.

3.4.4.1. They agree that the problem should be fixed.

3.5. TAN-TBN Cross-Over:

3.5.1. The two San Antonio labs have a TAN-TBN cross-over with REO1012 that is about 25HRS apart.

3.5.2. *Is this due to the measurement technique?*

3.6. Kinematic Viscosity at 40°C:

3.6.1. The KV40 data is similar for all the laboratories.

3.6.2. This supports the assertion that the fuel dilution differences are due to measurement technique.

4. NEXT STEPS:

4.1. Update to Precision Matrix Design:

4.1.1. The statisticians kept the number of runs the same but updated the run order.

4.1.2. They also added the supplemental tests from the three dependent laboratories.

4.1.3. The statisticians reserve the right to change the run order of the supplemental tests if needed.

4.2. Toyota's Comments Regarding Timing:

4.2.1. The Industry is at a point where it is considering delaying GF-6 because of GF-5+.

4.2.2. Any further delays with the Sequence IVB will create serious problems in the Industry.

4.2.3. They propose the following:

4.2.3.1. Keep working on the oil gallery temperature control issues.

4.2.3.2. Use the one "good" Southwest stand in the Precision Matrix.

4.2.3.3. Use four of Intertek's stands instead of three.

4.2.3.4. The extra Southwest stand can be added later if it becomes viable.

4.2.4. Afton's Comments:

4.2.4.1. This group needs to proceed cautiously if it is going to pick and choose test stands.

4.2.4.2. They are concerned that the most severe test stand has the highest water.

4.2.5. Lubrizol's Comments:

4.2.5.1. Lubrizol agreed that Afton has valid concerns.

4.2.5.2. Lubrizol is also concerned about proceeding with the Precision Matrix before all the stands have had the oil temperature control improvements implemented.

4.2.5.3. To address the concerns of Afton and other members of the Surveillance Panel, Lubrizol will update its Golden Stand with the latest oil temperature control upgrades as soon as its current test completes.

4.2.5.3.1. This will allow Lubrizol to provide the Surveillance Panel with a set of results for REO300 and REO1012 both with and without the tighter temperature controls.

4.2.5.4. Lubrizol still must break-in its Precision Matrix engine, so the time necessary to add the oil temperature control modifications will likely limit Lubrizol to (2) Precision Matrix tests instead of the 3-4 previously planned tests.

4.2.6. Intertek's Comments:

4.2.6.1. Intertek confirmed that they will have (4) stands ready to start the Precision Matrix tomorrow.

4.2.6.2. Their 4th stand will be Stand #165.

4.2.6.2.1. This stand will be used "as a last resort".

4.2.6.2.2. This was the stand with the high water content.

4.2.7. Exxon's Comments:

4.2.7.1. Exxon asked why the one Southwest stand is being removed from the Precision Matrix and what needs to be done to get that stand back in.

4.2.7.2. Exxon is concerned that removing the one Southwest stand will limit the amount of data available for a lab-to-lab statistical comparison.

4.2.7.3. Southwest stated that there is a difference in performance between their two stands and they need to determine why.

4.2.7.4. Southwest is willing to provide Stand #20 as a 2nd Precision Matrix stand.

4.2.8. Afton's Comments:

4.2.8.1. *Will there be a planned pause during the middle of the Precision Matrix to review the results and operational data?*

4.2.8.2. Toyota stated that there are no plans to pause the Precision Matrix.

4.2.8.3. They will reconsider this if a major problem is encountered.

4.2.9. Lubrizol's Comments:

4.2.9.1. *Will the AOAP be looking for a vote from the Surveillance Panel before the Precision Matrix is restarted?*

4.2.9.2. Toyota stated that there will be no vote.

4.2.9.3. They are funding the Precision Matrix privately, so it is not attached to the MOA.

4.2.10. TMC's Comments:

4.2.10.1. They requested that all the labs complete their missing data transmission requirements.

4.2.10.2. It is important that all this data is posted since the Precision Matrix will be restarting.

4.3. Forward Action Plan:

4.3.1. Southwest will make two stands available for the Precision Matrix (Stand #18 and Stand #20).

4.3.2. Intertek will have Stand #165 available as a back-up in case it is needed.

4.3.3. Southwest, Lubrizol and Exxon will update their stands with the latest oil temperature control hardware as soon as possible.

4.3.4. Intertek will start the Precision Matrix immediately.

4.3.5. Southwest will start the Precision Matrix as soon as its two stands are modified.

4.3.6. Lubrizol and Exxon will be delayed because they must break-in their Precision Matrix engines.

Action Items	Person responsible	Completion Date

Follow-up Notes/Updates	Initials	Date Added

Attendees	Organization	Contact Information
See attachment.		

IVB Keyence and PDI Correlation Analysis

Statistics Group

October 10, 2017

Statistics Group

- Doyle Boese, Infineum
- Jo Martinez, Chevron Oronite
- Kevin O'Malley, Lubrizol
- Martin Chadwick, Intertek
- Richard Grundza, TMC
- Lisa Dingwell, Afton
- Todd Dvorak, Afton
- Travis Kostan, SwRI

Conclusions and Recommendation

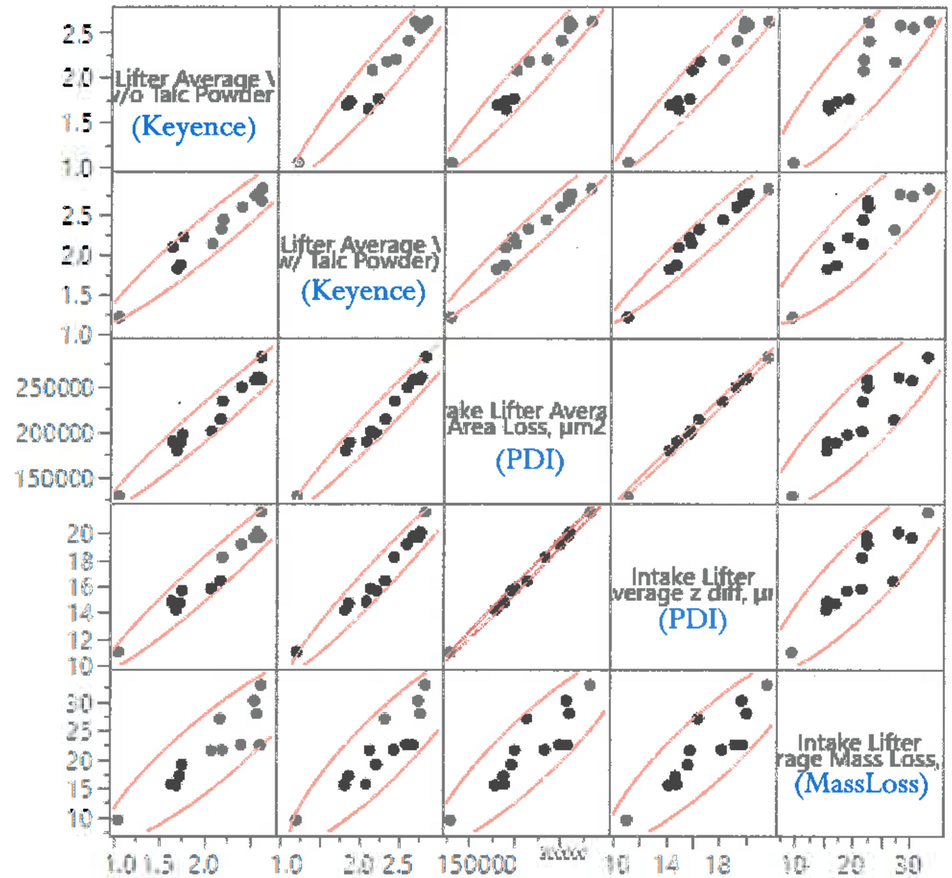
- Conclusions are valid in the range of 1.2-2.8 mm3 Intake Lifter Volume Loss as measured by Keyence with Talc
- Keyence measurements are highly correlated with PDI measurements.
- Keyence measurements are correlated with Mass Loss.

Recommendation:

- PDI lifter area loss and lifter z diff wear measurements, as well as the lifter mass loss measurements, can be eliminated.

Intake Lifter

- Keyence Intake Lifter Volume Loss With and Without Talc Powder are highly correlated with PDI Intake Lifter Area Loss, Average z Diff and Mass Loss (p-values<0.0001)

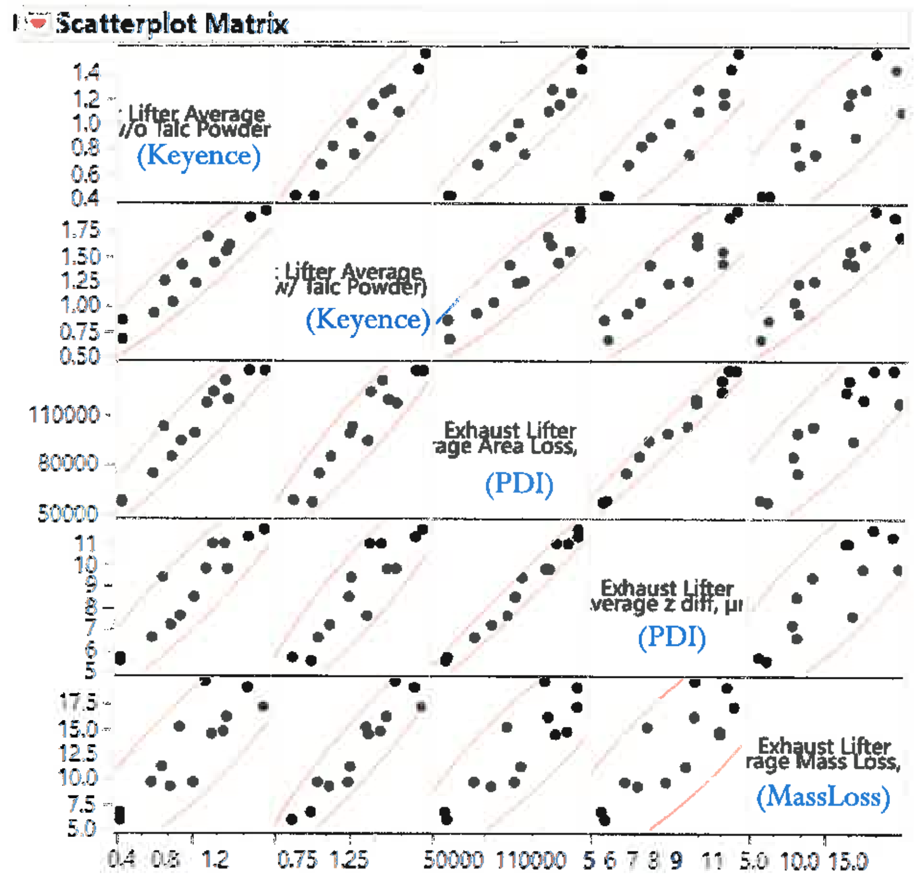


Correlations

	Intake Lifter Average Volume Loss (w/o Talc Powder), mm3	Intake Lifter Average Volume Loss (w/ Talc Powder), mm3
Intake Lifter Average Volume Loss (w/o Talc Powder), mm3	1.0000	0.9670
Intake Lifter Average Volume Loss (w/ Talc Powder), mm3	0.9670	1.0000
Intake Lifter Average Area Loss, µm2	0.9772	0.9808
Intake Lifter Average z diff, µm	0.9725	0.9773
Intake Lifter Average Mass Loss, mg	0.9025	0.8961

Exhaust Lifter

- Keyence Exhaust Lifter Volume Loss With and Without Talc Powder are highly correlated with PDI Exhaust Lifter Area Loss, Average z Diff and Mass Loss (p-values<0.0001)



Correlations

	Exhaust Lifter Average Volume Loss (w/o Talc Powder), mm3	Exhaust Lifter Average Volume Loss (w/ Talc Powder), mm3
Exhaust Lifter Average Volume Loss (w/o Talc Powder), mm3	1.0000	0.9511
Exhaust Lifter Average Volume Loss (w/ Talc Powder), mm3	0.9511	1.0000
Exhaust Lifter Average Area Loss, µm2	0.9623	0.9469
Exhaust Lifter Average z diff, µm	0.9296	0.9121
Exhaust Lifter Average Mass Loss, mg	0.8588	0.9483

Abbreviations used in the Individual Lifter Correlations

- IVLKT – Intake Volume Loss Keyence with Talc
- IVLK – Intake Volume Loss Keyence without Talc
- IALP – Intake Area Loss PDI
- IMZDP – Intake Max Z Diff PDI
- IML – Intake Mass Loss
- EVLKT – Exhaust Volume Loss Keyence with Talc
- EVLK – Exhaust Volume Loss Keyence without Talc
- EALP – Exhaust Area Loss PDI
- EMZDP – Exhaust Max Z Diff PDI
- EML – Exhaust Mass Loss
- 1-8 --- Lifters 1 to 8

Intake Lifter 1

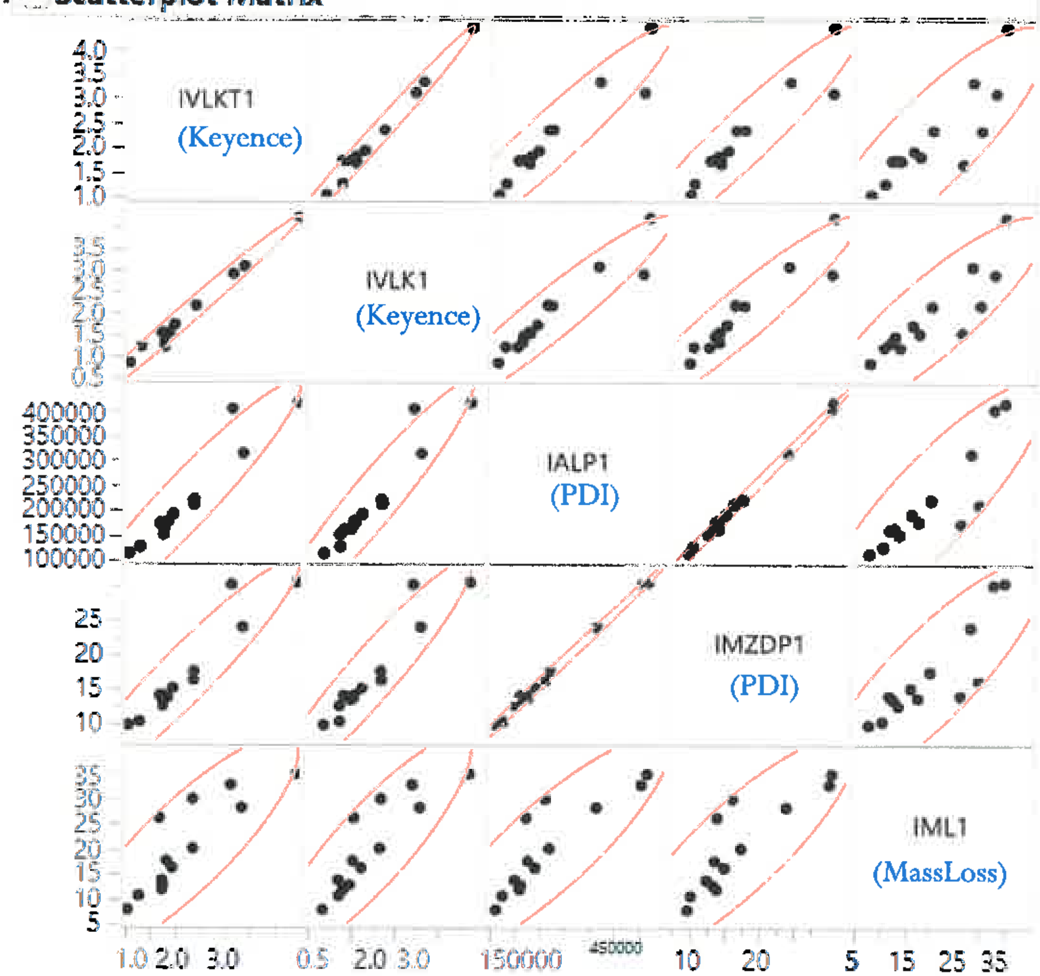
Correlations

	IVLKT1	IVLK1	IALP1	IMZDP1	IML1
IVLKT1	1.0000	0.9915	0.9500	0.9466	0.8506
IVLK1	0.9915	1.0000	0.9515	0.9447	0.8726
IALP1	0.9500	0.9515	1.0000	0.9984	0.8653
IMZDP1	0.9466	0.9447	0.9984	1.0000	0.8553
IML1	0.8506	0.8726	0.8653	0.8553	1.0000

Correlation Probability

	IVLKT1	IVLK1	IALP1	IMZDP1	IML1
IVLKT1	<.0001	<.0001	<.0001	<.0001	0.0002
IVLK1	<.0001	<.0001	<.0001	<.0001	<.0001
IALP1	<.0001	<.0001	<.0001	<.0001	0.0001
IMZDP1	<.0001	<.0001	<.0001	<.0001	0.0002
IML1	0.0002	<.0001	0.0001	0.0002	<.0001

Scatterplot Matrix



Intake Lifter 2

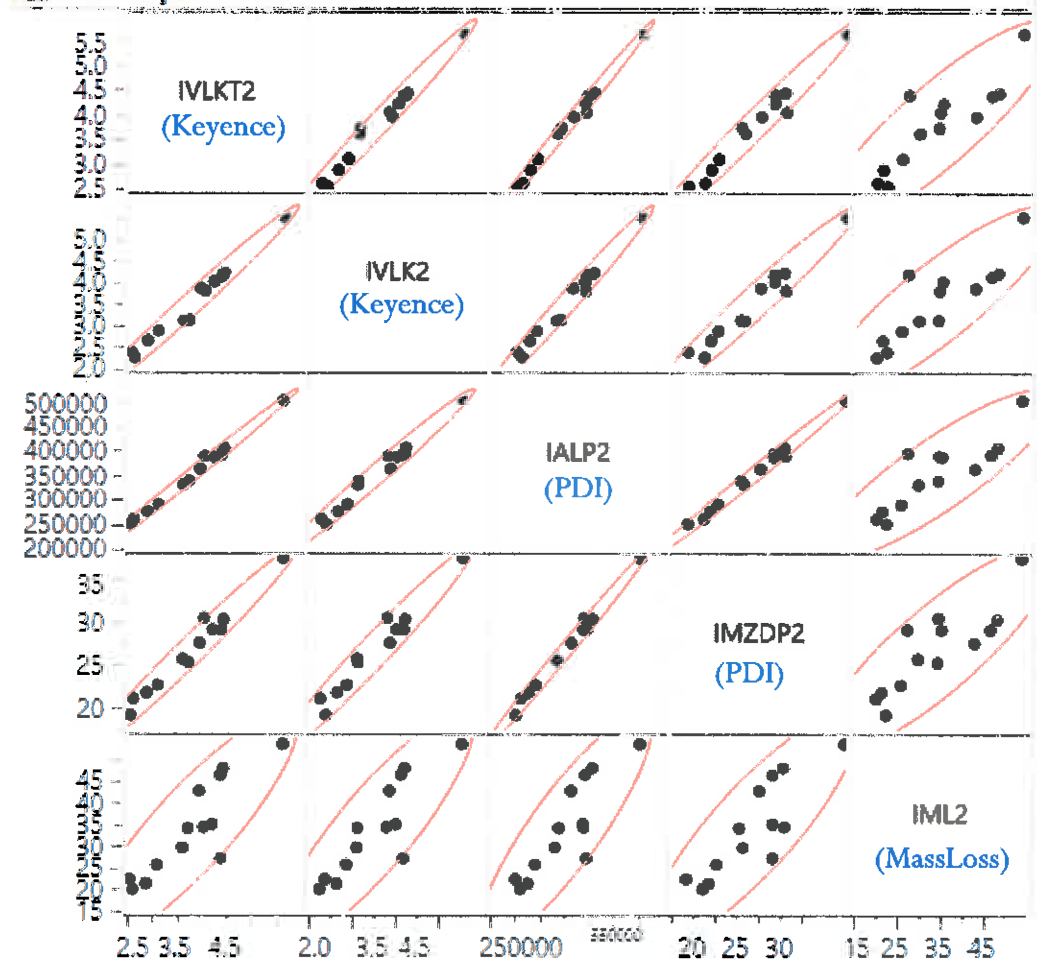
Correlations

	IVLKT2	IVLK2	IALP2	IMZDP2	IML2
IVLKT2	1.0000	0.9883	0.9956	0.9829	0.8709
IVLK2	0.9883	1.0000	0.9882	0.9763	0.8684
IALP2	0.9956	0.9882	1.0000	0.9944	0.8662
IMZDP2	0.9829	0.9763	0.9944	1.0000	0.8528
IML2	0.8709	0.8684	0.8662	0.8528	1.0000

Correlation Probability

	IVLKT2	IVLK2	IALP2	IMZDP2	IML2
IVLKT2	<.0001	<.0001	<.0001	<.0001	0.0001
IVLK2	<.0001	<.0001	<.0001	<.0001	0.0001
IALP2	<.0001	<.0001	<.0001	<.0001	0.0001
IMZDP2	<.0001	<.0001	<.0001	<.0001	0.0002
IML2	0.0001	0.0001	0.0001	0.0002	<.0001

Scatterplot Matrix



Intake Lifter 3

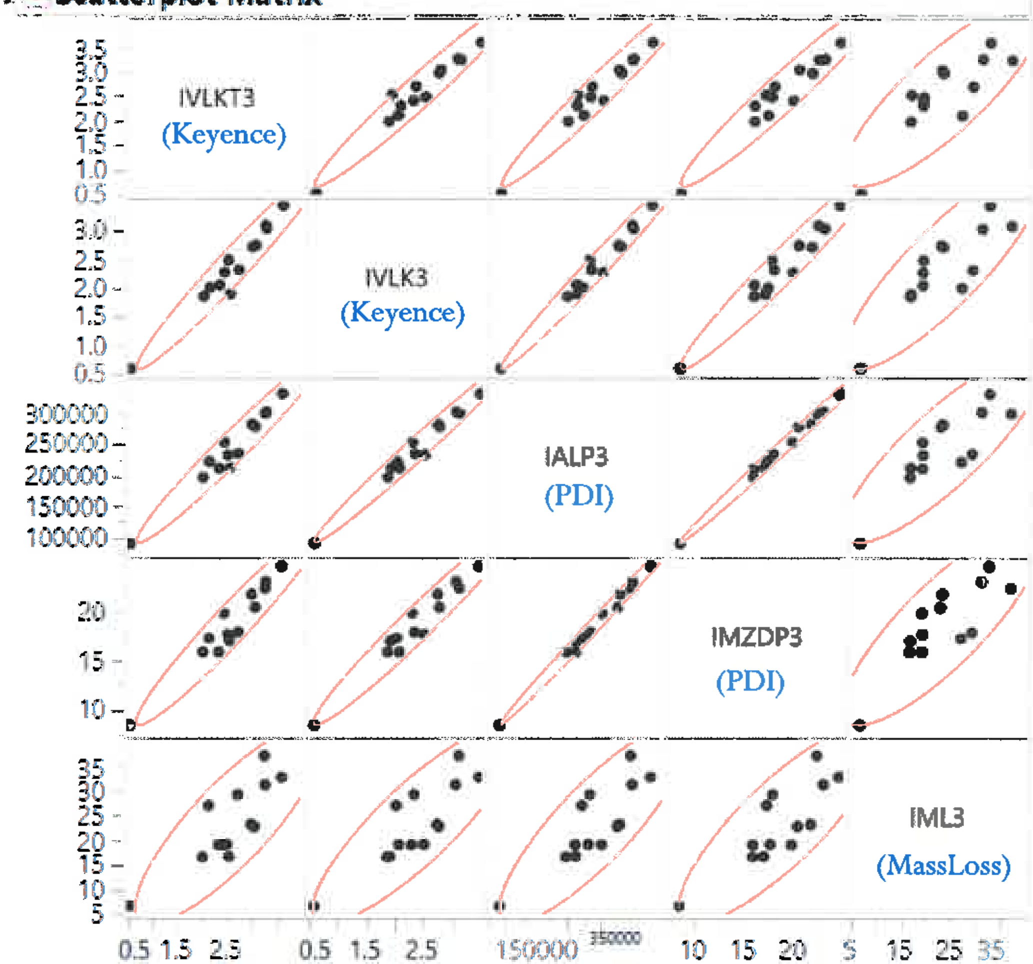
Correlations

	IVLKT3	IVLK3	IALP3	IMZDP3	IML3
IVLKT3	1.0000	0.9746	0.9754	0.9653	0.8330
IVLK3	0.9746	1.0000	0.9877	0.9750	0.8554
IALP3	0.9754	0.9877	1.0000	0.9957	0.8459
IMZDP3	0.9653	0.9750	0.9957	1.0000	0.8329
IML3	0.8330	0.8554	0.8459	0.8329	1.0000

Correlation Probability

	IVLKT3	IVLK3	IALP3	IMZDP3	IML3
IVLKT3	<.0001	<.0001	<.0001	<.0001	0.0004
IVLK3	<.0001	<.0001	<.0001	<.0001	0.0002
IALP3	<.0001	<.0001	<.0001	<.0001	0.0003
IMZDP3	<.0001	<.0001	<.0001	<.0001	0.0004
IML3	0.0004	0.0002	0.0003	0.0004	<.0001

Scatterplot Matrix



Intake Lifter 4

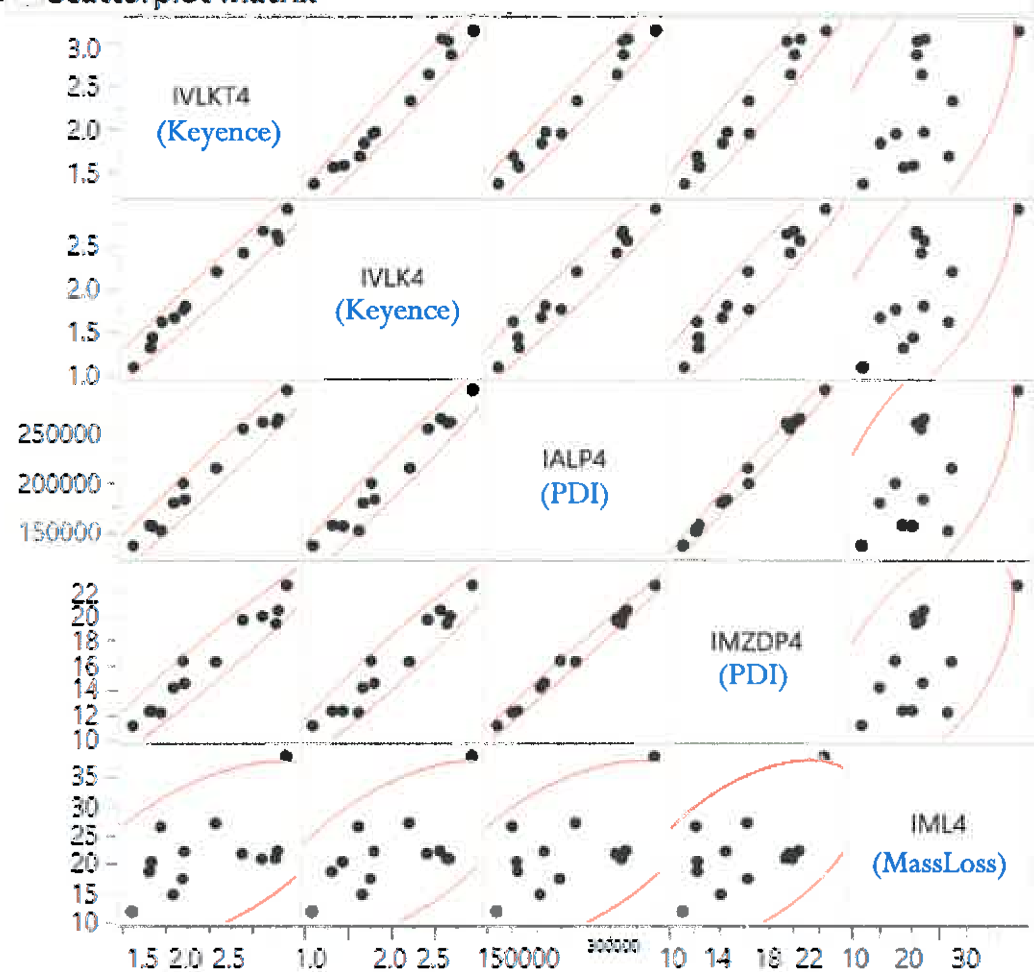
Correlations

	IVLKT4	IVLK4	IALP4	IMZDP4	IML4
IVLKT4	1.0000	0.9868	0.9856	0.9737	0.5586
IVLK4	0.9868	1.0000	0.9812	0.9704	0.6311
IALP4	0.9856	0.9812	1.0000	0.9962	0.5593
IMZDP4	0.9737	0.9704	0.9962	1.0000	0.5514
IML4	0.5586	0.6311	0.5593	0.5514	1.0000

Correlation Probability

	IVLKT4	IVLK4	IALP4	IMZDP4	IML4
IVLKT4	<.0001	<.0001	<.0001	<.0001	0.0472
IVLK4	<.0001	<.0001	<.0001	<.0001	0.0207
IALP4	<.0001	<.0001	<.0001	<.0001	0.0469
IMZDP4	<.0001	<.0001	<.0001	<.0001	0.0508
IML4	0.0472	0.0207	0.0469	0.0508	<.0001

Scatterplot Matrix



Intake Lifter 5

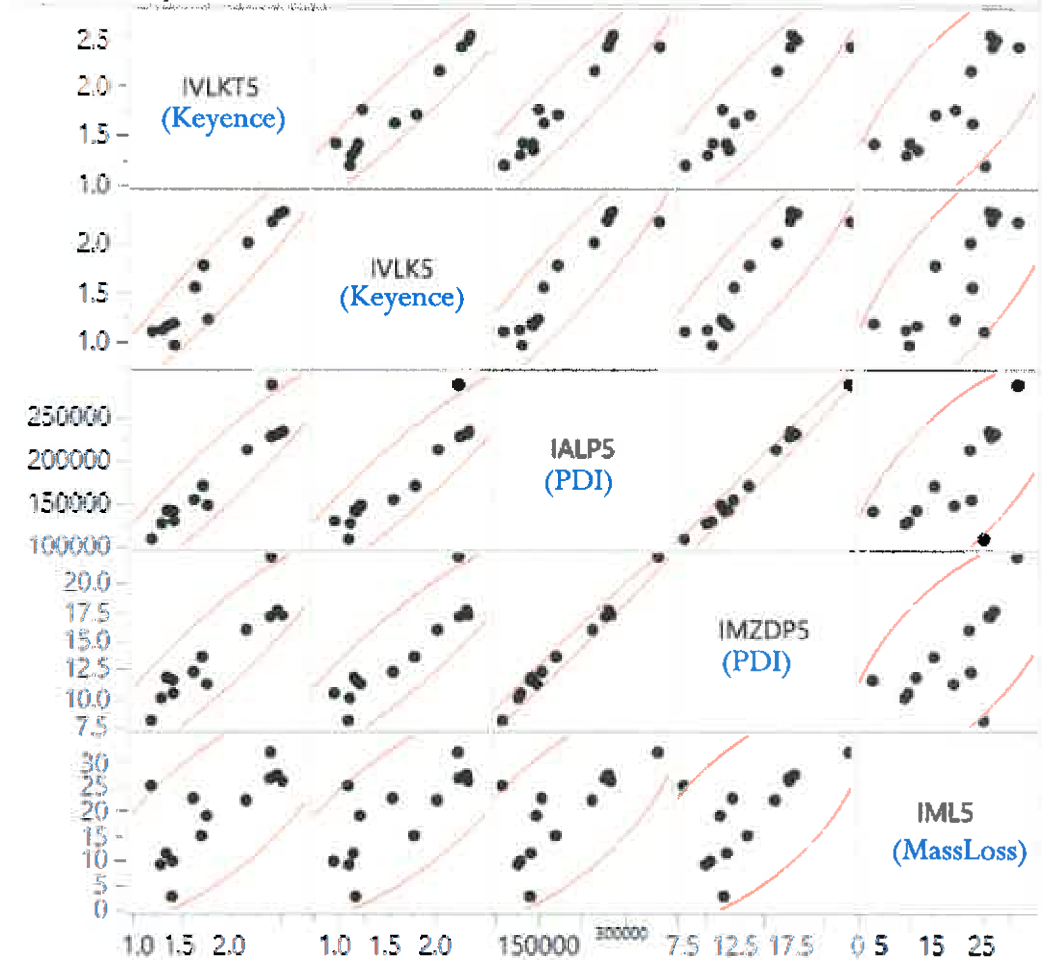
Correlations

	IVLKT5	IVLK5	IALP5	IMZDP5	IML5
IVLKT5	1.0000	0.9576	0.9430	0.9118	0.7298
IVLK5	0.9576	1.0000	0.9319	0.9063	0.7467
IALP5	0.9430	0.9319	1.0000	0.9938	0.7094
IMZDP5	0.9118	0.9063	0.9938	1.0000	0.6594
IML5	0.7298	0.7467	0.7094	0.6594	1.0000

Correlation Probability

	IVLKT5	IVLK5	IALP5	IMZDP5	IML5
IVLKT5	<.0001	<.0001	<.0001	<.0001	0.0046
IVLK5	<.0001	<.0001	<.0001	<.0001	0.0034
IALP5	<.0001	<.0001	<.0001	<.0001	0.0066
IMZDP5	<.0001	<.0001	<.0001	<.0001	0.0142
IML5	0.0046	0.0034	0.0066	0.0142	<.0001

Scatterplot Matrix



Intake Lifter 6

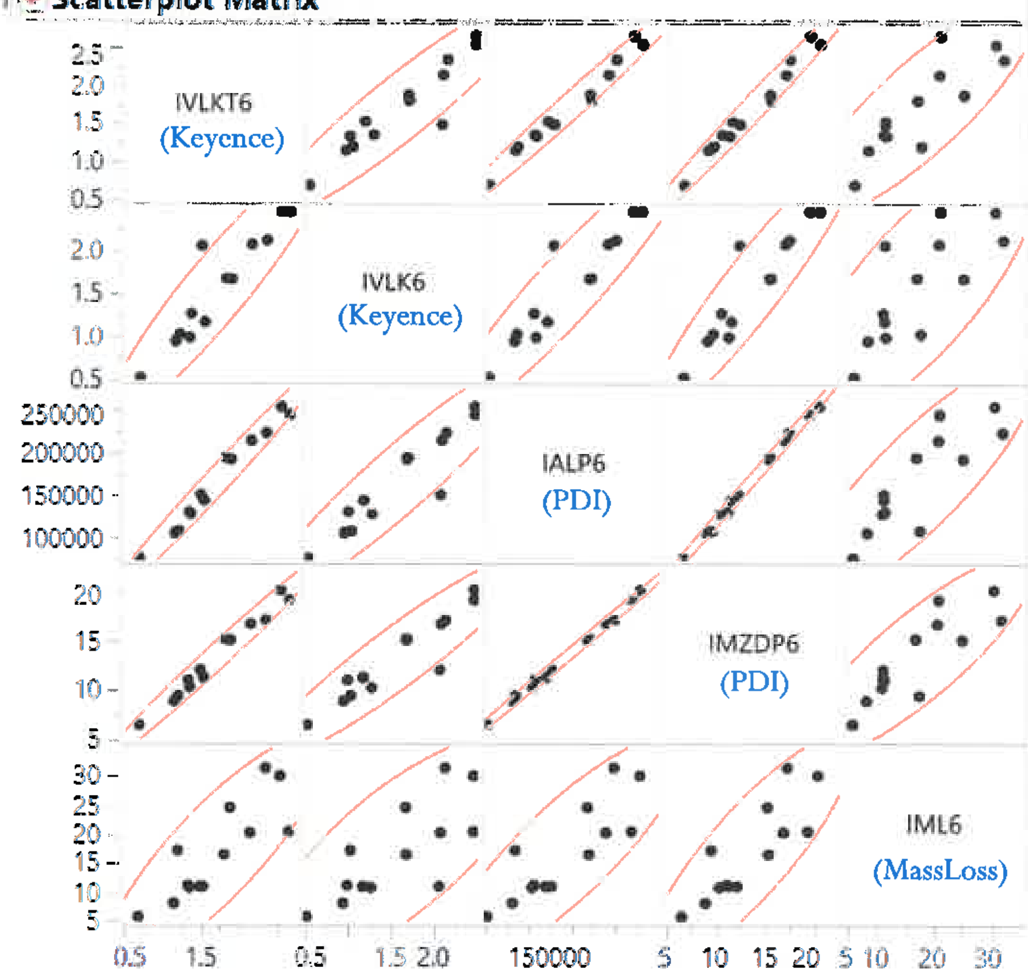
Correlations

	IVLKT6	IVLK6	IALP6	IMZDP6	IML6
IVLKT6	1.0000	0.9321	0.9877	0.9872	0.8458
IVLK6	0.9321	1.0000	0.9362	0.9346	0.7568
IALP6	0.9877	0.9362	1.0000	0.9978	0.8496
IMZDP6	0.9872	0.9346	0.9978	1.0000	0.8523
IML6	0.8458	0.7568	0.8496	0.8523	1.0000

Correlation Probability

	IVLKT6	IVLK6	IALP6	IMZDP6	IML6
IVLKT6	<.0001	<.0001	<.0001	<.0001	0.0003
IVLK6	<.0001	<.0001	<.0001	<.0001	0.0027
IALP6	<.0001	<.0001	<.0001	<.0001	0.0002
IMZDP6	<.0001	<.0001	<.0001	<.0001	0.0002
IML6	0.0003	0.0027	0.0002	0.0002	<.0001

Scatterplot Matrix



Intake Lifter 7

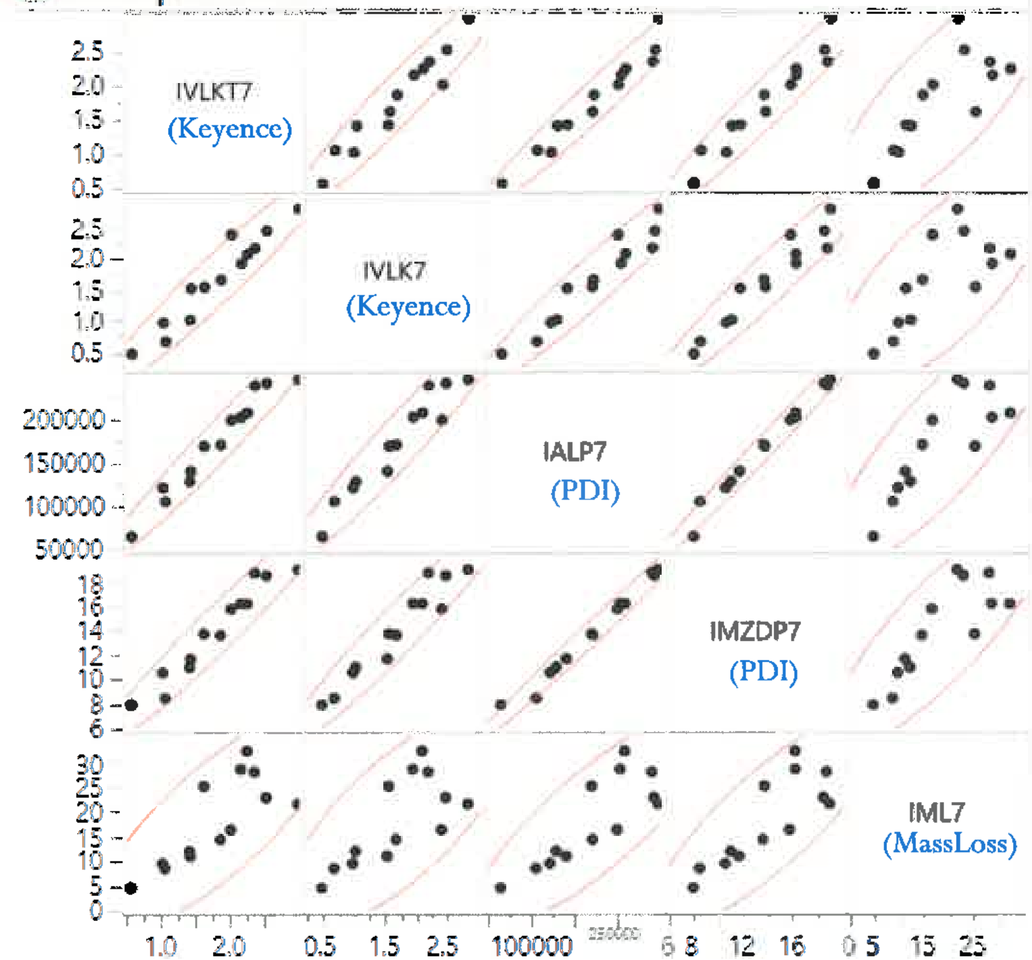
Correlations

	IVLKT7	IVLK7	IALP7	IMZDP7	IML7
IVLKT7	1.0000	0.9617	0.9775	0.9679	0.7788
IVLK7	0.9617	1.0000	0.9630	0.9616	0.7248
IALP7	0.9775	0.9630	1.0000	0.9923	0.8270
IMZDP7	0.9679	0.9616	0.9923	1.0000	0.8278
IML7	0.7788	0.7248	0.8270	0.8278	1.0000

Correlation Probability

	IVLKT7	IVLK7	IALP7	IMZDP7	IML7
IVLKT7	<.0001	<.0001	<.0001	<.0001	0.0017
IVLK7	<.0001	<.0001	<.0001	<.0001	0.0051
IALP7	<.0001	<.0001	<.0001	<.0001	0.0005
IMZDP7	<.0001	<.0001	<.0001	<.0001	0.0005
IML7	0.0017	0.0051	0.0005	0.0005	<.0001

Scatterplot Matrix



Intake Lifter 8

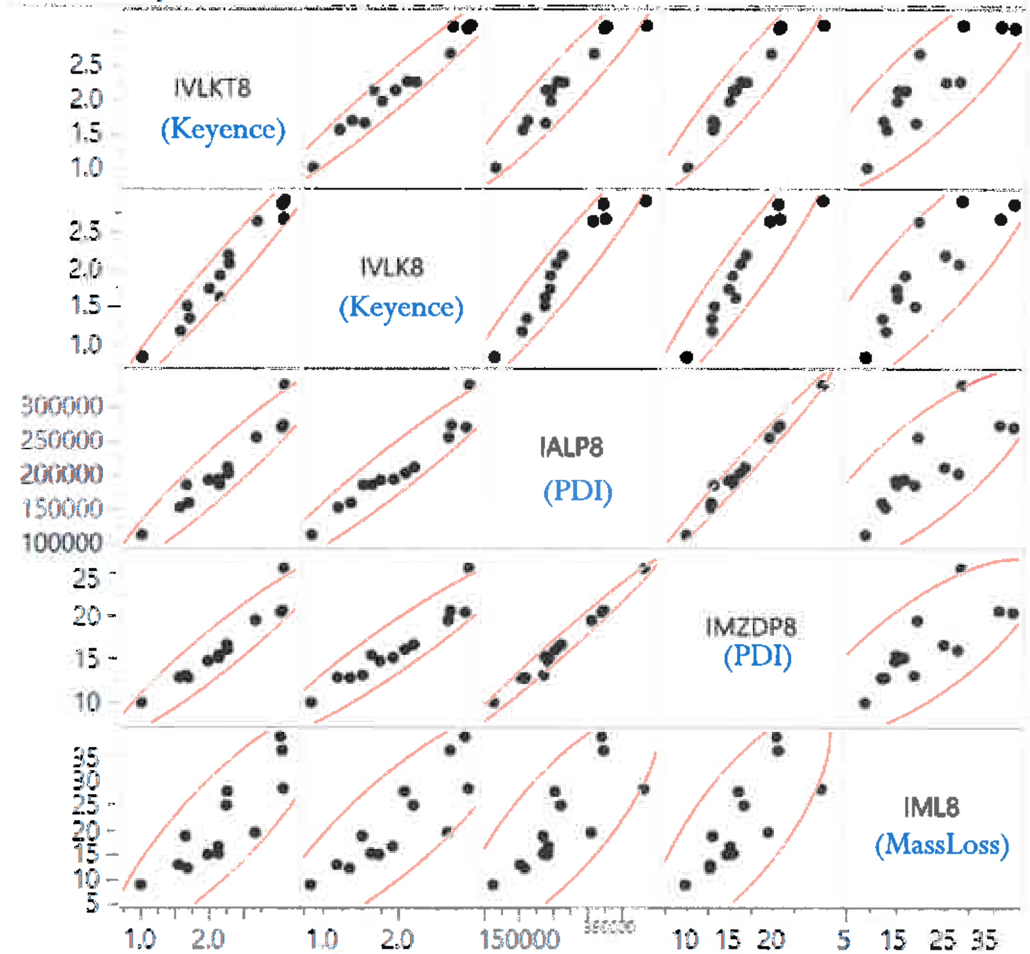
Correlations

	IVLKT8	IVLK8	IALP8	IMZDP8	IML8
IVLKT8	1.0000	0.9790	0.9556	0.9533	0.8623
IVLK8	0.9790	1.0000	0.9610	0.9491	0.8579
IALP8	0.9556	0.9610	1.0000	0.9902	0.7983
IMZDP8	0.9533	0.9491	0.9902	1.0000	0.7747
IML8	0.8623	0.8579	0.7983	0.7747	1.0000

Correlation Probability

	IVLKT8	IVLK8	IALP8	IMZDP8	IML8
IVLKT8	<.0001	<.0001	<.0001	<.0001	0.0001
IVLK8	<.0001	<.0001	<.0001	<.0001	0.0002
IALP8	<.0001	<.0001	<.0001	<.0001	0.0011
IMZDP8	<.0001	<.0001	<.0001	<.0001	0.0019
IML8	0.0001	0.0002	0.0011	0.0019	<.0001

Scatterplot Matrix



Exhaust Lifter 1

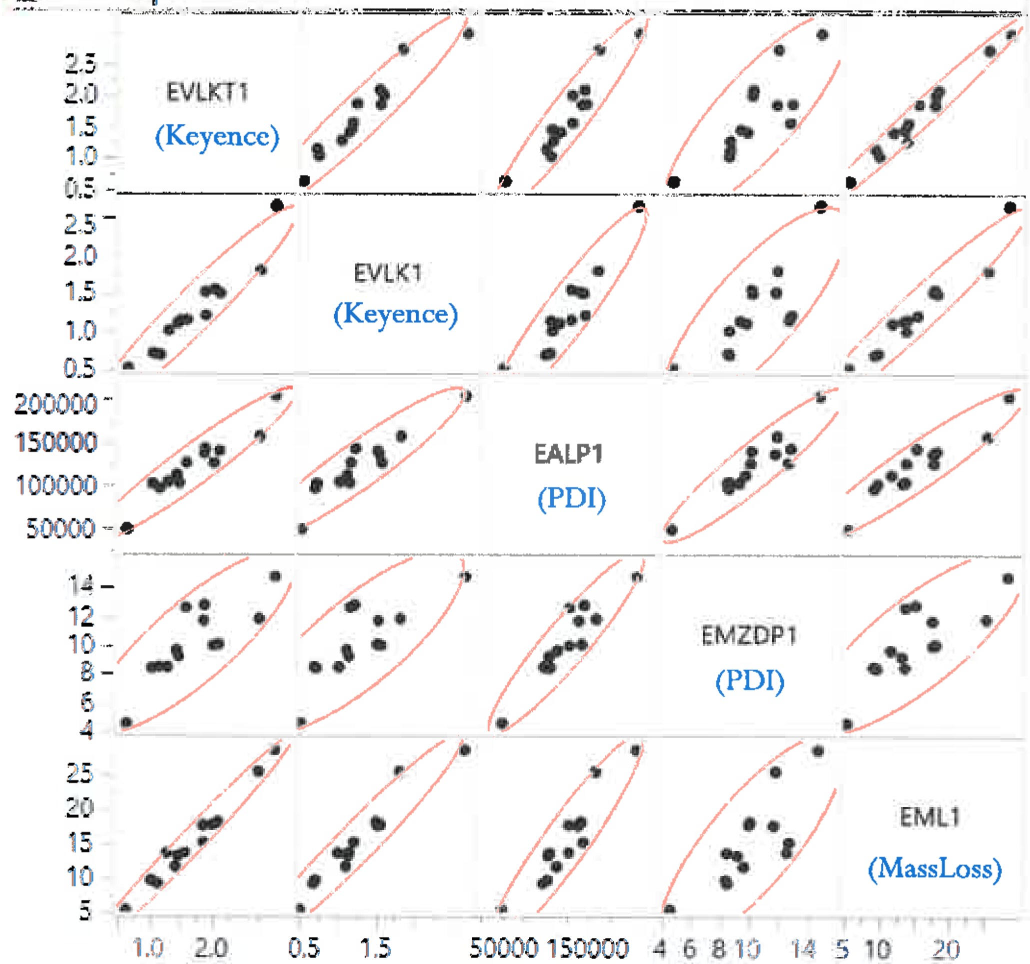
Correlations

	EVLKT1	EVLK1	EALP1	EMZDP1	EML1
EVLKT1	1.0000	0.9573	0.9477	0.8299	0.9862
EVLK1	0.9573	1.0000	0.9329	0.8029	0.9672
EALP1	0.9477	0.9329	1.0000	0.9313	0.9367
EMZDP1	0.8299	0.8029	0.9313	1.0000	0.8021
EML1	0.9862	0.9672	0.9367	0.8021	1.0000

Correlation Probability

	EVLKT1	EVLK1	EALP1	EMZDP1	EML1
EVLKT1	<.0001	<.0001	<.0001	0.0004	<.0001
EVLK1	<.0001	<.0001	<.0001	0.0010	<.0001
EALP1	<.0001	<.0001	<.0001	<.0001	<.0001
EMZDP1	0.0004	0.0010	<.0001	<.0001	0.0010
EML1	<.0001	<.0001	<.0001	0.0010	<.0001

Scatterplot Matrix



Exhaust Lifter 2

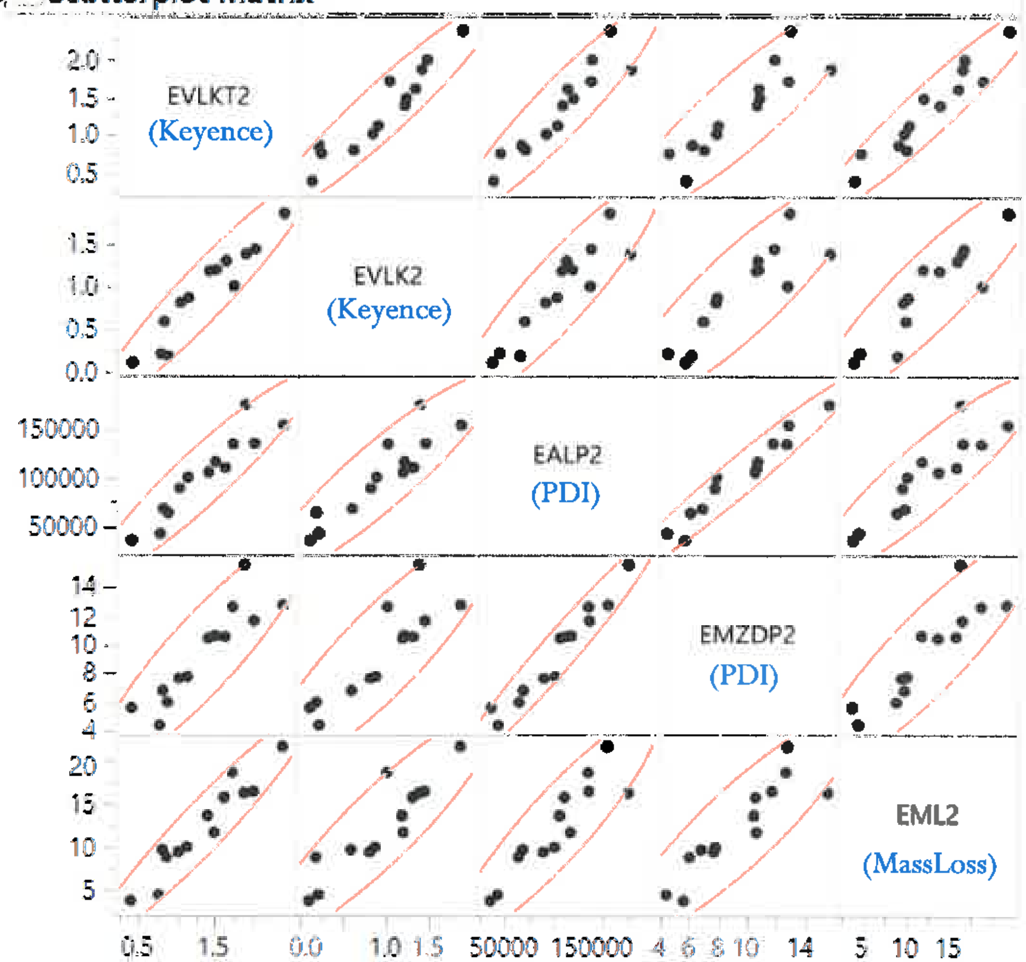
Correlations

	EVLKT2	EVLK2	EALP2	EMZDP2	EML2
EVLKT2	1.0000	0.9467	0.9340	0.8970	0.9539
EVLK2	0.9467	1.0000	0.9094	0.8738	0.9021
EALP2	0.9340	0.9094	1.0000	0.9724	0.9061
EMZDP2	0.8970	0.8738	0.9724	1.0000	0.8913
EML2	0.9539	0.9021	0.9061	0.8913	1.0000

Correlation Probability

	EVLKT2	EVLK2	EALP2	EMZDP2	EML2
EVLKT2	<.0001	<.0001	<.0001	<.0001	<.0001
EVLK2	<.0001	<.0001	<.0001	<.0001	<.0001
EALP2	<.0001	<.0001	<.0001	<.0001	<.0001
EMZDP2	<.0001	<.0001	<.0001	<.0001	<.0001
EML2	<.0001	<.0001	<.0001	<.0001	<.0001

Scatterplot Matrix



Exhaust Lifter 3

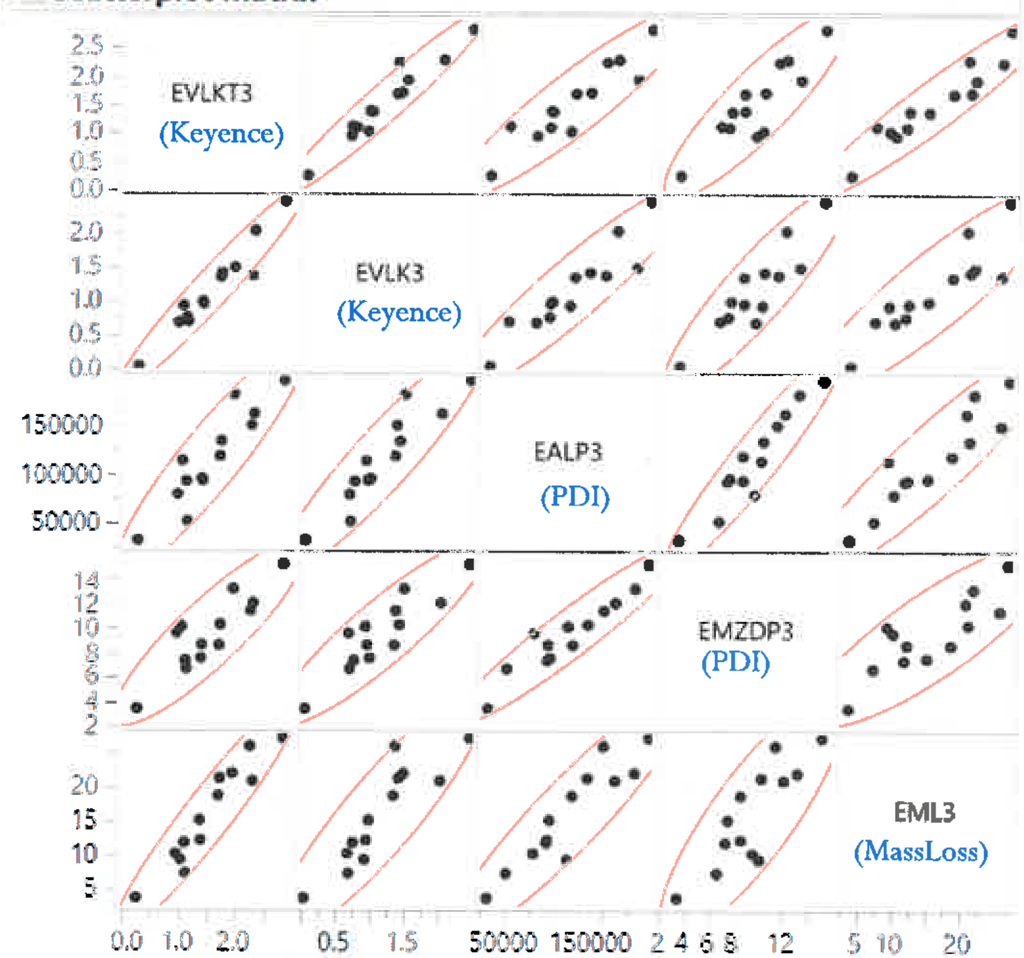
Correlations

	EVLKT3	EVLK3	EALP3	EMZDP3	EML3
EVLKT3	1.0000	0.9656	0.9178	0.8810	0.9498
EVLK3	0.9656	1.0000	0.9265	0.8980	0.8925
EALP3	0.9178	0.9265	1.0000	0.9482	0.9214
EMZDP3	0.8810	0.8980	0.9482	1.0000	0.8400
EML3	0.9498	0.8925	0.9214	0.8400	1.0000

Correlation Probability

	EVLKT3	EVLK3	EALP3	EMZDP3	EML3
EVLKT3	<.0001	<.0001	<.0001	<.0001	<.0001
EVLK3	<.0001	<.0001	<.0001	<.0001	<.0001
EALP3	<.0001	<.0001	<.0001	<.0001	<.0001
EMZDP3	<.0001	<.0001	<.0001	<.0001	0.0003
EML3	<.0001	<.0001	<.0001	0.0003	<.0001

Scatterplot Matrix



Exhaust Lifter 4

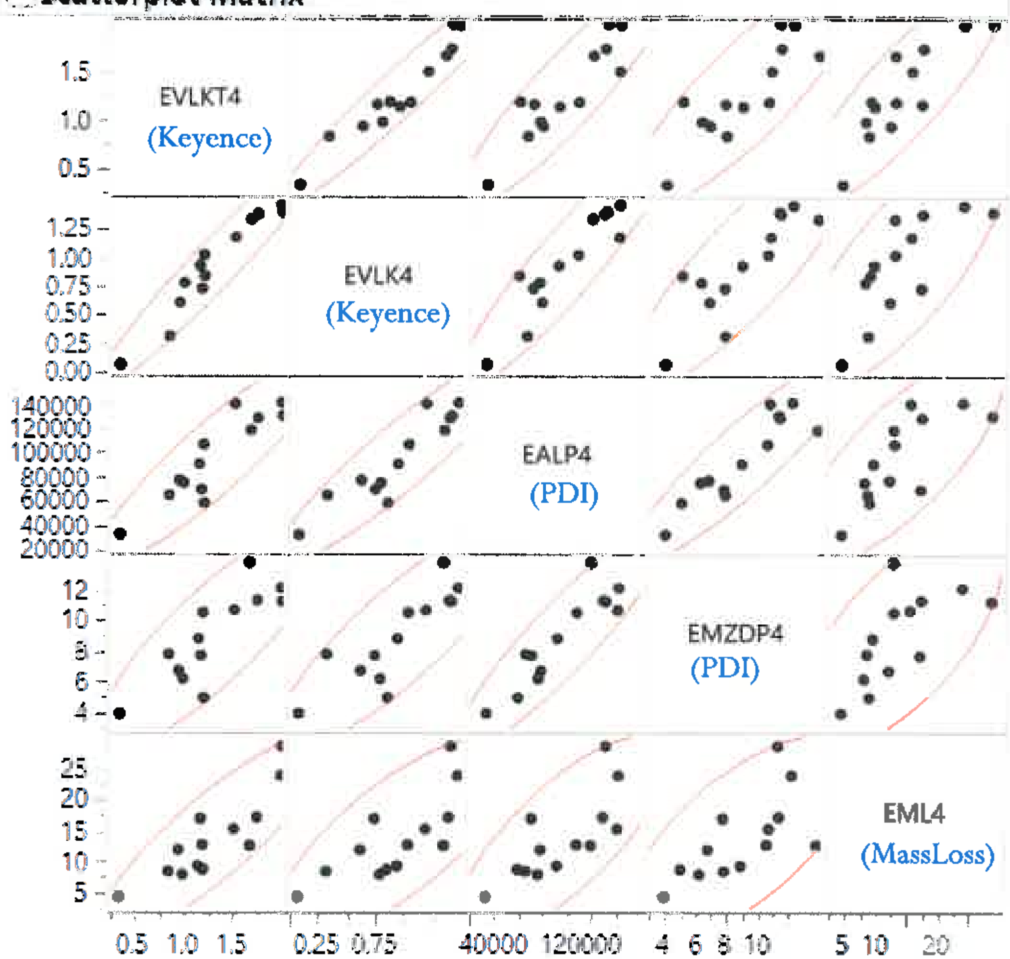
Correlations

	EVLKT4	EVLK4	EALP4	EMZDP4	EML4
EVLKT4	1.0000	0.9630	0.9040	0.8428	0.8652
EVLK4	0.9630	1.0000	0.9213	0.8528	0.7548
EALP4	0.9040	0.9213	1.0000	0.9094	0.7605
EMZDP4	0.8428	0.8528	0.9094	1.0000	0.6659
EML4	0.8652	0.7548	0.7605	0.6659	1.0000

Correlation Probability

	EVLKT4	EVLK4	EALP4	EMZDP4	EML4
EVLKT4	<.0001	<.0001	<.0001	0.0003	0.0001
EVLK4	<.0001	<.0001	<.0001	0.0002	0.0029
EALP4	<.0001	<.0001	<.0001	<.0001	0.0025
EMZDP4	0.0003	0.0002	<.0001	<.0001	0.0130
EML4	0.0001	0.0029	0.0025	0.0130	<.0001

Scatterplot Matrix



Exhaust Lifter 5

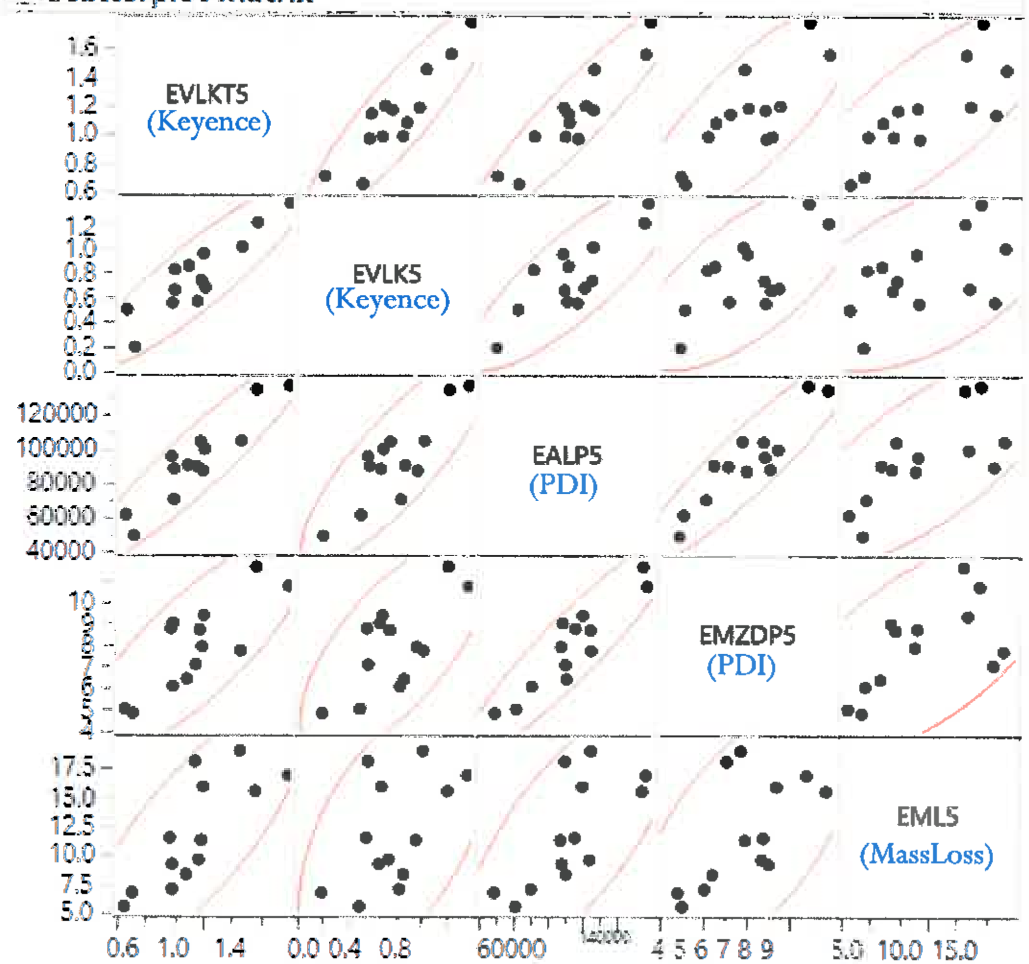
Correlations

	EVLKT5	EVLK5	EALP5	EMZDP5	EML5
EVLKT5	1.0000	0.9021	0.9298	0.7974	0.7870
EVLK5	0.9021	1.0000	0.8365	0.6898	0.5243
EALP5	0.9298	0.8365	1.0000	0.9206	0.7161
EMZDP5	0.7974	0.6898	0.9206	1.0000	0.6148
EML5	0.7870	0.5243	0.7161	0.6148	1.0000

Correlation Probability

	EVLKT5	EVLK5	EALP5	EMZDP5	EML5
EVLKT5	<.0001	<.0001	<.0001	0.0011	0.0014
EVLK5	<.0001	<.0001	0.0004	0.0091	0.0659
EALP5	<.0001	0.0004	<.0001	<.0001	0.0059
EMZDP5	0.0011	0.0091	<.0001	<.0001	0.0253
EML5	0.0014	0.0659	0.0059	0.0253	<.0001

Scatterplot Matrix



Exhaust Lifter 6

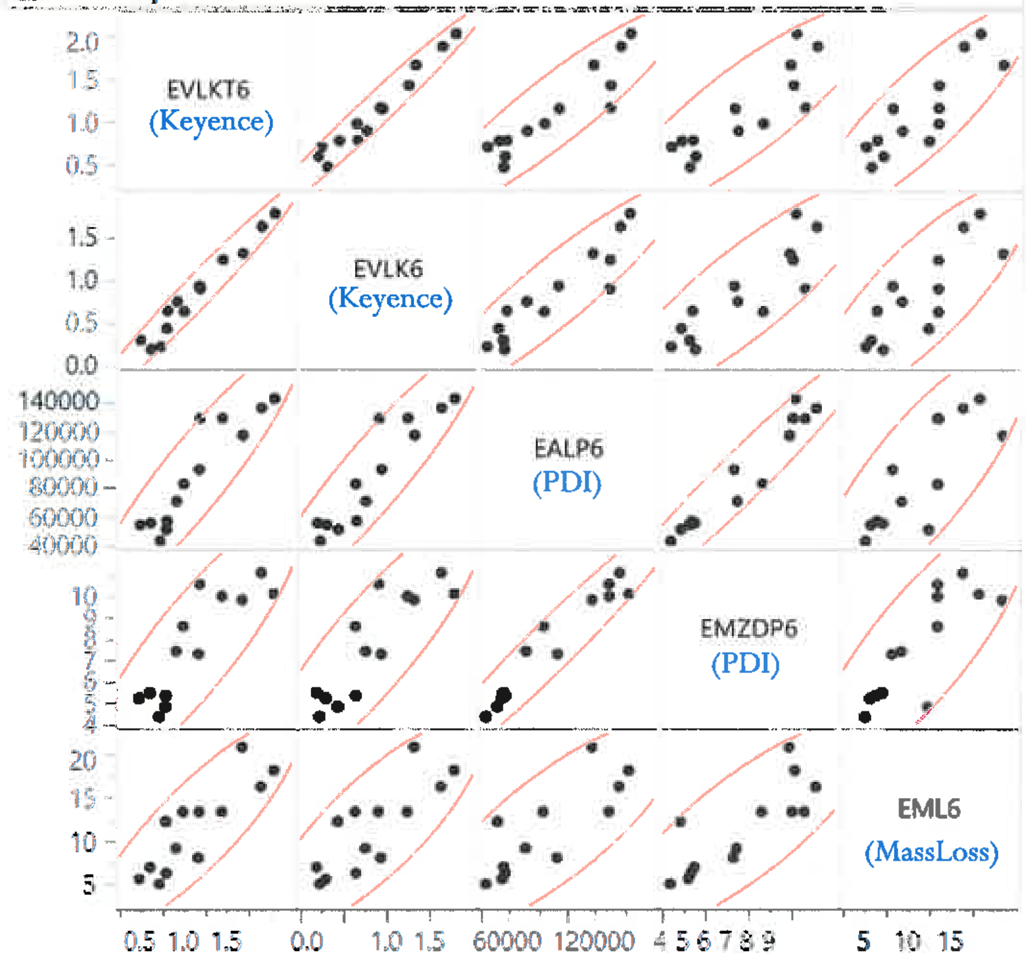
Correlations

	EVLKT6	EVLK6	EALP6	EMZDP6	EML6
EVLKT6	1.0000	0.9794	0.9171	0.8610	0.8589
EVLK6	0.9794	1.0000	0.9243	0.8683	0.8124
EALP6	0.9171	0.9243	1.0000	0.9656	0.8048
EMZDP6	0.8610	0.8683	0.9656	1.0000	0.8178
EML6	0.8589	0.8124	0.8048	0.8178	1.0000

Correlation Probability

	EVLKT6	EVLK6	EALP6	EMZDP6	EML6
EVLKT6	<.0001	<.0001	<.0001	0.0002	0.0002
EVLK6	<.0001	<.0001	<.0001	0.0001	0.0007
EALP6	<.0001	<.0001	<.0001	<.0001	0.0009
EMZDP6	0.0002	0.0001	<.0001	<.0001	0.0006
EML6	0.0002	0.0007	0.0009	0.0006	<.0001

Scatterplot Matrix



Exhaust Lifter 7

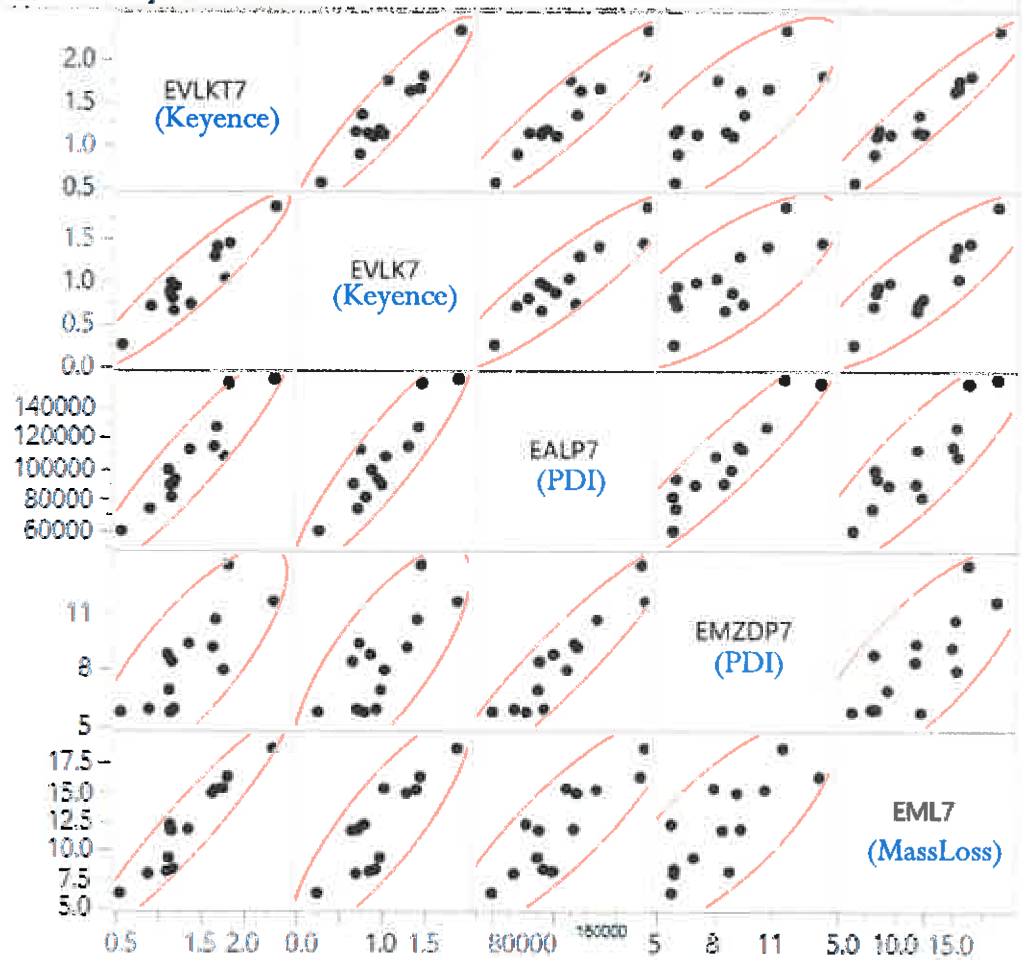
Correlations

	EVLKT7	EVLK7	EALP7	EMZDP7	EML7
EVLKT7	1.0000	0.9301	0.9306	0.7831	0.9486
EVLK7	0.9301	1.0000	0.9082	0.7548	0.8477
EALP7	0.9306	0.9082	1.0000	0.9334	0.8695
EMZDP7	0.7831	0.7548	0.9334	1.0000	0.7732
EML7	0.9486	0.8477	0.8695	0.7732	1.0000

Correlation Probability

	EVLKT7	EVLK7	EALP7	EMZDP7	EML7
EVLKT7	<.0001	<.0001	<.0001	0.0015	<.0001
EVLK7	<.0001	<.0001	<.0001	0.0029	0.0003
EALP7	<.0001	<.0001	<.0001	<.0001	0.0001
EMZDP7	0.0015	0.0029	<.0001	<.0001	0.0019
EML7	<.0001	0.0003	0.0001	0.0019	<.0001

Scatterplot Matrix



Exhaust Lifter 8

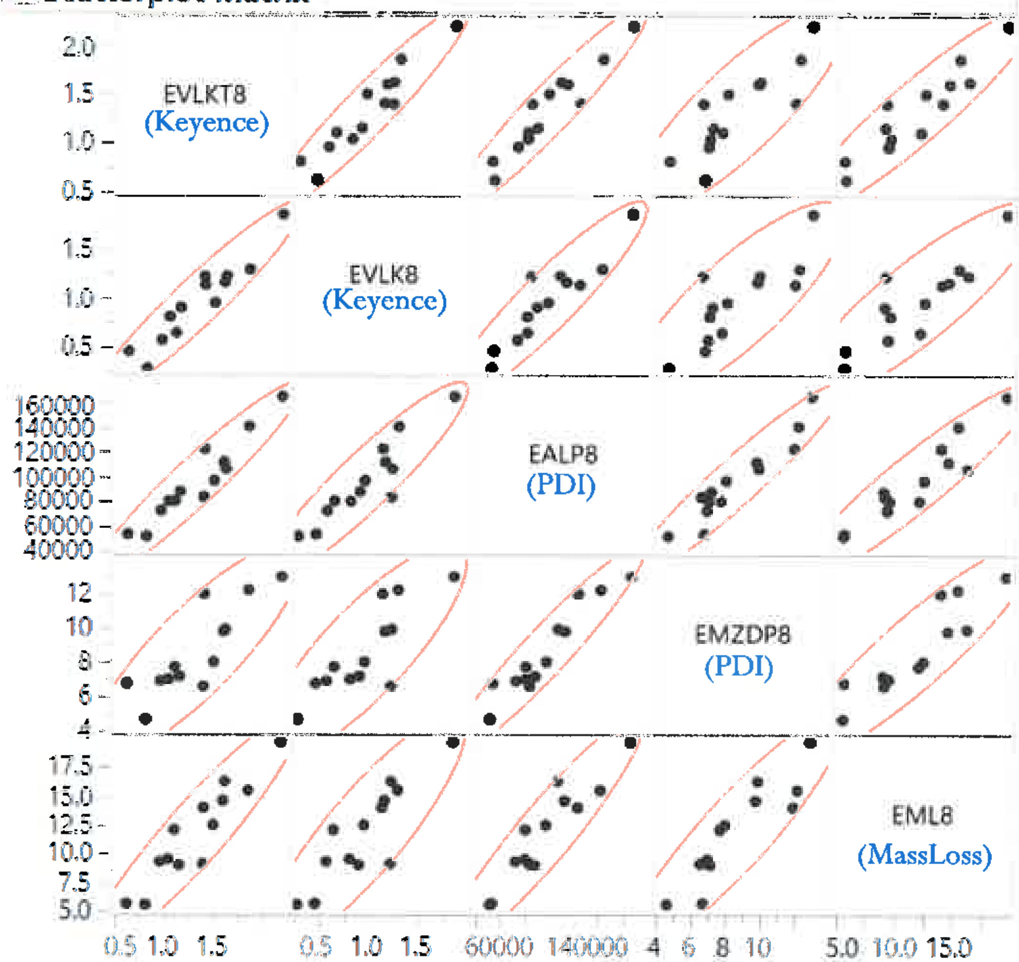
Correlations

	EVLKT8	EVLK8	EALP8	EMZDP8	EML8
EVLKT8	1.0000	0.9474	0.9492	0.8426	0.9298
EVLK8	0.9474	1.0000	0.9239	0.8274	0.8700
EALP8	0.9492	0.9239	1.0000	0.9505	0.9337
EMZDP8	0.8426	0.8274	0.9505	1.0000	0.9074
EML8	0.9298	0.8700	0.9337	0.9074	1.0000

Correlation Probability

	EVLKT8	EVLK8	EALP8	EMZDP8	EML8
EVLKT8	<.0001	<.0001	<.0001	0.0003	<.0001
EVLK8	<.0001	<.0001	<.0001	0.0005	0.0001
EALP8	<.0001	<.0001	<.0001	<.0001	<.0001
EMZDP8	0.0003	0.0005	<.0001	<.0001	<.0001
EML8	<.0001	0.0001	<.0001	<.0001	<.0001

Scatterplot Matrix

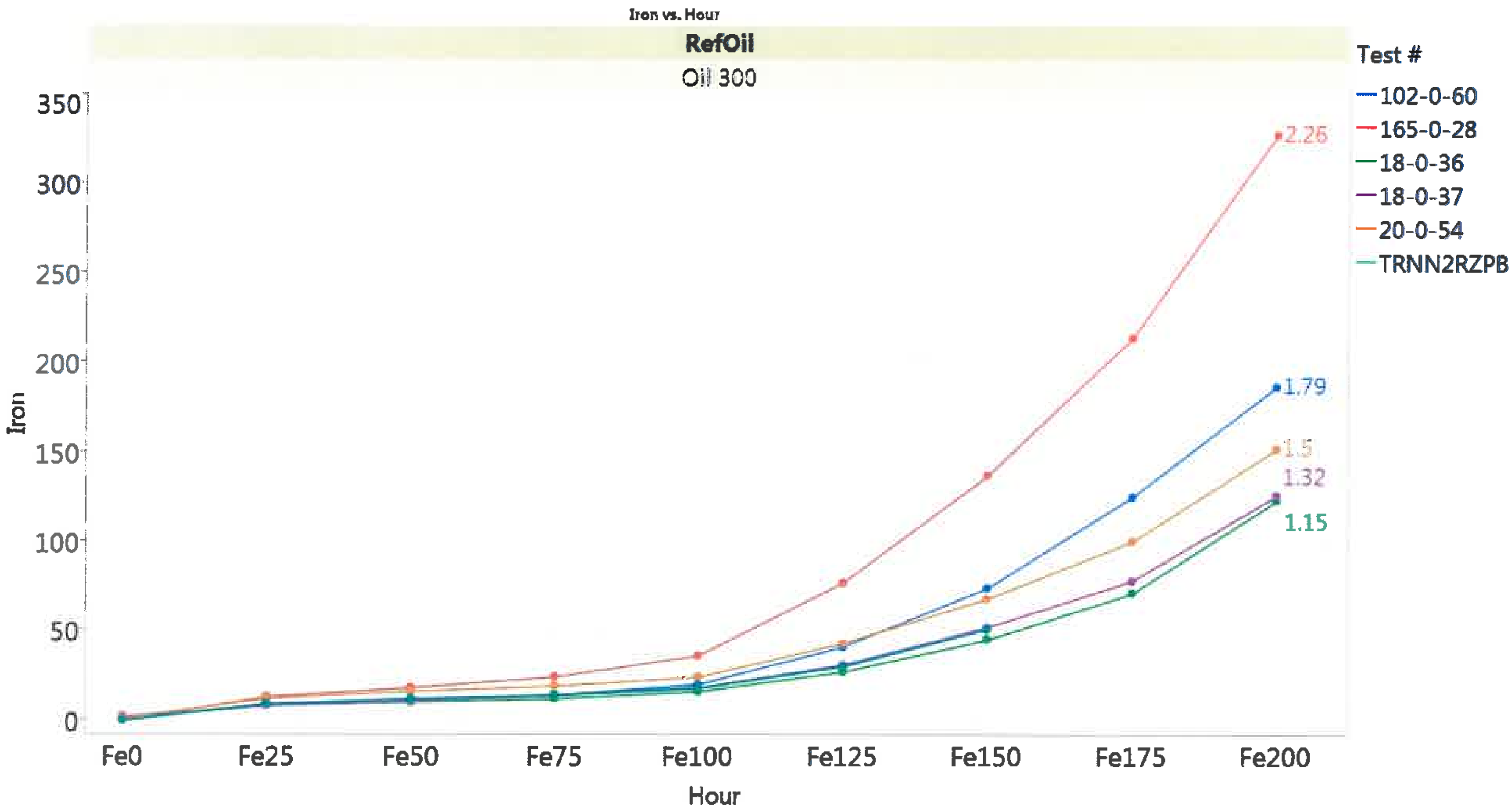


Additional Plots for IVB Discussion

SOUTHWEST RESEARCH INSTITUTE®

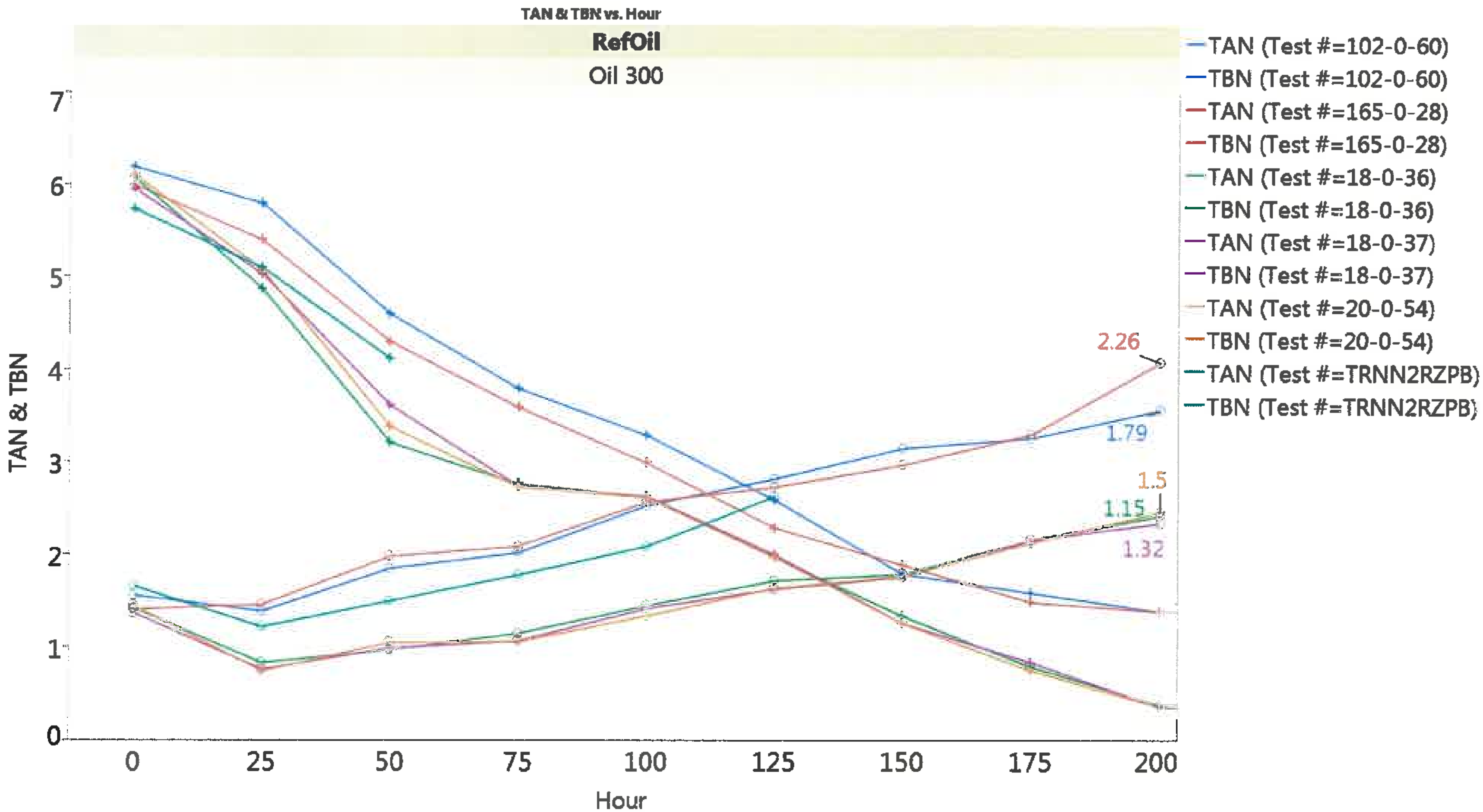
October 16, 2017

Iron Plot



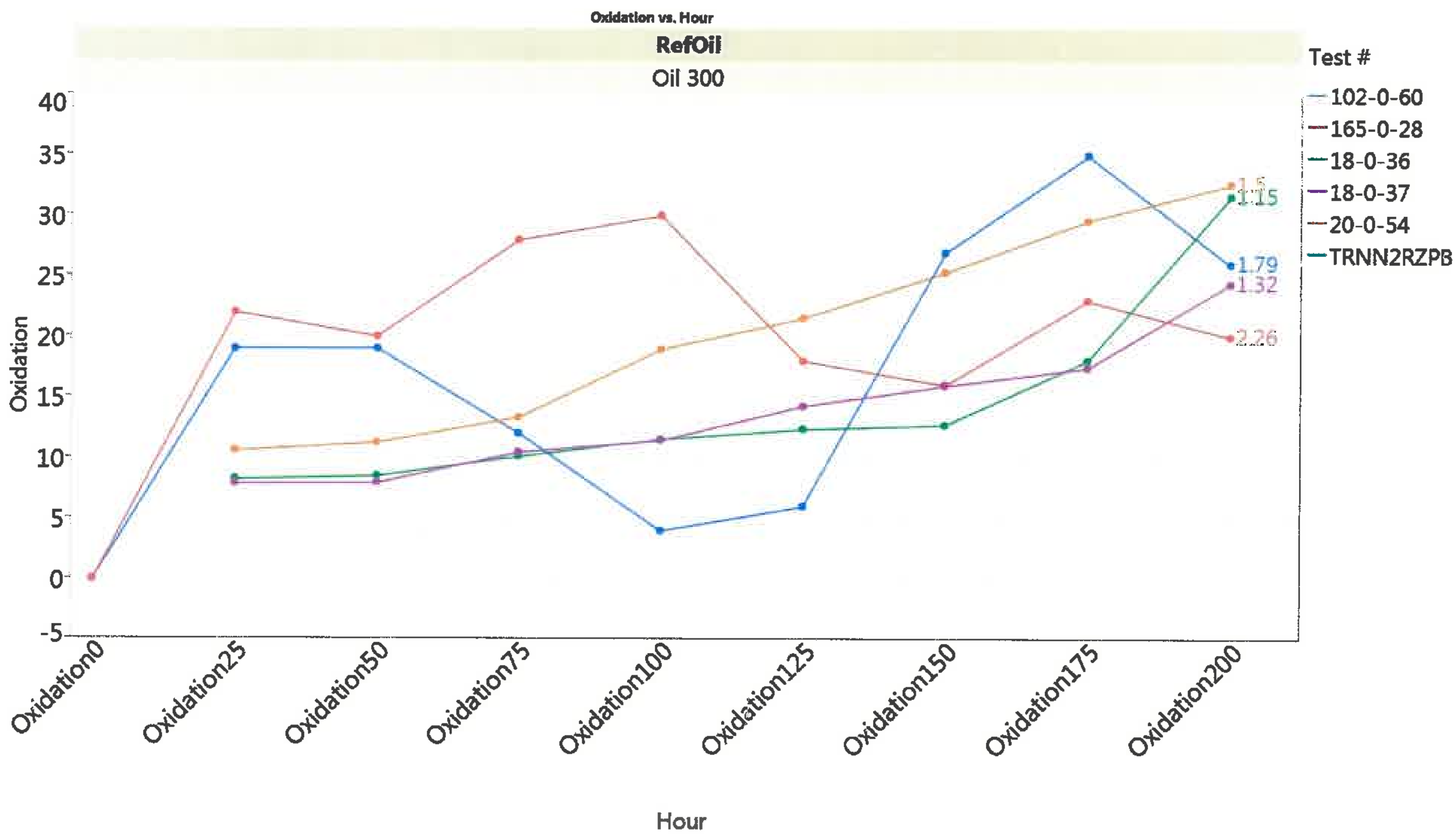
Iron vs. Hour
RefOil
Oil 300
Iron
350
300
250
200
150
100
50
0
Fe0
Fe25
Fe50
Fe75
Fe100
Fe125
Fe150
Fe175
Fe200
Hour
2.26
1.79
1.5
1.32
1.15
Test #
102-0-60
165-0-28
18-0-36
18-0-37
20-0-54
TRNN2RZPB

TAN & TBN

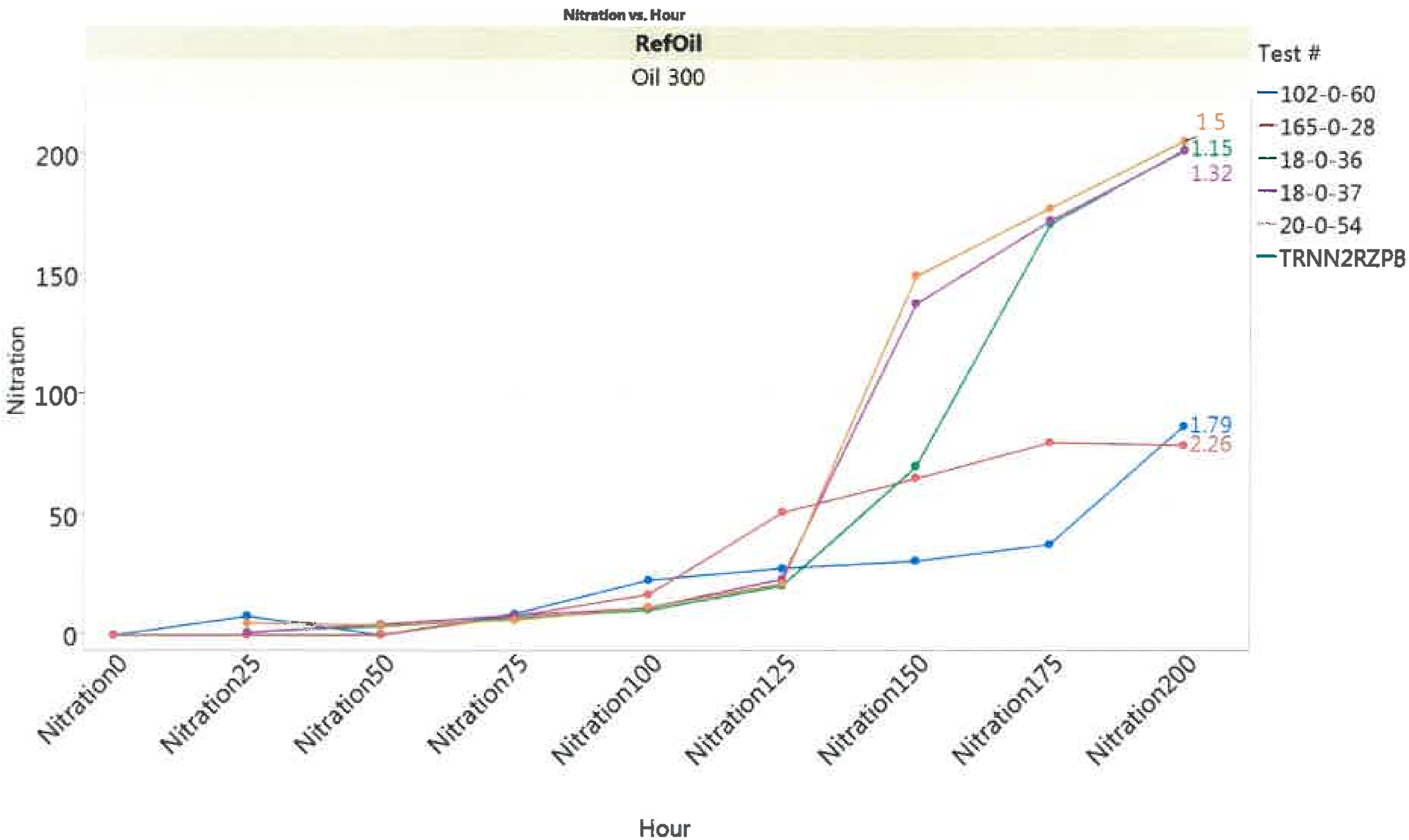


TAN & TBN vs. Hour
RefOil
Oil 300
TAN & TBN
0
1
2
3
4
5
6
7
0
25
50
75
100
125
150
175
200
Hour
2.26
1.79
1.5
1.15
1.32
TAN (Test #=102-0-60)
TBN (Test #=102-0-60)
TAN (Test #=165-0-28)
TBN (Test #=165-0-28)
TAN (Test #=18-0-36)
TBN (Test #=18-0-36)
TAN (Test #=18-0-37)
TBN (Test #=18-0-37)
TAN (Test #=20-0-54)
TBN (Test #=20-0-54)
TAN (Test #=TRNN2RZPB)
TBN (Test #=TRNN2RZPB)

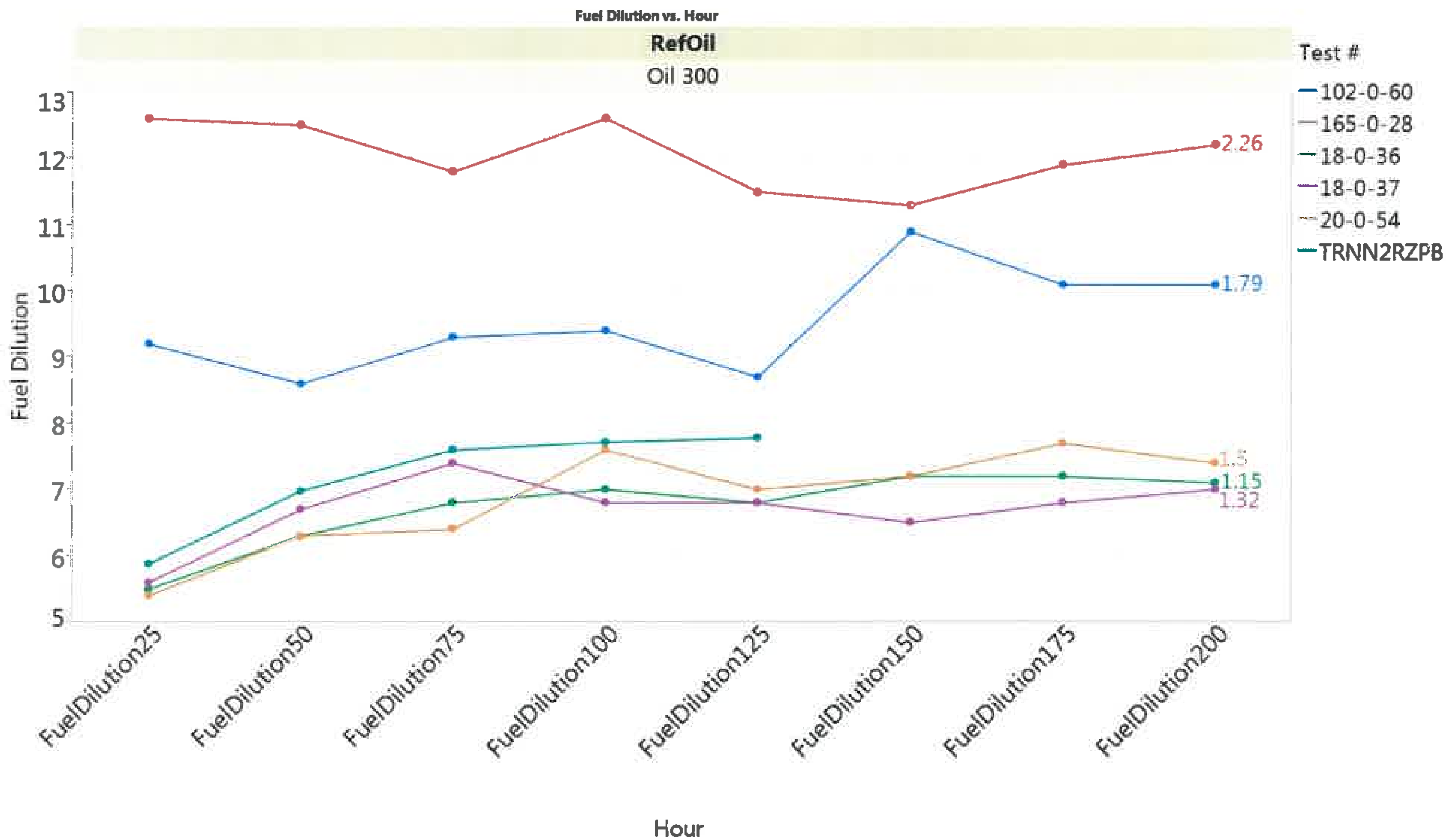
Oxidation Plot



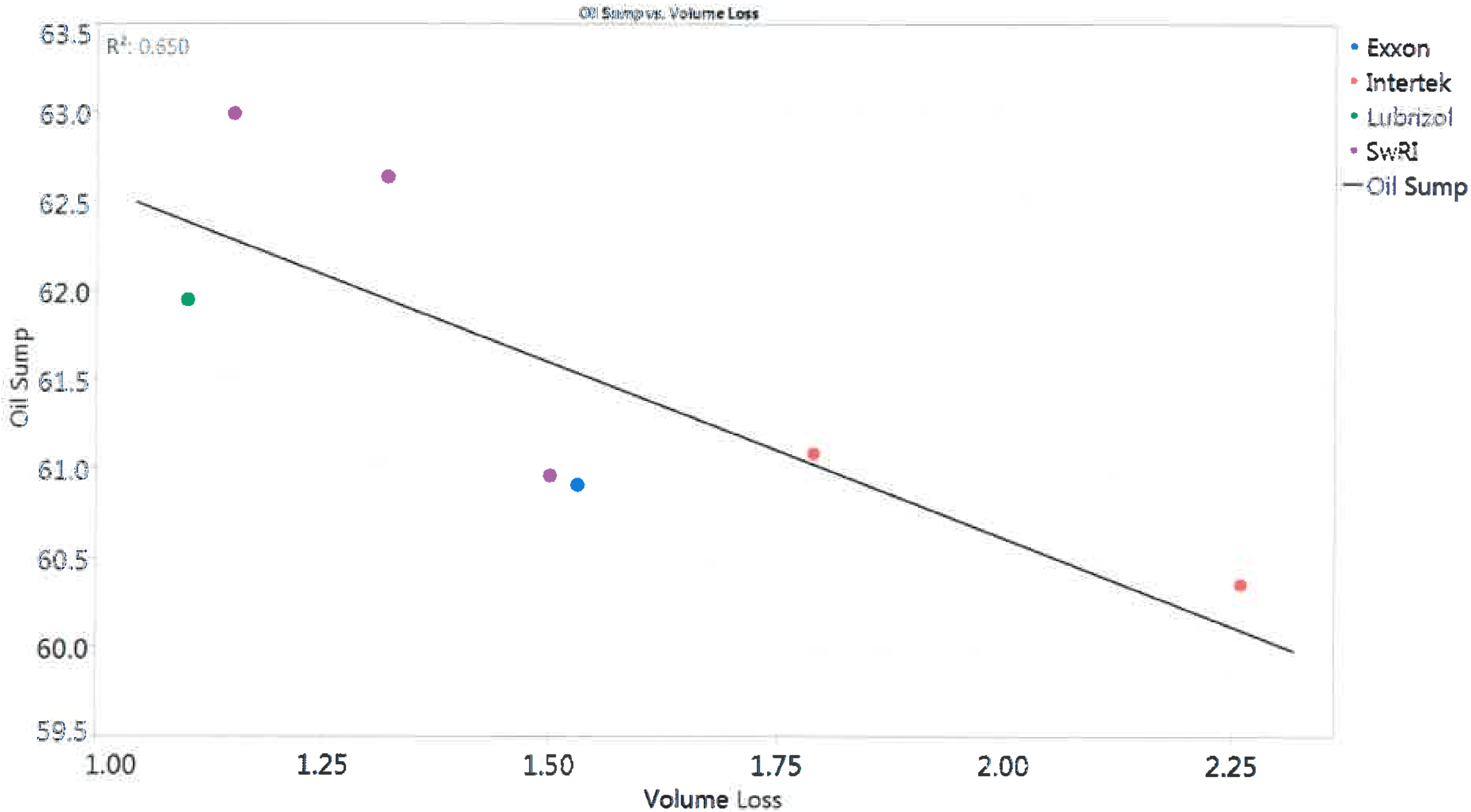
Nitration Plot



Fuel Dilution Plot



Oil Sump Temp



Oil Gallery Temp