Daimler Surveillance Panel Meeting Minutes

April 13, 2018
10:00 A.M. CST

Call Participants:
Lubrizol - Patrick Joyce, Kevin O'Malley
Southwest Research Institute – Jose Starling
Intertek - Jim Moritz, Josh Ward, Juan Vega
Daimler - Suzanne Neal, Greg Braziunas
Infineum - Jim Gutzwiller, Elisa Santos, David Brass, Bob Salgueiro, Jun Cui
Chevron Oronite – Mark Cooper
TEI – Derek Grosch
Afton – Bob Campbell
TMC – Sean Moyer
ExxonMobil – Prabhakar Bhaskar

<u>Reports:</u>
Parts Update – No update

<u>New Business</u>
Review Operational Data – (SP)
The three most recent tests on batch C liners were plotted alongside several other previous reference results and operational data reviewed for critical and non-critical parameters. There was a few odd portions of data for each of the labs but nothing seemed to be out of procedural specifications.

Action Items: Lubrizol will look into why the 100 hour operational data EGR temperatures do not seem to trend with typical soak periods. Southwest will review if there is a reason why front and rear exhaust manifold temperatures trend slightly lower than other labs. Intertek will review if there is a reason why return fuel temperature is consistently slightly higher than the other labs.

It was brought up whether the Lubrizol 200 hour run on batch C liners should be considered valid due to the various issues encountered during the test. This included a decent increase in torque and EGR issues in stage one for a short portion of the test and exhaust leak issue in stage two along with associated shutdown. Discussion in the panel suggested that since all the operational data points were within procedure specified limits the run should not be excluded unless the operational issues found pointed directly at it affecting the final end result which could not be conclusively stated. Iron and Chromium data was also reviewed and all looked normal for each of the tests based on when they scuffed.

Review TEI Measurement Data – (Kevin O'Malley)
Please see attached presentation by Kevin – File included 23 chartable results and the additional 3 tests on batch C liners. Various approaches were taken to attempt to correlate liner measurements from the cylinders that scuffed to test severity. A deep review of this analysis is

included in the presentation however none of the approaches provide sufficient support for liner characteristics influencing test severity.

Kevin asked the panel to consider separating the liner batch code individually in the LTMS file so that in future analysis it can be easier to analyze the data file and separate by batch. The panel will discuss this in upcoming meetings, but this would require labs to resubmit all previous reference tests conducted over the last few years.

Kevin was asked to separate the analysis by looking at tests that only scuffed one liner based on the TRWL limit of at least 250 mg and see if the surface data can shed any new details. Kevin will look into this and report back to the group if this analysis shows anything new

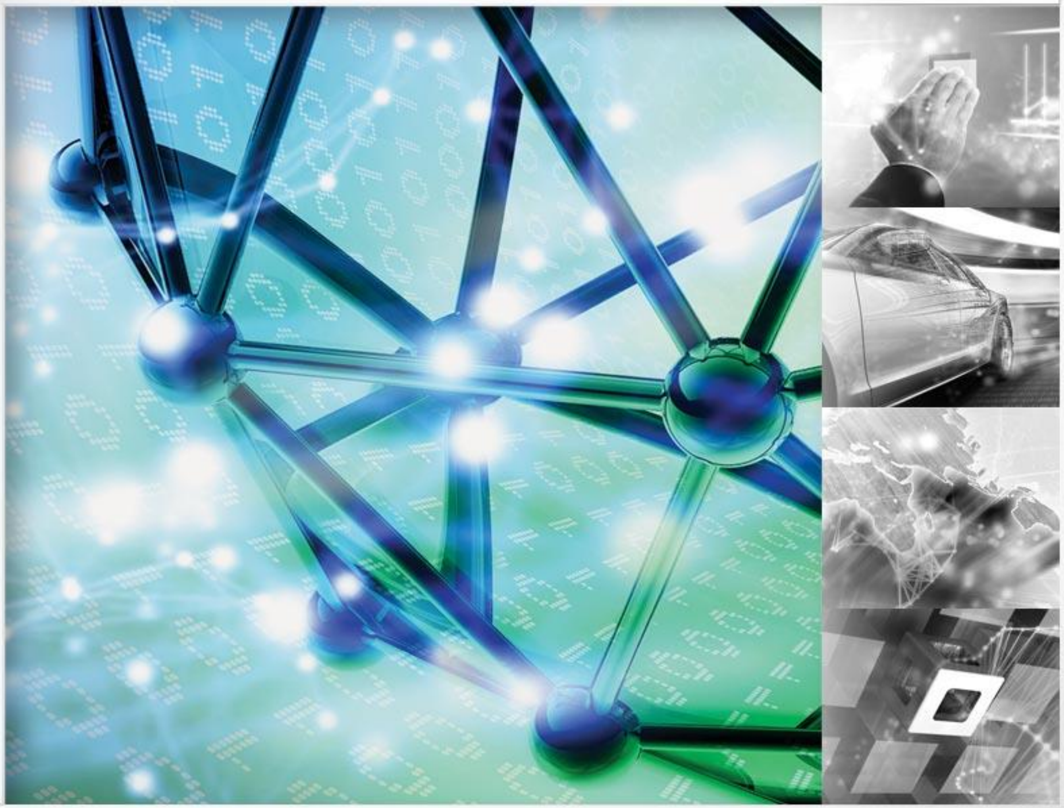
Review Batch C Liner Performance Analysis – (Bob Salgueiro)
Infineum conducted additional testing on the new batch liners with some of their internal reference oils. The presentation attached details their analysis but concluded that batch C liners may be more severe or that the new liners may not discriminate as it did on the PNB liners. Infineum suggested the possibility of running Oils C and D on the new batch liners to see if these new liners do show a shift in severity as they noticed with their internal runs.

Further discussion on how to proceed will be discussed in the next meeting.

Review Liner Analysis – (Patrick Joyce)
To be reviewed at the following SP meeting.

<u>Next Meeting:</u>

Next meeting is scheduled for Monday April 23rd from 10:30 AM to 11:30 PM CST.



DD13 Scuffing Test
Test Severity vs. Liner Measurements

Kevin O'Malley
The Lubrizol Corporation
April 2018

Lubrizol

Summary

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- Three recent tests were run on oil 864-1 using batch “C” liners. Hours to scuff were 30, 31, and 200.
  - A total of 26 tests were considered in this analysis (23 chart=“Y” and 3 Liner C; through 3-27-2018)
- Various approaches were used to determine whether liner measurements correlate to test severity
  - Approach 1: Individual cylinder liner measurements vs. hours to scuff
  - Approach 2: Average cylinder liner measurements vs. hours to scuff
  - Approach 3: Cylinder liner measurement of cylinder with max TRWL vs. hours to scuff
  - Plots associated with approaches 2 and 3 are included for review
- Approach 3 attempts to correlate liner measurements from the cylinder that scuffed to test severity. It makes a large, but perhaps reasonable, assumption that the cylinder with the highest top ring weight loss was the first cylinder to scuff. Subsequent scuffing could be influenced by the initial scuff.
- None of the approaches provide sufficient support for liner characteristics influencing test severity
- It could be helpful to have liner serial number added to the LTMS file so we can track liner changes; a unique column for liner batch would be ideal

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Hours to Scuff

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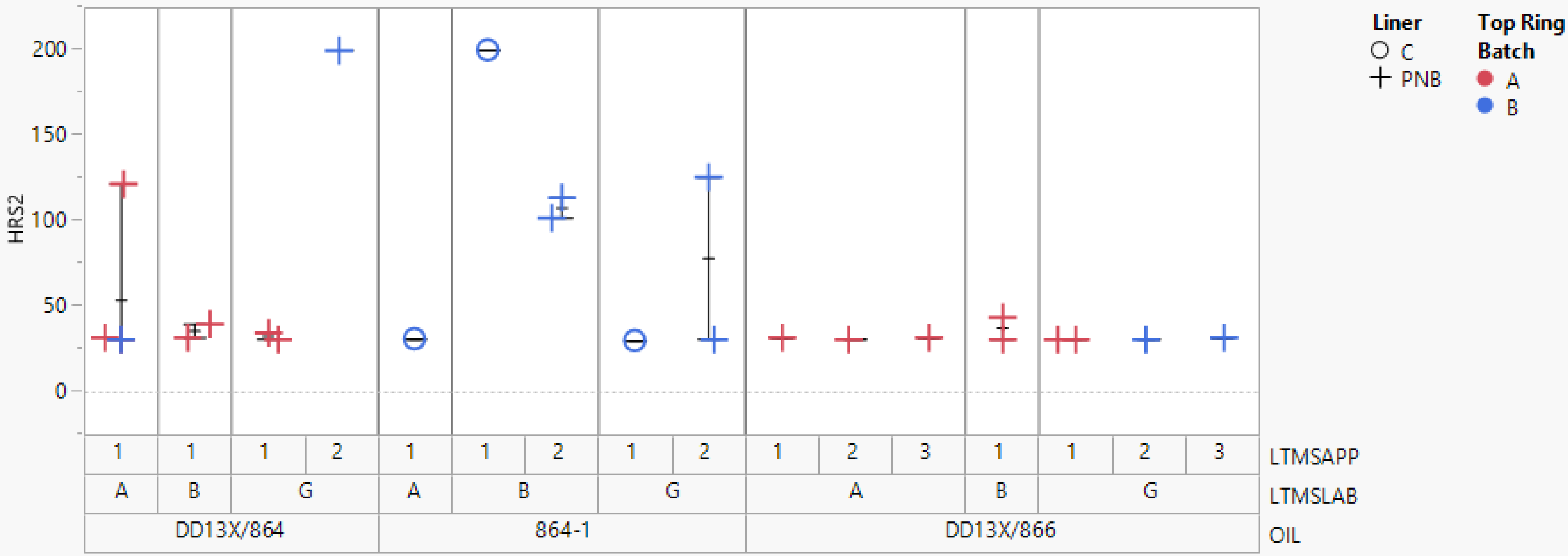
Chart = “Y” + Liner C tests



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Approach 2

This approach correlates the average of the six liner measurements to hours to scuff

An example of Ra is shown below

TESTKEY	LTMSDATE	LTMSLAB	LTMSAPP	VAL	CHART	DTCOMP	IND	Oil	HRS2	RAAVLR1	RAAVLR2	RAAVLR3	RAAVLR4	RAAVLR5	RAAVLR6	AVG RAAVLR
116652-DD13	20151120	G	1	AC	Y	20151120	DD13X	864	35	0.17	0.23	0.24	0.39	0.3	0.32	0.28
116656-DD13	20151121	B	1	AC	Y	20151121	DD13X	864	32	0.44	0.34	0.37	0.41	0.39	0.38	0.39
116648-DD13	20151231	A	1	AC	Y	20151231	DD13C	866	32	0.26	0.24	0.21	0.36	0.21	0.26	0.26
116653-DD13	20160102	G	1	AC	Y	20160102	DD13C	866	31	0.28	0.34	0.34	0.32	0.29	0.28	0.31
116657-DD13	20160116	B	1	AC	Y	20160116	DD13C	866	31	0.21	0.21	0.23	0.31	0.32	0.34	0.27
116654-DD13	20160123	G	1	AC	Y	20160123	DD13C	866	31	0.24	0.19	0.19	0.2	0.2	0.2	0.20
116649-DD13	20160127	A	1	AC	Y	20160127	DD13X	864	32	0.19	0.2	0.31	0.2	0.2	0.2	0.22
116658-DD13	20160204	B	1	AC	Y	20160204	DD13X	864	40	0.29	0.34	0.22	0.34	0.29	0.34	0.30
120064-DD13	20160212	A	2	AC	Y	20160212	DD13C	866	31	0.3	0.3	0.25	0.2	0.24	0.3	0.27
116659-DD13	20160218	B	1	AC	Y	20160218	DD13C	866	44	0.28	0.38	0.3	0.29	0.33	0.35	0.32
116650-DD13	20160218	A	1	AC	Y	20160218	DD13C	866	32	0.33	0.85	0.21	0.3	0.22	0.31	0.37
120065-DD13	20160225	A	3	AC	Y	20160225	DD13C	866	32	0.29	0.3	0.31	0.24	0.32	0.32	0.30
116655-DD13	20160226	G	1	AC	Y	20160226	DD13X	864	31	0.35	0.33	0.31	0.34	0.2	0.34	0.31
116651-DD13	20160229	A	1	OC	Y	20160229	DD13X	864	122	0.3	0.29	0.28	0.32	0.32	0.28	0.30
117347-DD13	20160416	A	1	AC	Y	20160416	DD13X	864	31	0.36	0.38	0.45	0.42	0.35	0.4	0.39
118393-DD13	20160622	A	1	AC	Y	20160622	864	864	31	0.34	0.32	0.27	0.25	0.3	0.41	0.32
119058-DD13	20160820	G	2	OC	Y	20160820	864	864	200	0.34	0.26	0.23	0.22	0.23	0.32	0.27
119743-DD13	20160915	G	2	OC	Y	20160915	864-1	864-1	126	0.4	0.31	0.31	0.33	0.32	0.39	0.34
120881-DD13	20161012	G	2	AC	Y	20161012	866	866	31	0.46	0.48	0.37	0.3	0.44	0.44	0.42
120882-DD13	20161107	G	3	AC	Y	20161107	866	866	32	0.5	0.42	0.51	0.5	0.35	0.34	0.44
121505-DD13	20161124	B	2	OC	Y	20161124	864-1	864-1	114	0.23	0.27	0.28	0.24	0.31	0.32	0.28
121506-DD13	20170214	B	2	AC	Y	20170214	864-1	864-1	102	0.51	0.48	0.48	0.47	0.49	0.49	0.49
119744-DD13	20171025	G	2	AC	Y	20171025	864-1	864-1	31	0.35	0.35	0.36	0.35	0.41	0.33	0.36
121501-DD13	20180316	A	1	PC	Y	20180316	864-1	864-1	31	0.25	0.21	0.23	0.24	0.24	0.25	0.24
134325-DD13	20180319	G	1	PC	N	20180319	864-1	864-1	30	0.24	0.22	0.21	0.22	0.31	0.25	0.24
134612-DD13	20180327	B	1	PC	N	20180327	864-1	864-1	200	0.22	0.31	0.2	0.31	0.19	0.23	0.24

The individual cylinder liner measurements were correlate to hours to scuff in Approach 1

Average Liner Ra

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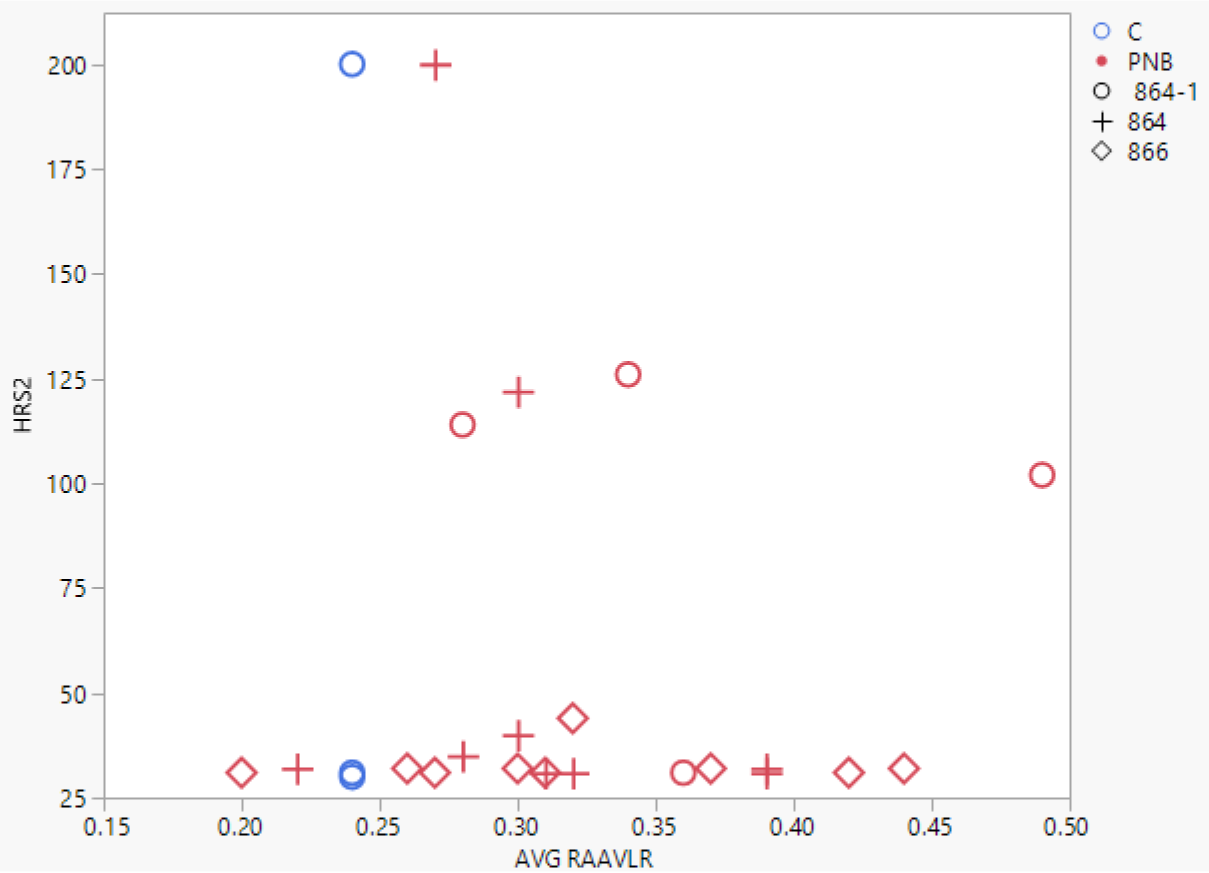

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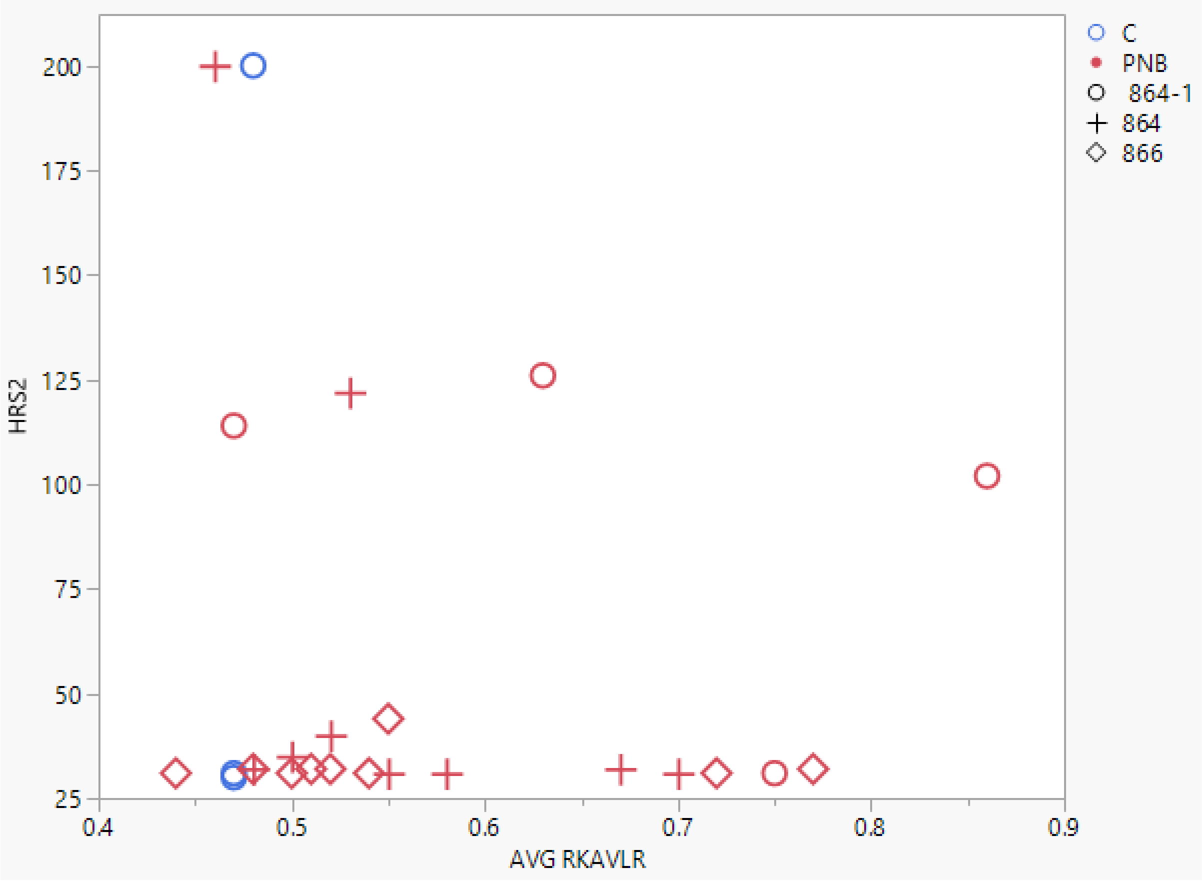
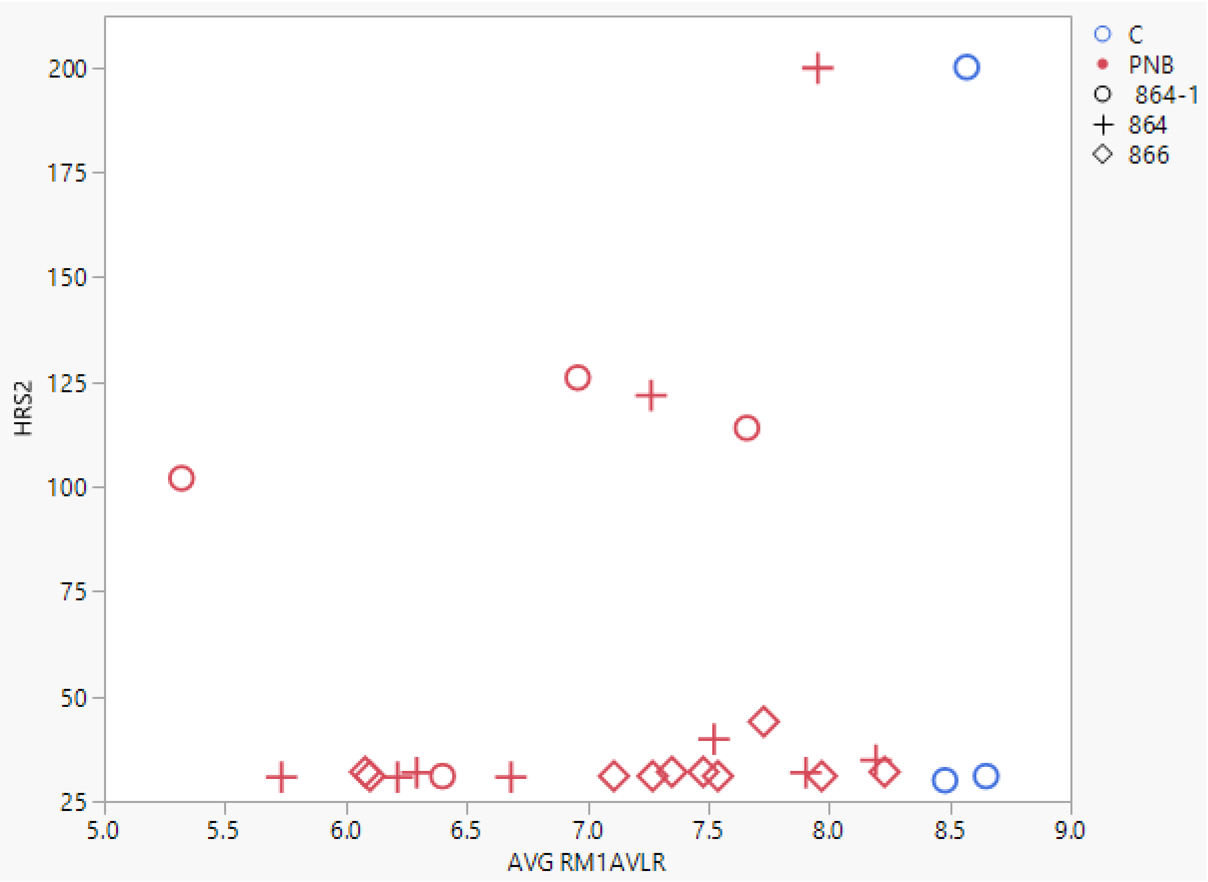
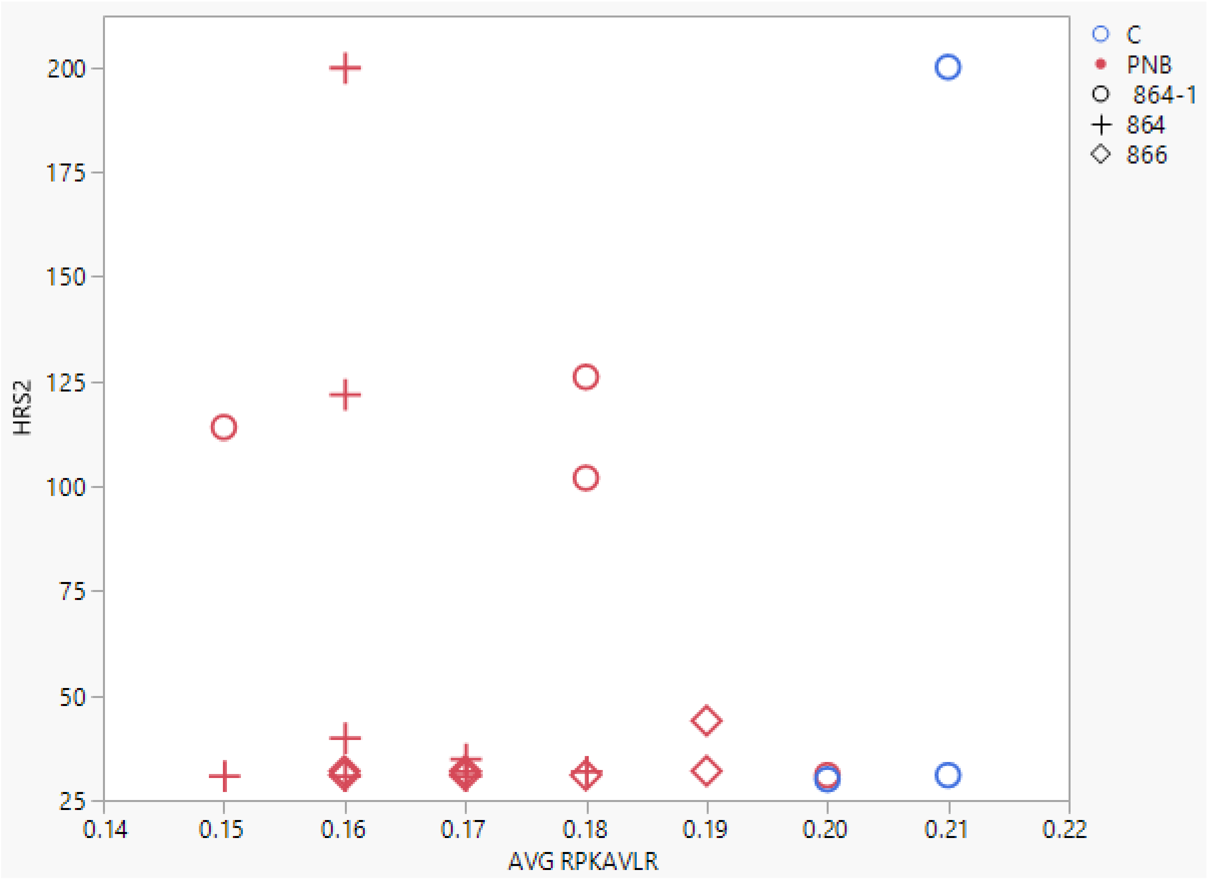
Average Liner Rk



Average Liner RM1

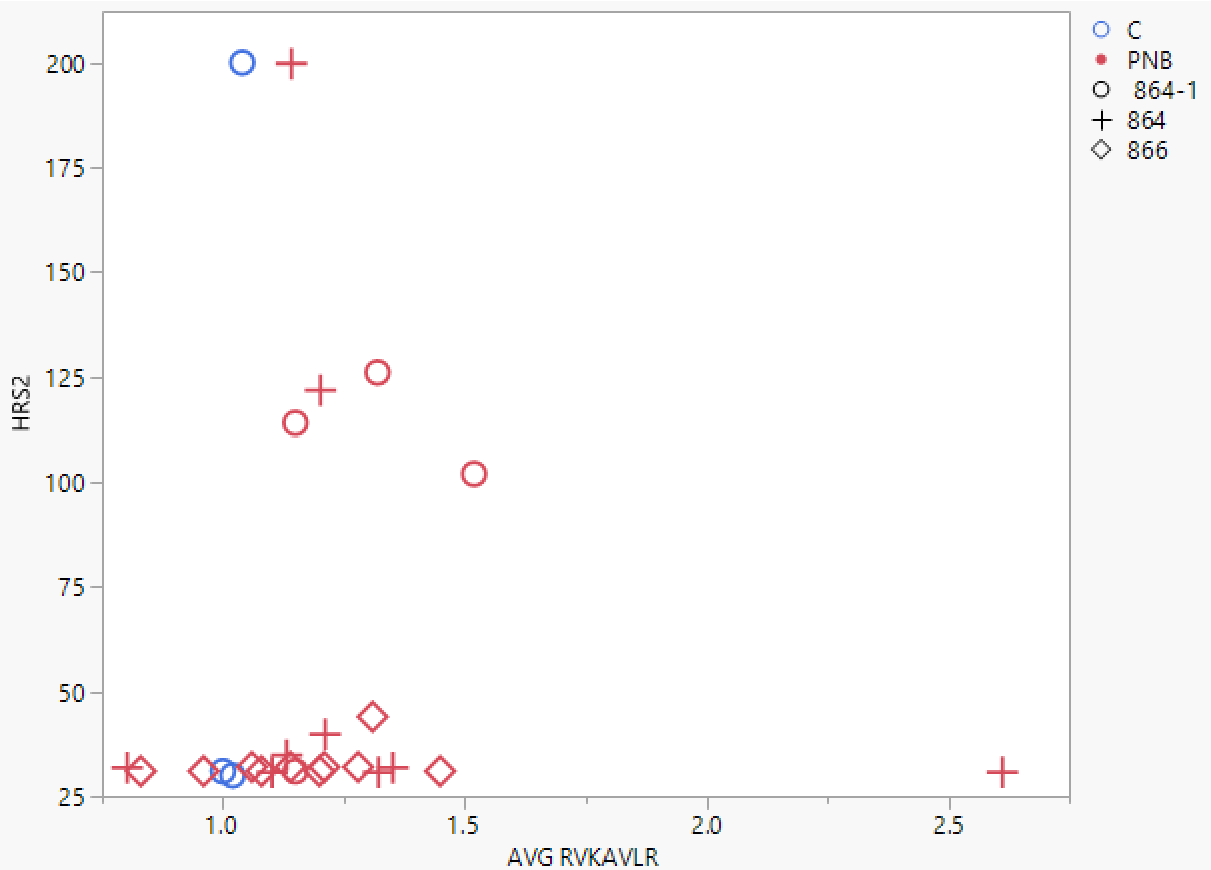


Average Liner Rpk



Average Liner Rvk

SUCCESS TOGETHER



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LINER CROSSHATCH ANGLE

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TESTKEY	LTMSLAB	LTMSAPP	IND	Oil	HRS2	LCRSHTC1	LCRSHTC2	LCRSHTC3	LCRSHTC4	LCRSHTC5	LCRSHTC6
116652-DD13	G	1	DD13X	864	35	48.1	46.7	46.3	46.5	46.7	46.7
116656-DD13	B	1	DD13X	864	32	46.7	47.8	46.3	46.7	46.7	46.3
116648-DD13	A	1	DD13C	866	32	47.7	46.4	4601	4603	48.1	46.3
116653-DD13	G	1	DD13C	866	31	46.6	46.6	46.3	46.7	46.3	46.3
116657-DD13	B	1	DD13C	866	31	48.1	48.9	48.1	46.3	46.6	47
116654-DD13	G	1	DD13C	866	31	45.9	47.8	48.2	48.2	47.8	46.3
116649-DD13	A	1	DD13X	864	32	48.2	48.4	4700	48.4	48.5	48.2
116658-DD13	B	1	DD13X	864	40	46.3	46.3	46.3	46.3	47	46.3
120064-DD13	A	2	DD13C	866	31	46.3	46.5	46.3	48.5	48.1	46.6
116659-DD13	B	1	DD13C	866	44	46.3	47	46.7	45.9	46.7	46.7
116650-DD13	A	1	DD13C	866	32	46.3	46.3	48.5	46.6	46.3	46.3
120065-DD13	A	3	DD13C	866	32	4700	4670	4630	4700	4670	4700
116655-DD13	G	1	DD13X	864	31	46.7	46.7	46.3	46.3	46.7	45.9
116651-DD13	A	1	DD13X	864	122	46.7	46.7	46.3	46.3	46.3	45.9
117347-DD13	A	1	DD13X	864	31	4670	4590	4630	4590	4630	4630
118393-DD13	A	1	864	864	31	4700	4670	4670	4670	4630	4630
119058-DD13	G	2	864	864	200	46.7	46.7	47	46.3	46.3	46.3
119743-DD13	G	2	864-1	864-1	126	46.6	46.7	46.7	46.7	46.3	46.3
120881-DD13	G	2	866	866	31	47	46.6	46.7	46.3	46.7	46.7
120882-DD13	G	3	866	866	32	46.3	46.7	46.3	46.3	46.7	46.3
121505-DD13	B	2	864-1	864-1	114	46.7	46.3	46.3	46.3	47	46.7
121506-DD13	B	2	864-1	864-1	102	47	46.3	46.3	46.3	46.3	46.3
119744-DD13	G	2	864-1	864-1	31	46.7	46.3	46.6	45.9	46.7	45.9
121501-DD13	A	1	864-1	864-1	31	50	50.4	50	50	50.4	50
134325-DD13	G	1	864-1	864-1	30	50	50.4	50.4	50.3	50.4	50
134612-DD13	B	1	864-1	864-1	200	49.7	50.4	49.7	50	50.4	50.4

I assumed some results were reported without a decimal place (e.g., 4700 should be 47.00)

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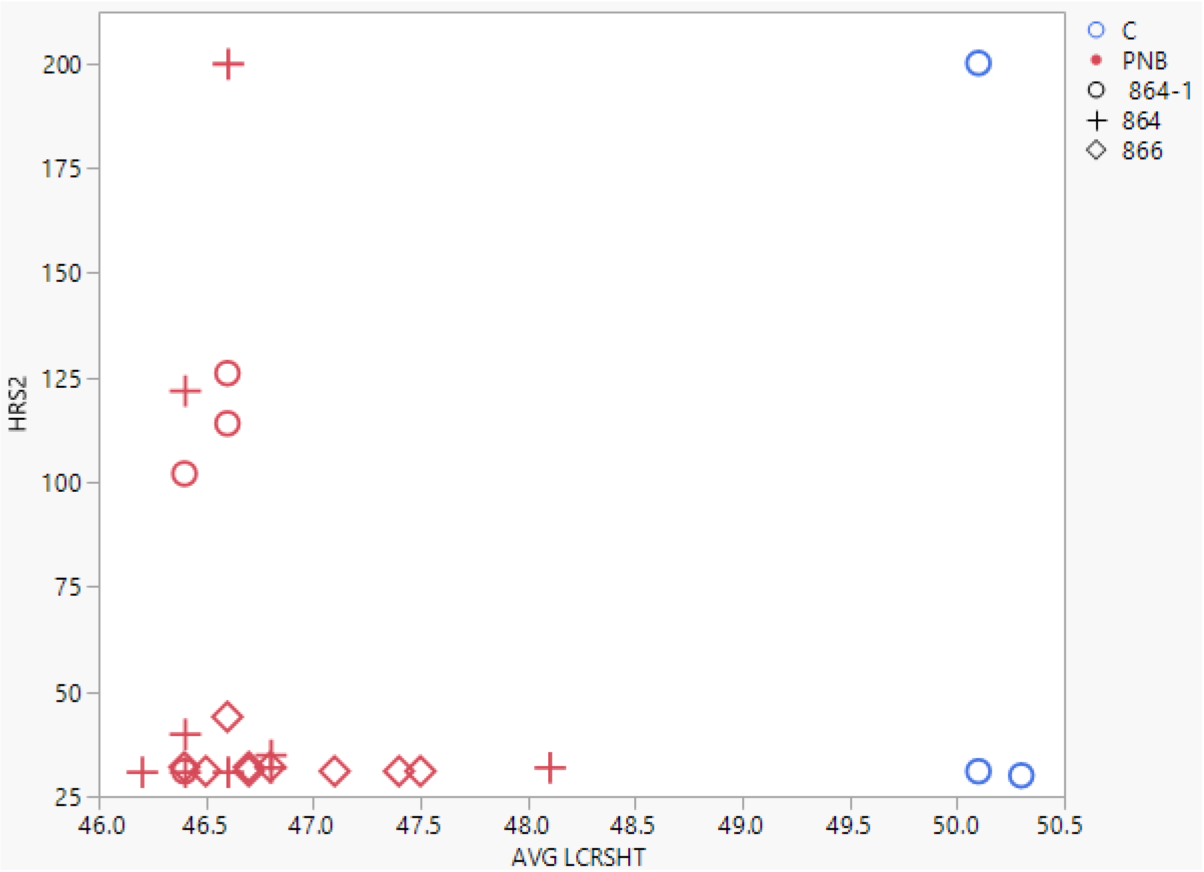
Average Liner Crosshead Angle



Approach 3

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This approach correlates the liner measurement from the cylinder with the highest top ring weight loss to hours to scuff. We are trying to correlate the liner measurement of scuffed cylinders to test severity without the influence of liner measurements from cylinders that don't scuff. An example of Ra:

TESTKEY	TRWL1	TRWL2	TRWL3	TRWL4	TRWL5	TRWL6	RAAVLR1	RAAVLR2	RAAVLR3	RAAVLR4	RAAVLR5	RAAVLR6	RAAVLR of Cylinder with Max TRWL
116652-DD13	-0.5	-0.6	5460.3	-0.2	0.6	0.4	0.17	0.23	0.24	0.39	0.3	0.32	0.24
116656-DD13	1.5	0.9	5618.3	3.3	1	2.1	0.44	0.34	0.37	0.41	0.39	0.38	0.37
116648-DD13	3.6	1.3	2056	3722.3	1.6	2029.1	0.26	0.24	0.21	0.36	0.21	0.26	0.36
116653-DD13	9.2	934.1	2094.6	706.1	5.8	3202.2	0.28	0.34	0.34	0.32	0.29	0.28	0.28
116657-DD13	22.3	7.4	2622.7	47.5	11.8	9.7	0.21	0.21	0.23	0.31	0.32	0.34	0.23
116654-DD13	2726.1	321.1	1505.7	2743.9	1.1	4	0.24	0.19	0.19	0.2	0.2	0.2	0.2
116649-DD13	3.3	5.4	4.9	5476.5	1517.3	6.8	0.19	0.2	0.31	0.2	0.2	0.2	0.2
116658-DD13	7.4	5.9	6.7	4755.5	7.7	16.7	0.29	0.34	0.22	0.34	0.29	0.34	0.34
120064-DD13	2.6	0.8	588.7	1.3	2.5	0.4	0.3	0.3	0.25	0.2	0.24	0.3	0.25
116659-DD13	6.5	9.4	5.9	7422.6	7.2	5	0.28	0.38	0.3	0.29	0.33	0.35	0.29
116650-DD13	2298.1	1.6	2467	1183.4	3.4	1522.3	0.33	0.85	0.21	0.3	0.22	0.31	0.21
120065-DD13	2.9	5.6	1426.9	4	4.7	2.6	0.29	0.3	0.31	0.24	0.32	0.32	0.31
116655-DD13	6.5	5.2	7.1	2163.6	2680.9	3.9	0.35	0.33	0.31	0.34	0.2	0.34	0.2
116651-DD13	4.4	14	2.6	2.3	55.4	819.4	0.3	0.29	0.28	0.32	0.32	0.28	0.28
117347-DD13	3.1	1.9	4.1	2323.6	8	5.4	0.36	0.38	0.45	0.42	0.35	0.4	0.42
118393-DD13	1264	12.5	1191.2	1515.3	6.4	1466.2	0.34	0.32	0.27	0.25	0.3	0.41	0.25
119058-DD13	52.8	7.5	19.7	50.7	142.4	36.5	0.34	0.26	0.23	0.22	0.23	0.32	0.23
119743-DD13	7.6	10.5	0.2	-0.4	1931.1	3.8	0.4	0.31	0.31	0.33	0.32	0.39	0.32
120881-DD13	4.2	9.1	9.5	9.1	3349.3	14	0.46	0.48	0.37	0.3	0.44	0.44	0.44
120882-DD13	3.6	-2.8	1587.9	897.1	2173.2	3079.1	0.5	0.42	0.51	0.5	0.35	0.34	0.34
121505-DD13	54.2	27.4	20	1679.9	106.2	597.1	0.23	0.27	0.28	0.24	0.31	0.32	0.24
121506-DD13	1387.3	5	9.7	100.5	29.6	1790.2	0.51	0.48	0.48	0.47	0.49	0.49	0.49
119744-DD13	2260.1	-1	3030	-4.7	1753.3	2710	0.35	0.35	0.36	0.35	0.41	0.33	0.36
121501-DD13	3723.2	1.6	1.4	0.7	1	5557.2	0.25	0.21	0.23	0.24	0.24	0.25	0.25
134325-DD13	240.2	2430.3	882.9	0.6	1.4	2.3	0.24	0.22	0.21	0.22	0.31	0.25	0.22
134612-DD13	102.8	7.8	4.4	8.6	33	53.5	0.22	0.31	0.2	0.31	0.19	0.23	0.22

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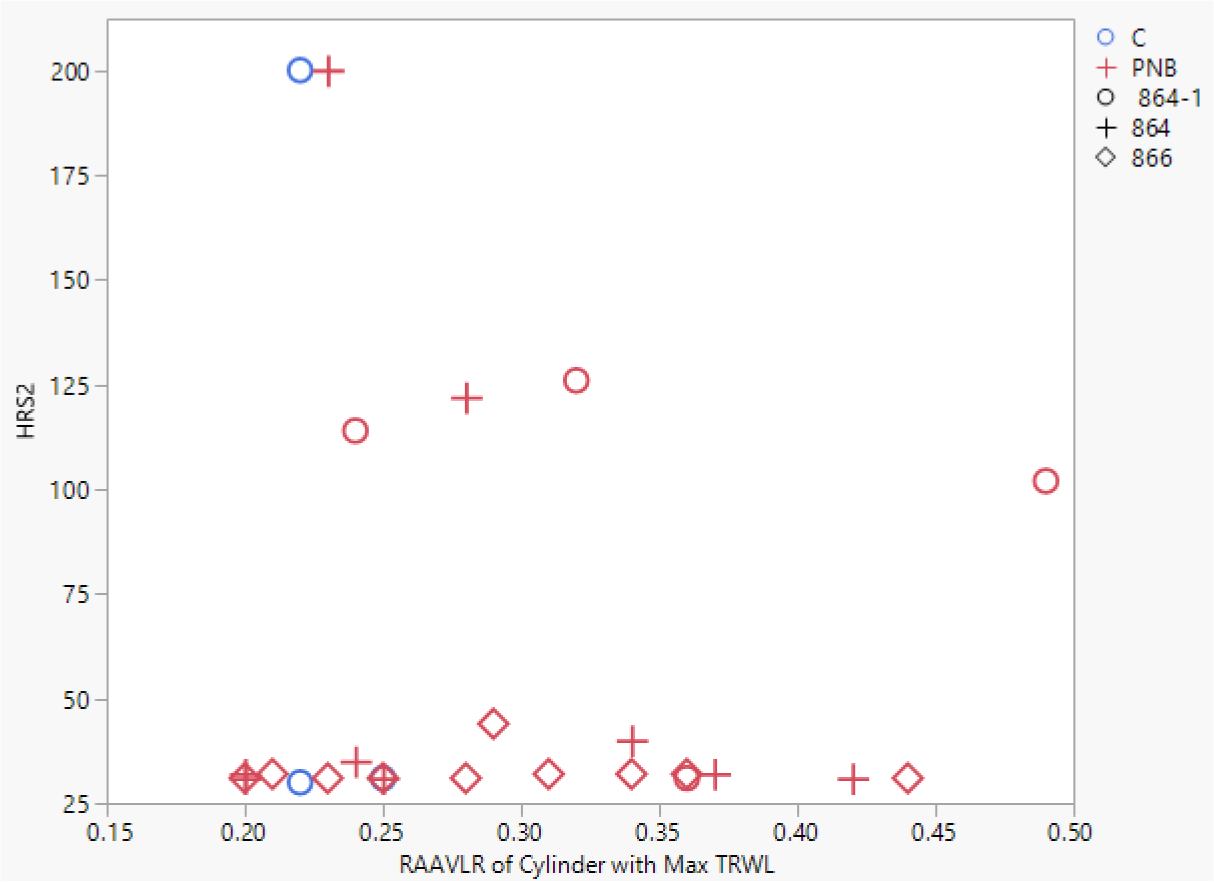
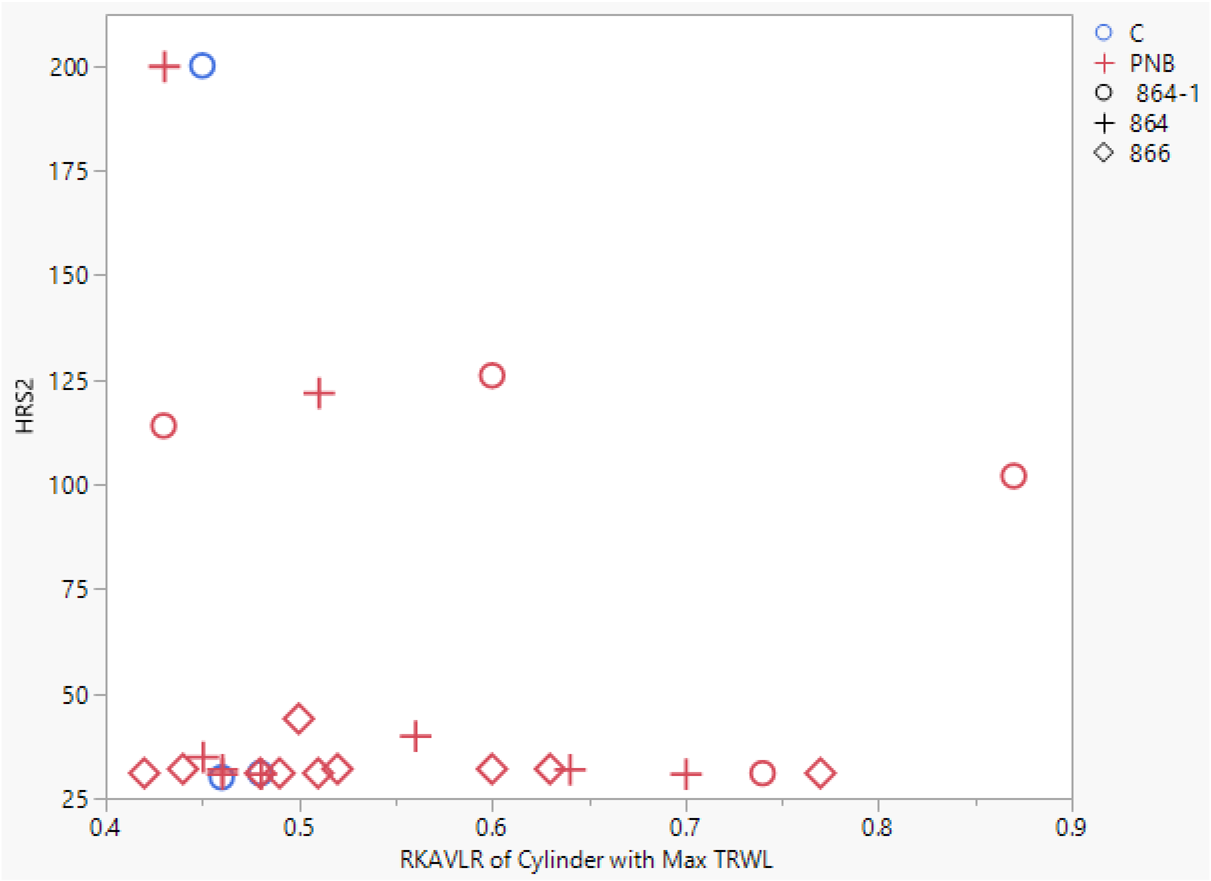
Liner Ra from Cylinder with Max Top Ring Weight Loss



Liner Rk from Cylinder with Max Top Ring Weight Loss

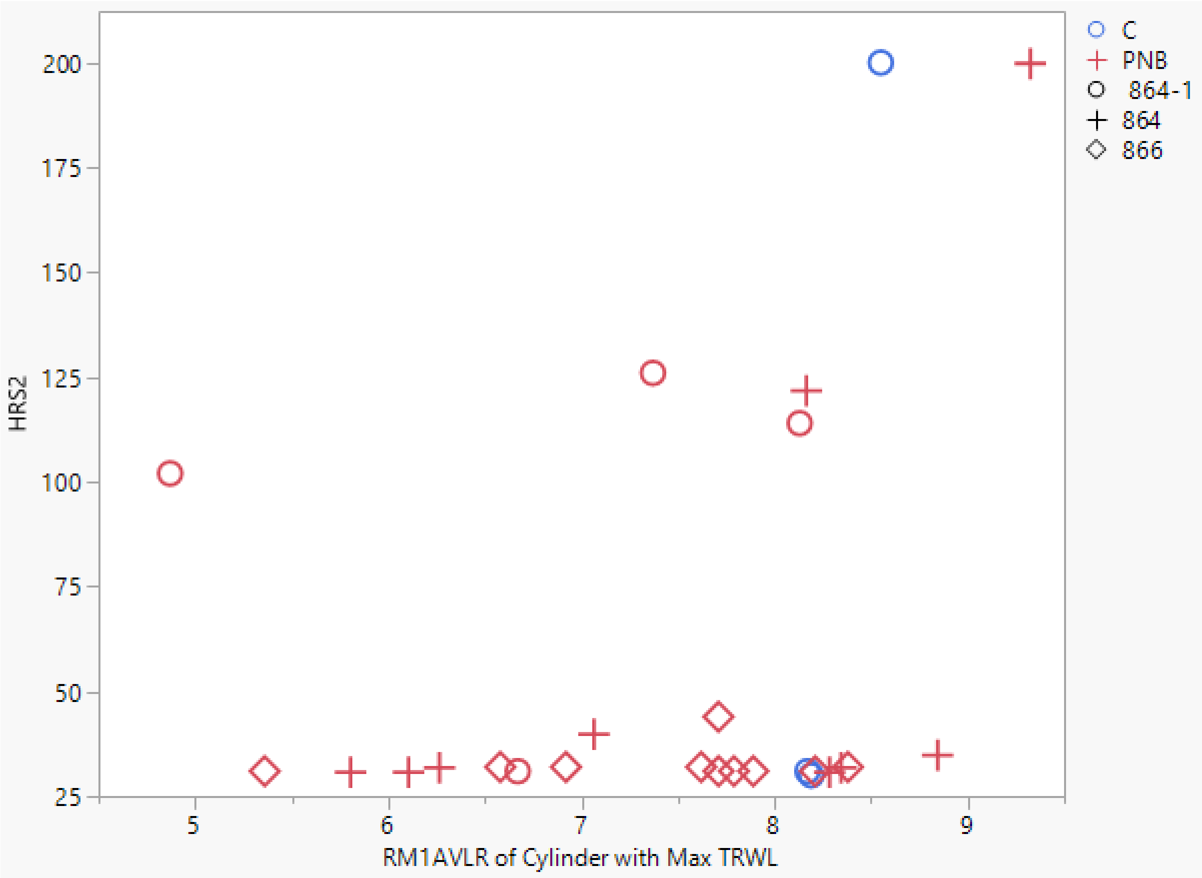
SUCCESS TOGETHER



Lubrizol

Liner RM1 from Cylinder with Max Top Ring Weight Loss

SUCCESS TOGETHER



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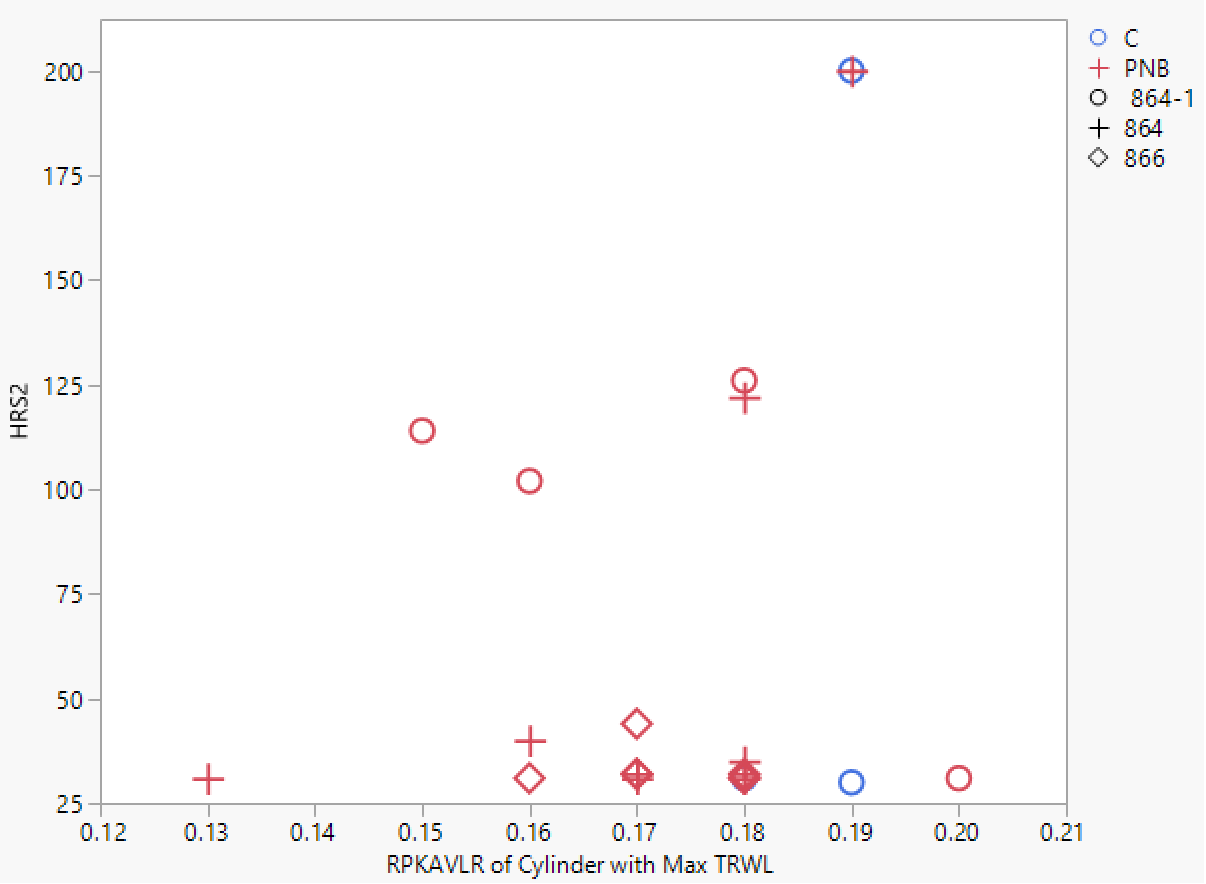
Liner Rpk from Cylinder with Max Top Ring Weight Loss

SUCCESS TOGETHER



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Liner Rvk from Cylinder with Max Top Ring Weight Loss

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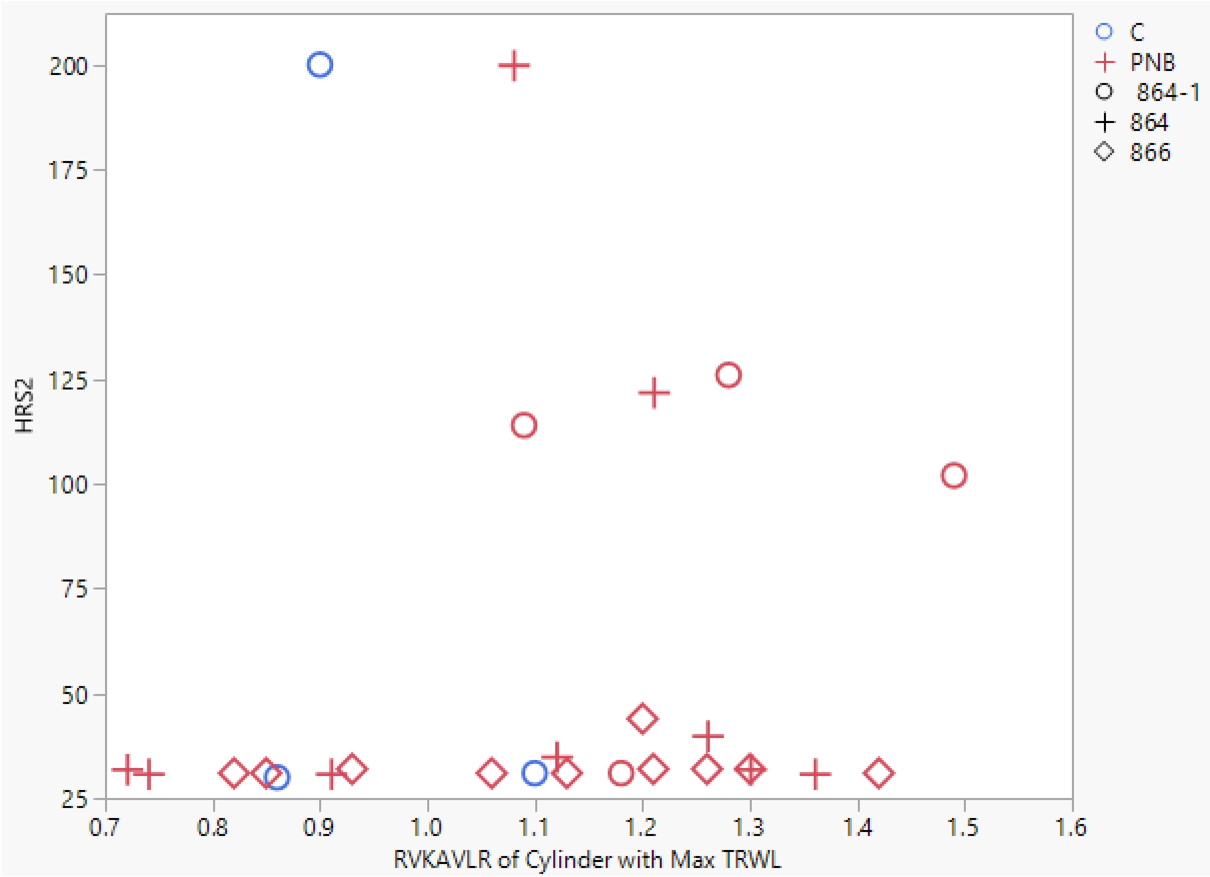

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Liner Crosshead Angle from Cylinder with Max Top Ring Weight Loss

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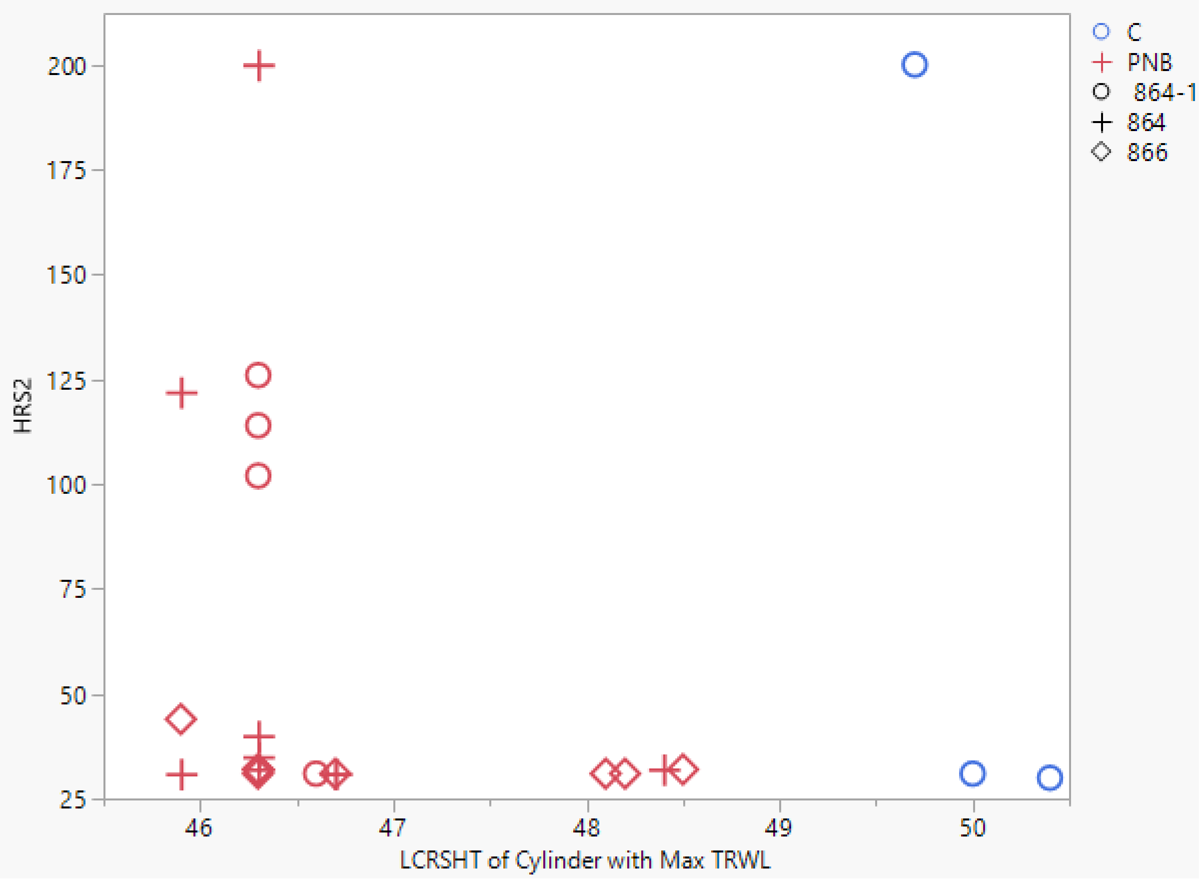

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Appendix - Liner Batch Comparison
PNB vs. C

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Liner Measurements

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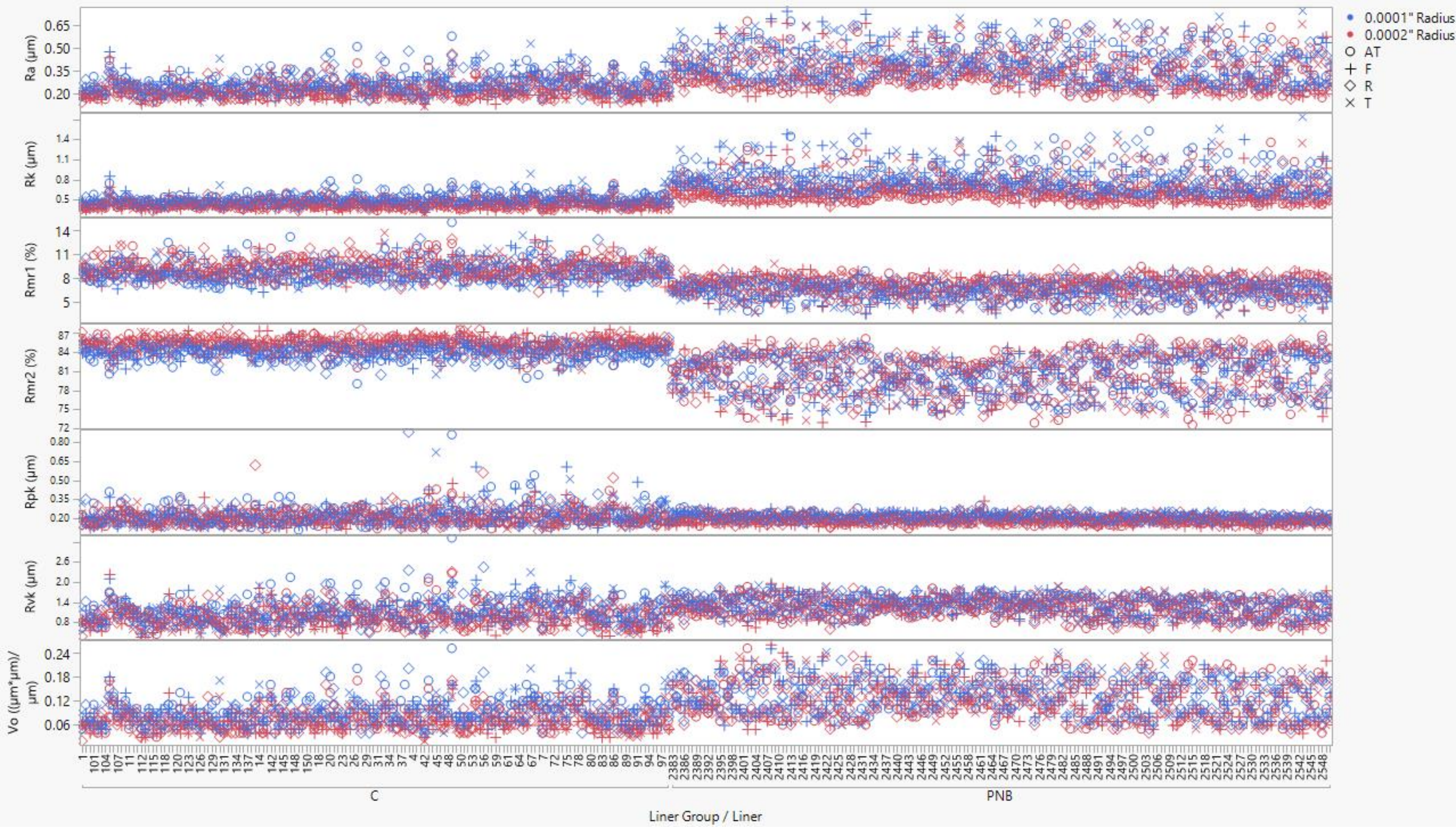
Batch C liners differ from PNB liners



Deriving equivalent specs for 0.0001" Radius Stylus

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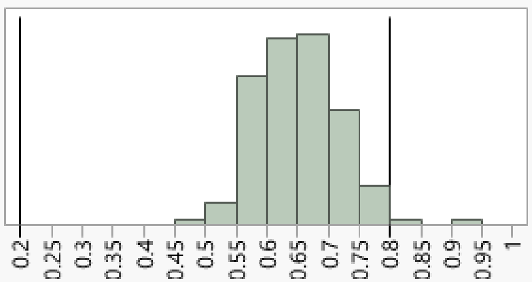
Proposed Batch C liner specs were derived to achieve similar probability of acceptance as PNB using Daimler specs (assumption of normality was used in calculations; the four measurements for each liner were averaged)

PNB, Stylus=0.0002" Radius

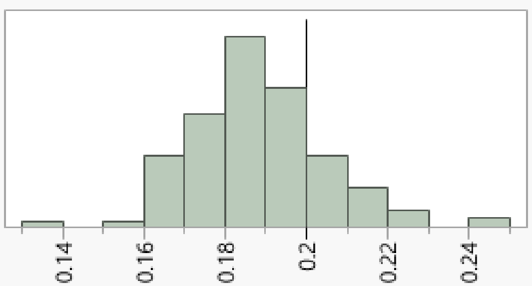
Mean(Rk (μm))



Summary Statistics

Mean	0.6505357
Std Dev	0.0670771
Std Err Mean	0.0051751
Upper 95% Mean	0.6607528
Lower 95% Mean	0.6403186
N	168

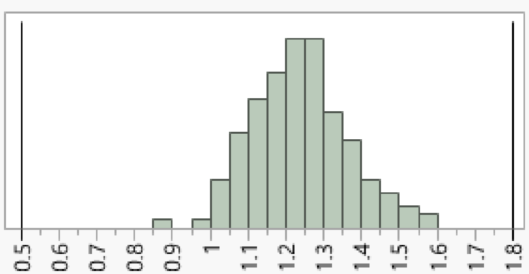
Mean(Rpk (μm))



Summary Statistics

Mean	0.1875298
Std Dev	0.0161138
Std Err Mean	0.0012432
Upper 95% Mean	0.1899842
Lower 95% Mean	0.1850753
N	168

Mean(Rvk (μm))

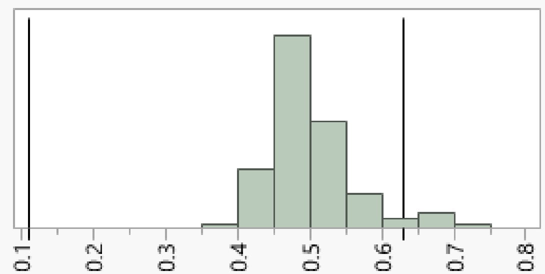


Summary Statistics

Mean	1.2379911
Std Dev	0.1258308
Std Err Mean	0.0097081
Upper 95% Mean	1.2571574
Lower 95% Mean	1.2188247
N	168

C, Stylus=0.0001" Radius

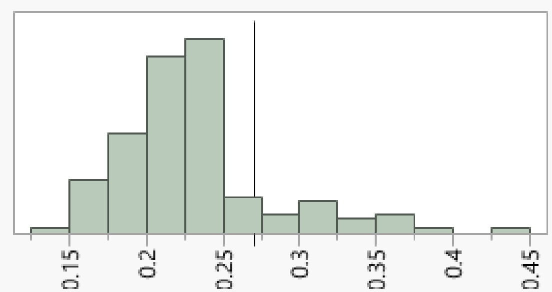
Mean(Rk (μm))



Summary Statistics

Mean	0.4970167
Std Dev	0.0579101
Std Err Mean	0.0047283
Upper 95% Mean	0.5063599
Lower 95% Mean	0.4876734
N	150

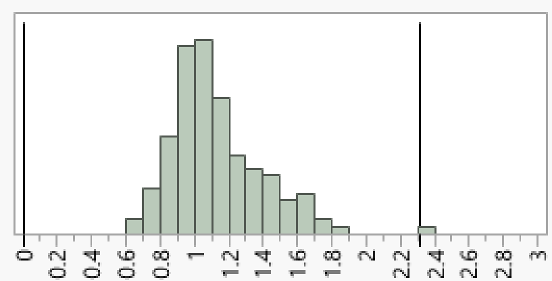
Mean(Rpk (μm))



Summary Statistics

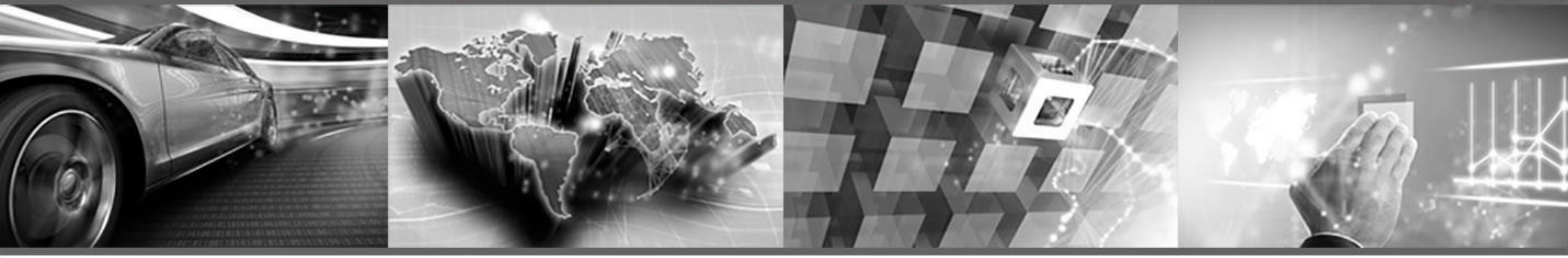
Mean	0.2283333
Std Dev	0.0490332
Std Err Mean	0.0040035
Upper 95% Mean	0.2362444
Lower 95% Mean	0.2204223
N	150

Mean(Rvk (μm))



Summary Statistics

Mean	1.1275833
Std Dev	0.2655661
Std Err Mean	0.0216834
Upper 95% Mean	1.17043
Lower 95% Mean	1.0847367
N	150



SUCCESS TOGETHER

Working together, achieving great things

When your company and ours combine energies, great things can happen. You bring ideas, challenges and opportunities. We'll bring powerful additive and market expertise, unmatched testing capabilities, integrated global supply and an independent approach to help you differentiate and succeed.

Lubrizol

DD13 Scuffing Test
Impact of Batch C Liners on test results

Presented to the Daimler Surveillance Panel

April 13, 2018

Performance you can rely on.

Overview

- **Industry activities:**
  - In 2018 there was a change in liner suppler for the DD13 scuffing test
  - The DD surveillance panel agreed to evaluate the suitability of the new batch of liners by testing the new liners:
    - In the 3 matrix test stands
    - Using Industry Reference oil X (TMC-864)
  - Preliminary results show that the hours to scuff at the three test labs are 30 hours, 31 hours, and 200 hours, respectively
    - Oil X had never delivered a 30 hr. result before and this could signal a severity issue

- **Infineum activities:**
  - Infineum also ran the DD13 scuffing test with batch C liners using two different internal non-commercial oils
  - Results show that both oils scuffed significantly earlier than the results tested with the previous batch of PNB liners

Infineum information shared with the Daimler Surveillance Panel

DD13 Scuffing Results

- An “outstanding” performing experimental oil that can consistently achieve 200 hours has scuffed at 31 and 92 hours with new batch C liners

Liners	Hours to Scuff
PNB liners	200, 200, 98, 200
Batch C liners	31, 92

- A “good” performing experimental oil that always passed 31 hours, has failed the DD13 test twice with the batch C liners

Liners	Hours to Scuff
PNB liners	31 hrs. (5 out of 7 tests)
Batch C liners	30, 16

Conclusions and Recommendations

- **Conclusions:**
  - There is concern that batch C liners may result in the DD13 Scuff test no longer discriminating the way it did as developed and with PNB liners
  - Reference oil X (designed to perform between development oil C & D) may not be sensitive enough to catch the increase in severity, given the large variability in the recent DD13 scuffing tests results
  - Current liner measurements may not be sufficient to characterize the liner differences, which may require further surface analysis to confirm

- **Recommendations:**
  - The Surveillance Panel should ensure DD13 Scuff test performance remains consistent through hardware changes
  - Consider running industry reference oil C and "DD13 development oil D" to confirm if the batch C liners do in fact shift the discrimination of the DD13 scuffing test towards greater severity as observed using the Infineum reference oils
  - Infineum is willing to perform further evaluation of batch C liners via surface analysis to identify any differences between the liner batches which may explain the observed differences
    - Visual differences were noted in graphite flake distribution on liner surface, warranting further investigation

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