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ASTM D02.B0.07 Semi-Annual Report Bench Test Monitoring

D6417, D5133 (GI), D5800, D6335 (TEOST), D7097(MTEOS), D6082, D874 and D7528 (ROBO)

April 2019

B0.07 Bench Testing Executive Summary

- D6417 (Volatility by GC)
- Precision (Pooled s) is less precise than prior period
  - Less precise than target precision
  - Influenced somewhat by one result 3.2 s severe
    - (Lab G, Oil 55)
- Performance (Mean Δ/s) is 0.35 s severe
- CUSUM plot shows overall severe performance this period.

B0.07 Bench Testing Executive Summary

- D5800 (Volatility by Noack)

- Precision (Pooled s) is less precise than the target LTMS pooled precision of 0.73 mass %, but comparable to the prior report period.
- Performance (Mean Δ/s) is 0.51 s severe.
- All operationally valid tests (AC & OC) reported this period were within $\pm$ 3 s of targets, no significant outliers.
- Fail rate of operationally valid tests (AC & OC) has increased to 7% this period, slightly more than expected 5%. The fail rate had dropped to 5% or less for the prior four report periods using EWMA LTMS, compared to approximately 26% under the Shewhart severity only system.
- CUSUM plot shows a continuing overall severe trend with reference testing.

B0.07 Bench Testing Executive Summary

- D5133 (Gelation Index)
- Fail rate of operationally valid tests is 0% this period. Historic period fail rates have ranged between 6% and 26%.
- Performance (Mean Δ/s) is 0.13 s severe
  - Comparable to last two periods.
- Precision (Pooled s) is more precise than target precision.
- All operationally valid tests (AC & OC) reported this period were within ± 3 s of targets, no significant outliers.
- Oil GIA17 was approved by panel vote as a severe performing reference oil replacement for oil 62, which is in low supply.

B0.07 Bench Testing Executive Summary

- D5133 (Gelation Index, continued)
- While performance and precision this period is good, prior erratic calibration performance of certain heads should raise concerns about the adequacy of the current 'single-test' Shewhart monitoring system to catch severe or mild performing instruments or heads in a timely manner. And, whether those instruments demonstrating multiple failing results should be considered properly calibrated based on just one passing Shewhart test result on just one viscometer head.
  - While the panel has recently been considering proposals for a head-based Shewhart calibration system, industry might be better served if an LTMS EWMA based monitoring system was considered for this test, much like what is currently done in D5800. Capturing data on a head based calibration system, over time, should provide additional data for consideration.
- Severe performing GI reference oil 62 is in low supply. On March 26, 2019, the panel approved a replacement oil GIA17 with preliminary targets from a round robin study.

B0.07 Bench Testing Executive Summary

- D6335 (TEOST-33C)

- Precision (Pooled s) is less precise than prior period, and less precise than target precision.
  - All five OC fails this period were on mild performing oil 435-2.
  - Precision on 435-2 is unusually poor this period as a result.
- Performance (Mean Δ/s) is 0.11 s severe.
- Fail rate of 20% is unusually high for the period.
- All tests this period report using Rod Batch M.
- Oil 75-1 (reblend) was approved on 20190404 to replace severe performing reference oil 75, which is in low supply.

B0.07 Bench Testing Executive Summary

- D7097 (MHT-4 TEOST)
- Precision (Pooled s) is comparable to last report period and comparable to target precision
  - Improved precision last four report periods, compared to prior report periods, is coincident with use of new end cap flask seals
- Performance (Mean Δ/s) is -0.14 s mild.
- All operationally valid tests this period report using Rod Batch M
- All operationally valid calibration tests this period report using Catalyst Batch 15AA (n=2), 16DA (n=18) or 18AB (n=77).
- Overall severity of the newest catalyst batch 18AB (n=92) appears to be about -0.3 s mild, and comparably mild on both reference oils.

B0.07 Bench Testing Executive Summary

- D6082 (High Temperature Foam)

- Foam Tendency Precision (Pooled s) is less precise than the prior report period
  - More precise than target precision

- Performance (Mean Δ/s) is on target (slight mild bias)

- No non-zero occurrences of Foam Stability

  - Six of seven severe oil discrimination runs (on TMC oil 66) demonstrated acceptable discrimination.
    - One discrimination run reported mild of lower limit of 100 ml foam tendency (validity OS), repeat run showed acceptable discrimination.

B0.07 Bench Testing
Executive Summary

- D874 (Sulfated Ash)
- Precision (Pooled s) is comparable to prior periods
  - More precise than target precision
- Performance (Mean Δ/s) is -0.33 s mild

B0.07 Bench Testing Executive Summary

- D7528 (ROBO)
- Precision (Pooled s) is notably less precise than the last three periods
  - Continues to be less precise than target
  - Poorer precision this period is consistent across the three reference oils.
- Performance (Mean Δ/s) is on-target for this report period

B0.07 Bench Testing
Executive Summary

- D7528 (ROBO) continued

- CUSUM Severity Plot shows an overall leveling to on-target performance this period, following a long overall mild trend since the 01APR11 timeline (following a 2011 ROBO workshop). A similar, but brief, leveling is also noted in the CUSUM plot coincident with the October 2015 ROBO workshop held in San Antonio, TX, but the mild trend returned on subsequent periods, denoted by date timelines in the plot.

Calibrated Labs and Stands*

Test	Labs	Stands
D6417	6	8
D5800	9	24
D5133 (GI)	5	8
D6335 (TEOST)	7	10
D7097 (MTEOS)	11	48
D6082	6	7
D874	4	--
D7528 (ROBO)	4	19

*As of 3/31/2019

D02.B0.07
TMC Monitored Tests

- October 1, 2018 –
  March 31, 2019

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D6417: Estimation of Engine Oil Volatility by Capillary GC

Test Status	Validity Code	No. Tests
Acceptable Calibration Test	AC	18
Failed Calibration Test	OC	1
Operationally Invalidated by Lab	LC, XC	0
Operationally Invalidated After Initially Reported as Valid	RC	0
Non-Blind Instrument Shakedown	NN	1
Total		**20**

Number of Labs Reporting Data: 7
Fail Rate of Operationally Valid Tests: 5%

D6417: Estimation of Engine Oil Volatility by Capillary GC

Statistically Unacceptable Tests (OC)	No. Of Tests
Volatility Loss Mild	0
Volatility Loss Severe	1

- There were no operationally invalidated D6417 tests reported this period.

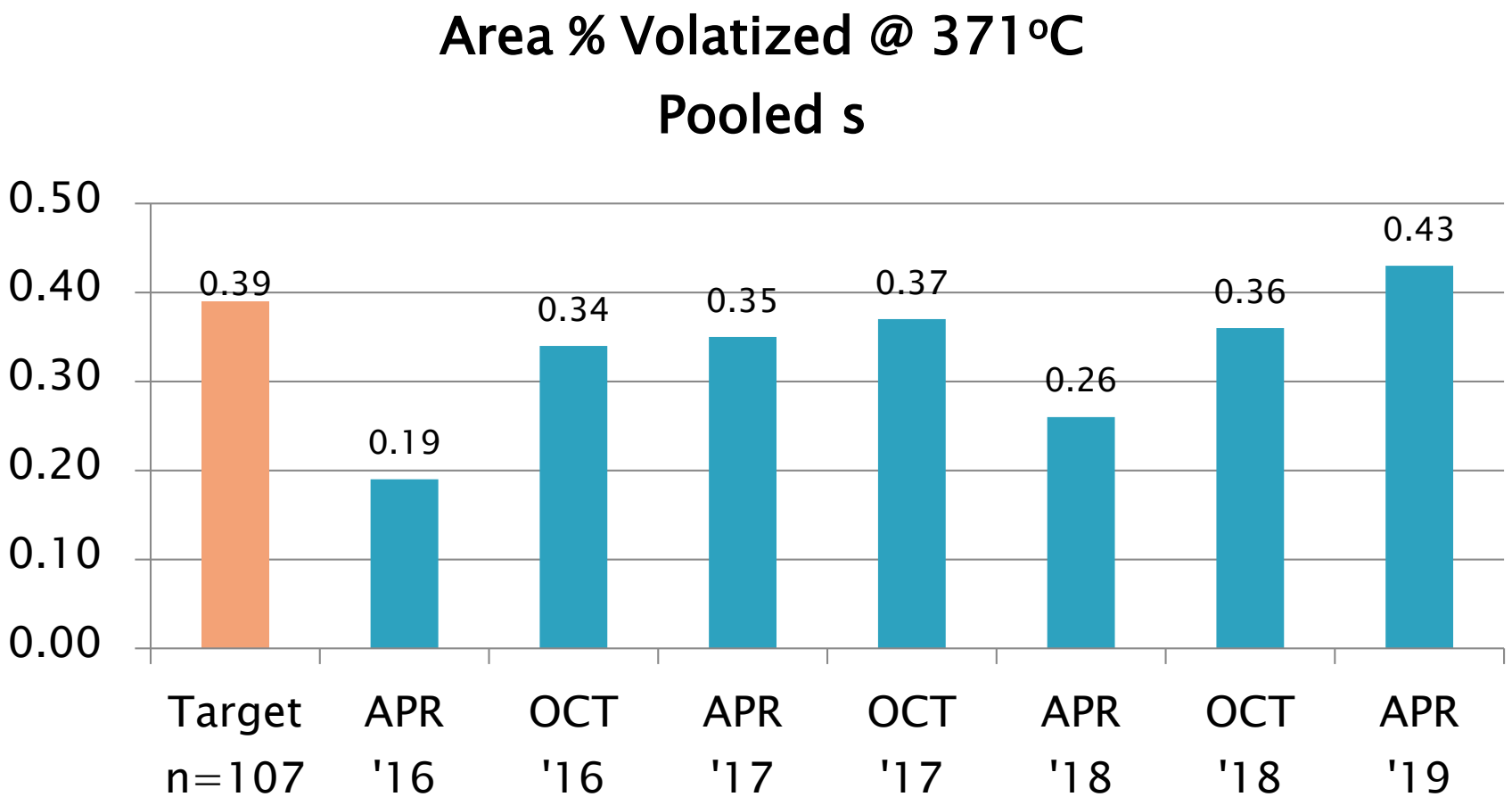
- Calibration requirement updates are issued as LTMS document updates

D6417: Estimation of Engine Oil Volatility by Capillary GC

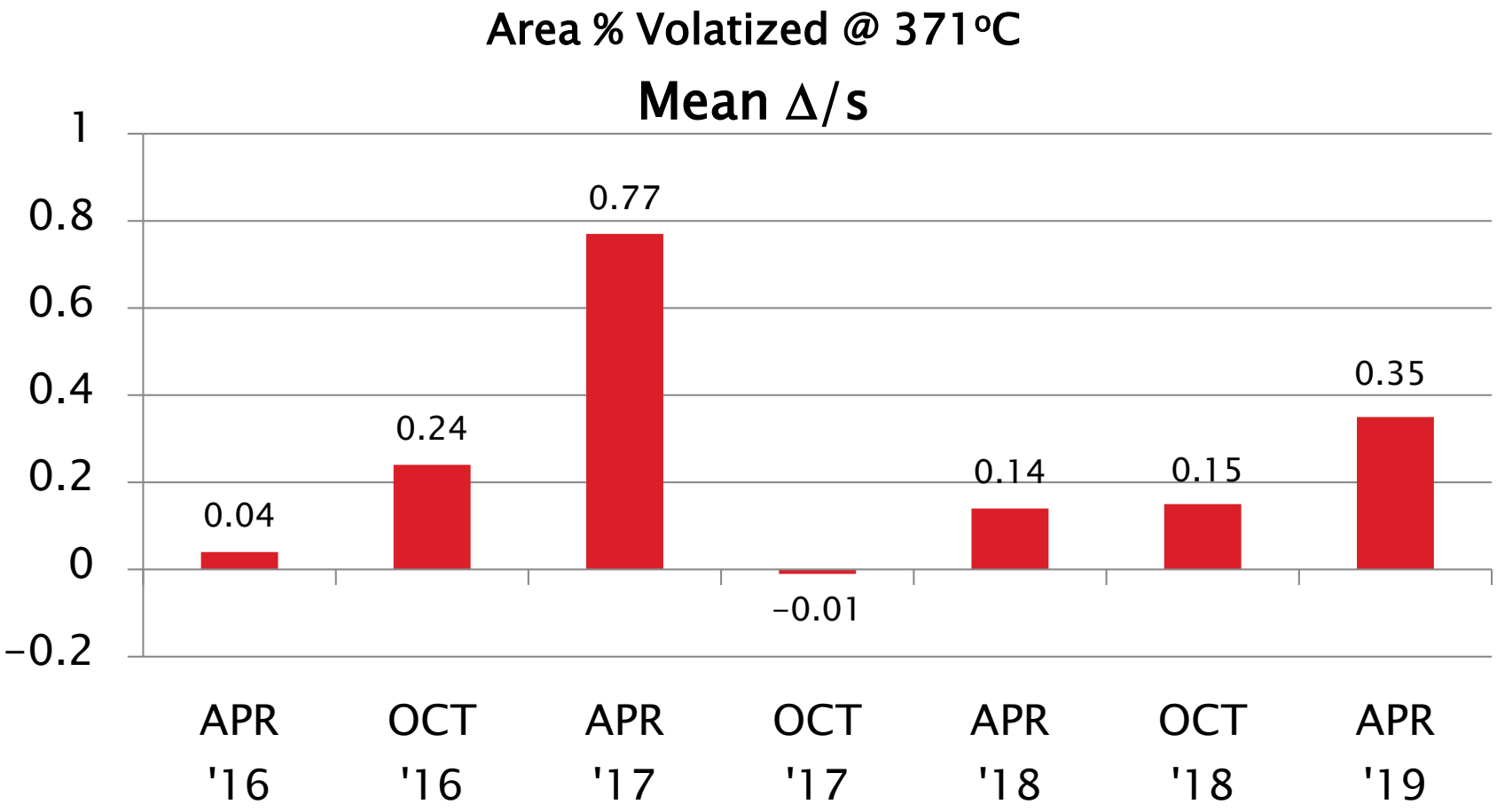
Period Precision and Severity Estimates

Area % Volatized @ 371°C	n	df	Pooled s	Mean Δ/s
Initial Selected Oils from RR	54	51	0.39	-----
10/1/15 through 3/31/16	13	10	0.19	0.04
4/1/16 through 9/30/16	11	8	0.34	0.24
10/1/16 through 3/31/17	13	10	0.35	0.77
4/1/17 through 9/30/17	15	12	0.37	-0.01
10/1/17 through 3/31/18	15	12	0.26	0.14
4/1/18 through 9/30/18	16	13	0.36	0.15
10/1/18 through 3/31/19	19	16	0.43	0.35

D6417 Precision Estimates



D6417 Severity Estimates

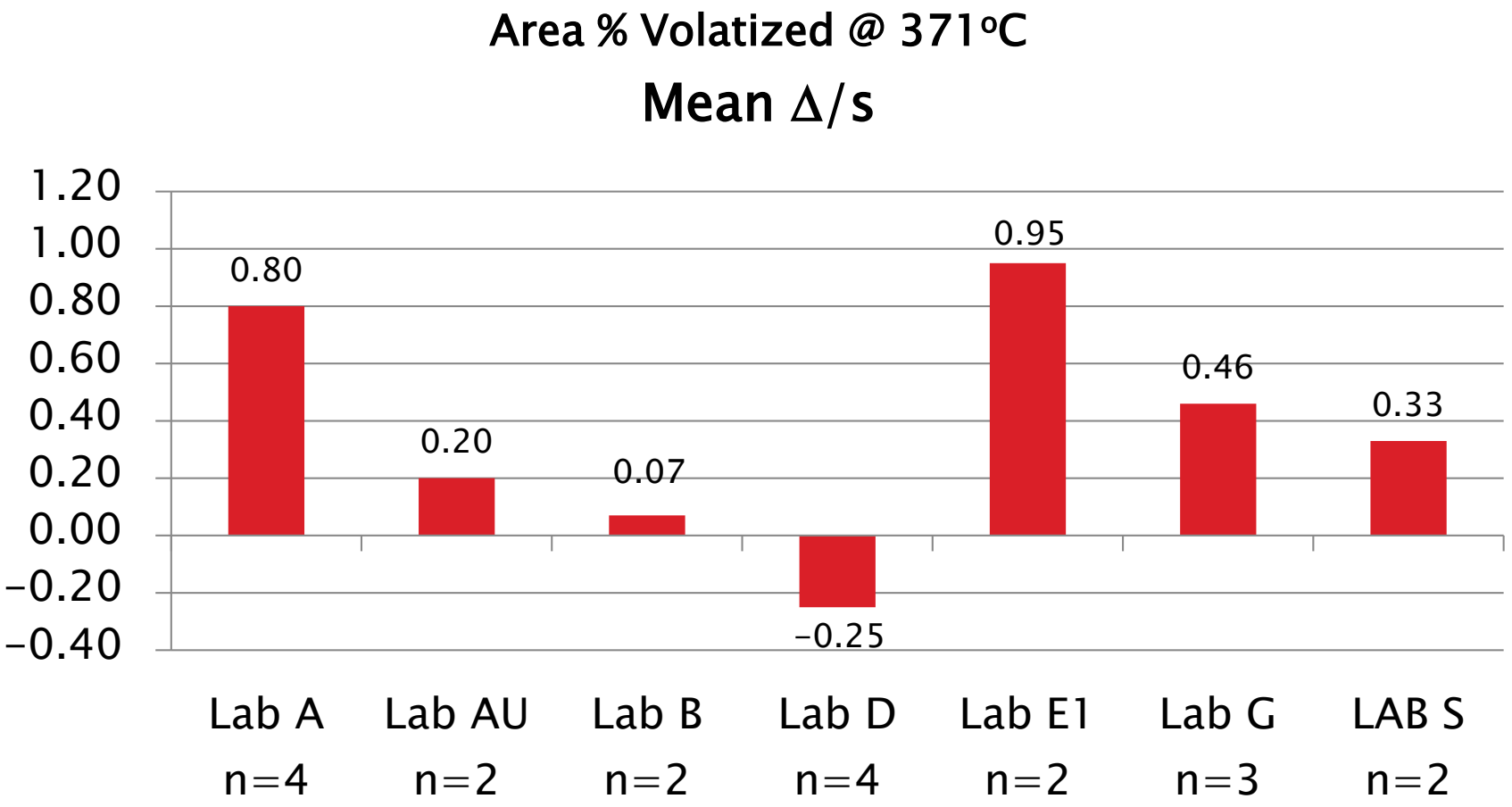


D6417: Estimation of Engine Oil Volatility by Capillary GC

Current Period Severity Estimates by Lab
Area % Volatized @ 371°C

	n	Mean Δ/s
Lab A	4	0.80
Lab AU	2	0.20
Lab B	2	0.07
Lab D	4	-0.25
Lab E1	2	0.95
Lab G	3	0.46
Lab S	2	0.33

D6417 Lab Severity Estimates



D6417: Estimation of Engine Oil Volatility by Capillary GC

- Precision (Pooled s) is less precise than prior period
  - Less precise than target precision
  - Influenced somewhat by one result 3.2 s severe
    - (Lab G, Oil 55)

- Performance (Mean Δ/s) is 0.35 s severe

- CUSUM plot shows overall severe performance this period.

D6417 VOLATILITY BY GC INDUSTRY OPERATIONALLY VALID DATA

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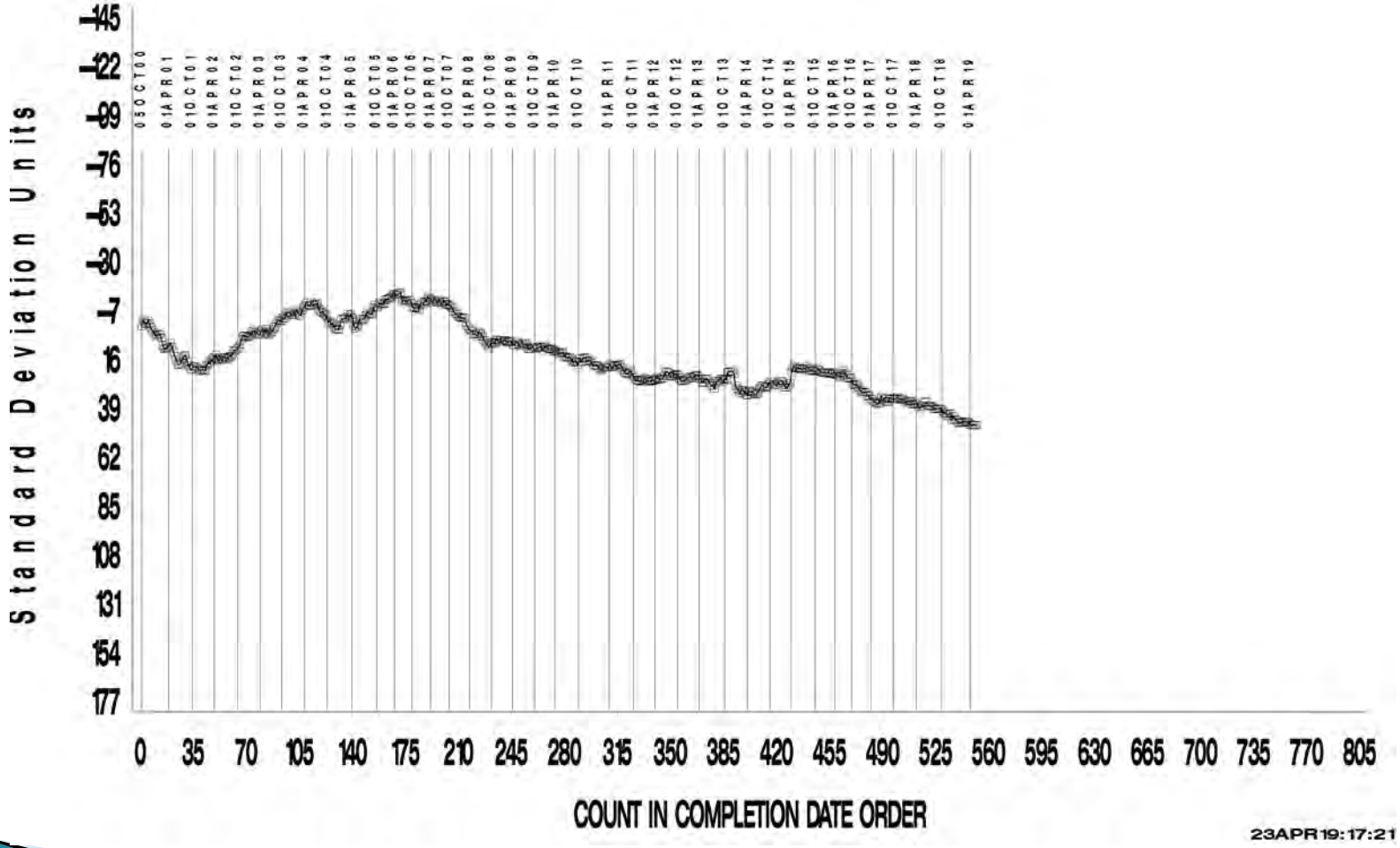
SAMPLE AREA % VOLATIZED

CUSUM Severity Analysis



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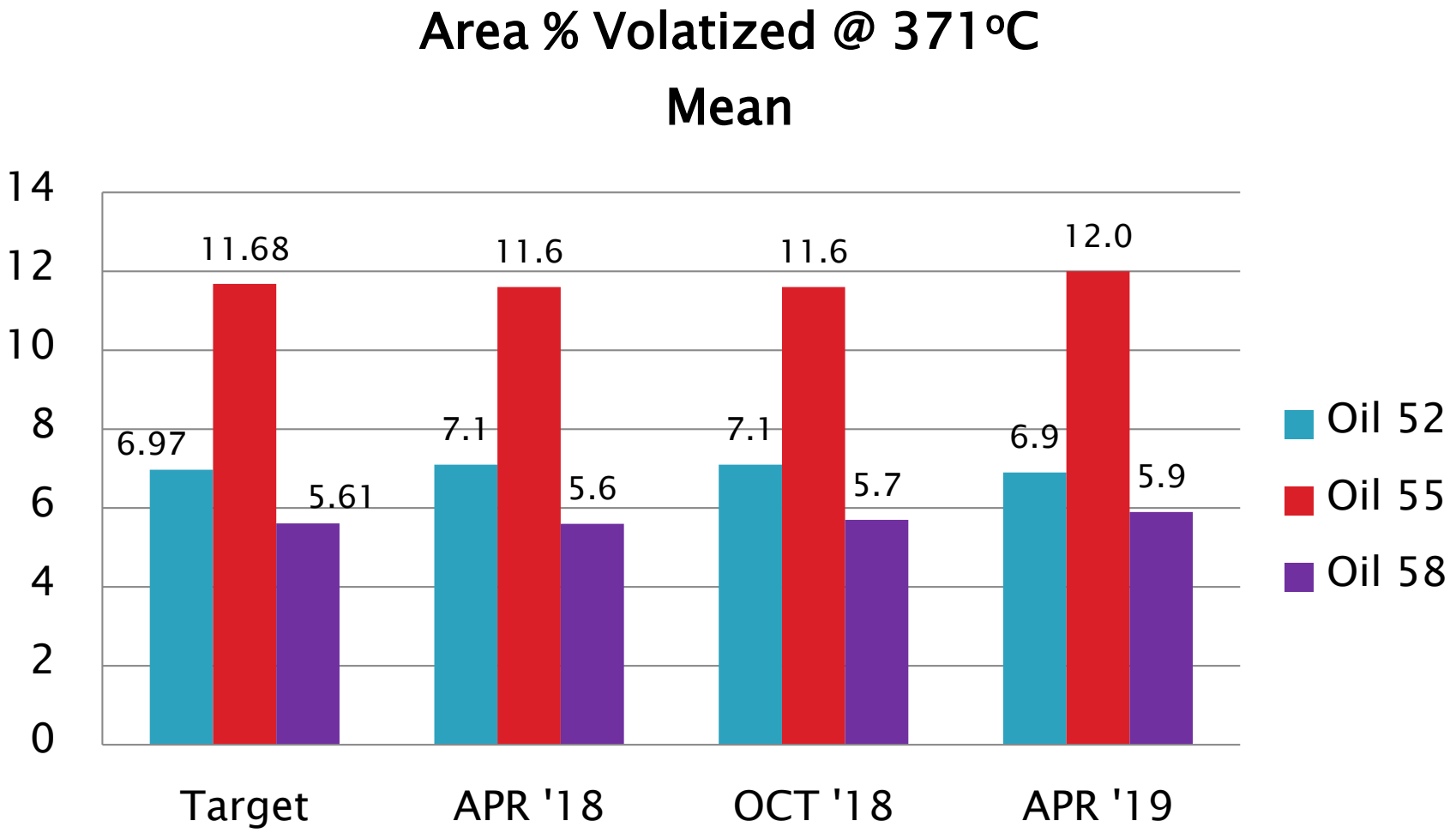
D6417: Estimation of Engine Oil Volatility by Capillary GC

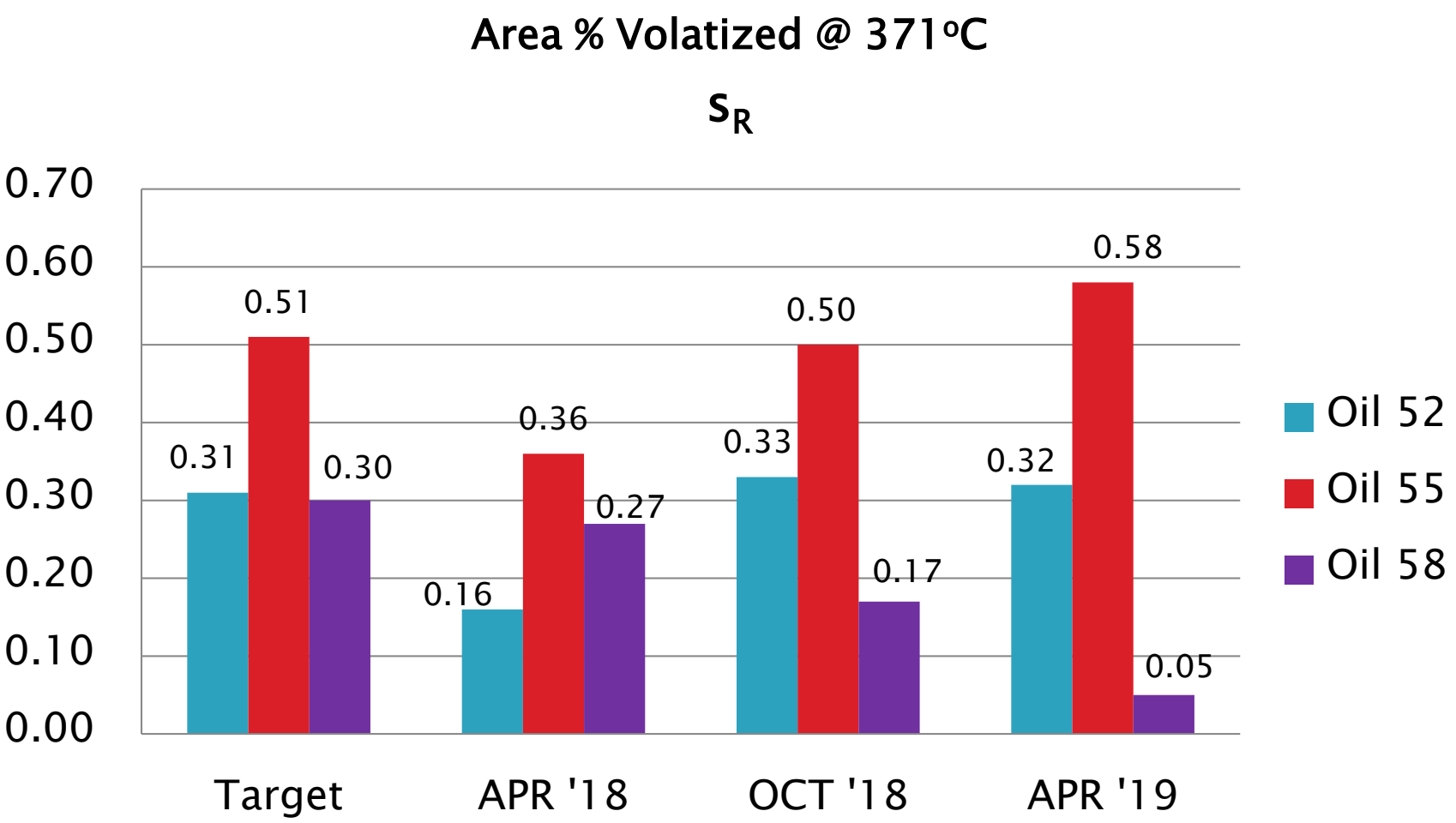
Area % Volatized @ 371°C
Performance by Oil

	Targets			10/1/17 - 3/31/18				4/1/18- 9/30/18				10/1/18 - 3/31/19			
Oil Code	n	Mean	s_R	n	Mean	s_R	Mean Δ/s	n	Mean	s_R	Mean Δ/s	n	Mean	s_R	Mean Δ/s
52	18	6.97	0.31	6	7.1	0.16	0.37	4	7.1	0.33	0.34	7	6.9	0.32	-0.23
55	18	11.68	0.51	4	11.6	0.36	-0.16	6	11.6	0.50	-0.06	8	12.0	0.58	0.59
58	18	5.61	0.30	5	5.6	0.27	0.10	6	5.7	0.17	0.24	4	5.9	0.05	0.88

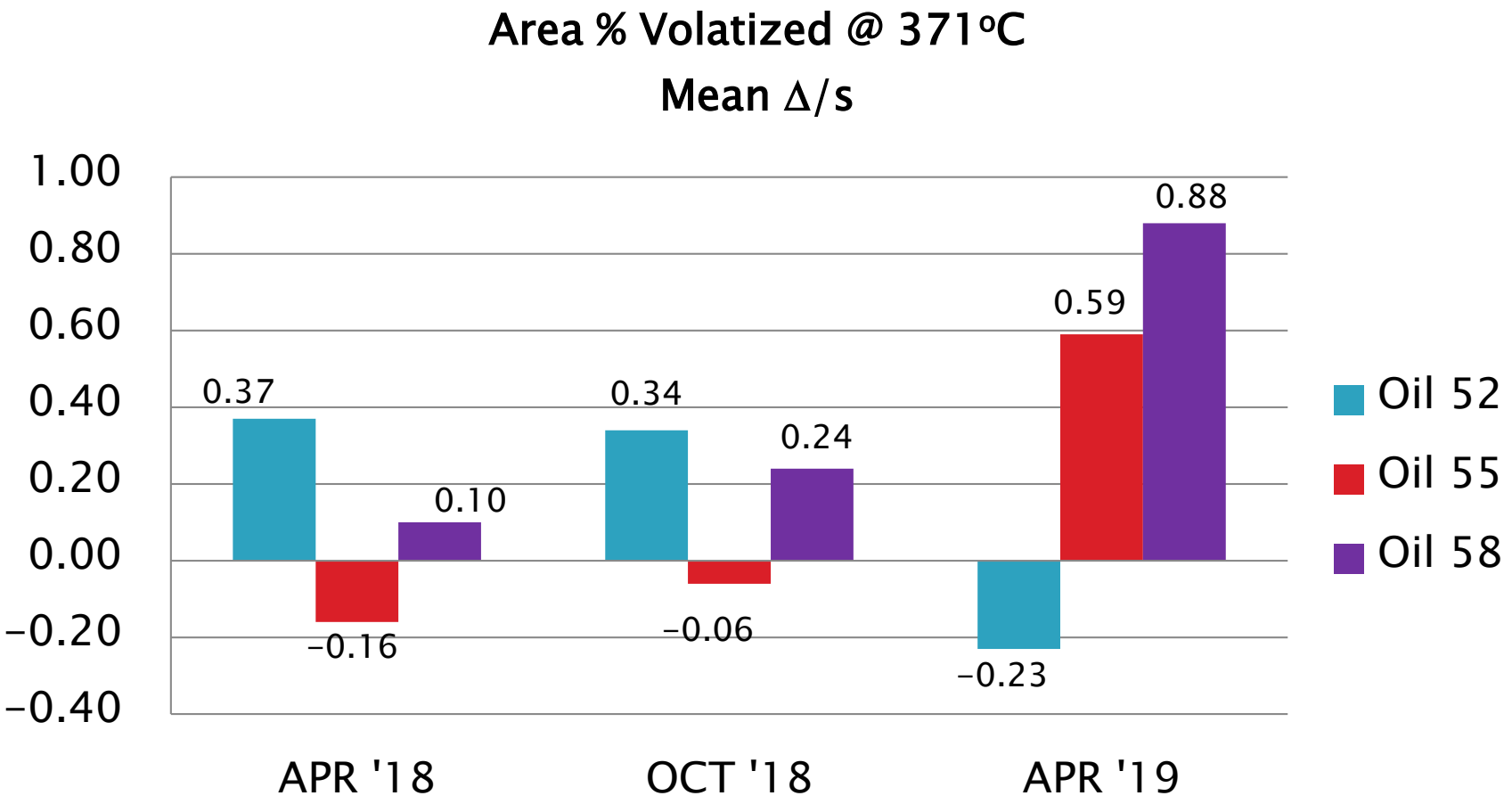
D6417 Performance by Oil



D6417 Performance by Oil



D6417 Performance by Oil



Return to Executive Summary

D5800: Evaporation Loss of Lubricating Oil by Noack Method

Test Status	Validity Code	No. Tests
Acceptable Calibration Test	AC	141
Failed Calibration Test	OC	10
Operationally Invalidated by Lab	LC, XC	2
Operationally Invalidated After Initially Reported as Valid	RC	6
Non-Blind Instrument Shakedown	NN	30
Replacement Reference Oil RR	LG	2
Total		**191**

Number of Labs Reporting Data: 11
Fail Rate of Operationally Valid Tests: 7%

D5800: Evaporation Loss of Lubricating Oil by Noack Method

Statistically Unacceptable Tests (OC)	No. Of Tests
Ei Level 3 Precision Alarm Mild	2
Ei Level 3 Precision Alarm Severe	1
Zi Level 2 Severity Severe	6
Zi Level 2 Severity Mild	1

- The 10 OC tests were on six different rigs at four labs.
  - Four on lab/rig J5 (two consecutive fails occurring twice in the period, with two passing calibrations in between the OC fails).
  - Two consecutive fails on lab/rig D3, and two additional fails on two other rigs at lab D.
  - Lab J had similar issues last report period with three OC failing runs, but on a different instrument (J4), but also an OC fail on rig J5.

- Eight operationally invalid calibration runs reported this period:
  - Three tests with QC sample not run (RC), two at Lab D, one at Lab J.
  - Two procedure D tests on a new rig where lab reports using wrong orifice size (RC), both at Lab D
  - Two reported with vacuum failure during test (LC) at Lab D.
  - One reported as biased by unusually cold ambient temperature in lab (RC), Lab V

D5800: Evaporation Loss of Lubricating Oil by Noack Method

- Non-calibration tests reported for the period:
  - Eighteen non-blind shakedown runs to troubleshoot instruments (NN).
  - Twelve TMC blind samples run mistakenly by lab J without prior TMC assignment (new operator, validity NN).
  - Two invalidated (LG) industry donated runs to evaluate proposed replacement QC check oil batch VOLD18.

- D5800 Technical memo 18-053 was issued 20181221: Pairing of Instrument Cups and Lids (Procedure B Tests Only)

- Calibration requirement updates are issued as LTMS document updates

D5800: Evaporation Loss of Lubricating Oil by Noack Method

Period Precision and Severity Estimates

Sample Evaporation Loss, mass %	n	df	Pooled s	Mean Δ/s
Targets Effective 10/19/2016	--	--	0.73	-----
4/1/16 through 9/30/16	62	59	0.60	0.99
10/1/16 through 3/31/17	136	133	0.70	0.53
4/1/17 through 9/30/17*	147	144	1.13	0.56
4/1/17 through 9/30/17*	146	143	0.84	0.47
10/1/17 through 3/31/18	133	130	0.81	0.15
4/1/18 through 9/30/18*	149	146	0.82	0.40
4/1/18 through 9/30/18*	148	145	0.76	0.44
10/1/18 through 3/31/19	151	148	0.81	0.51

*Extreme OC result included and excluded

D5800: Evaporation Loss of Lubricating Oil by Noack Method

Performance Comparison by Procedure & Model

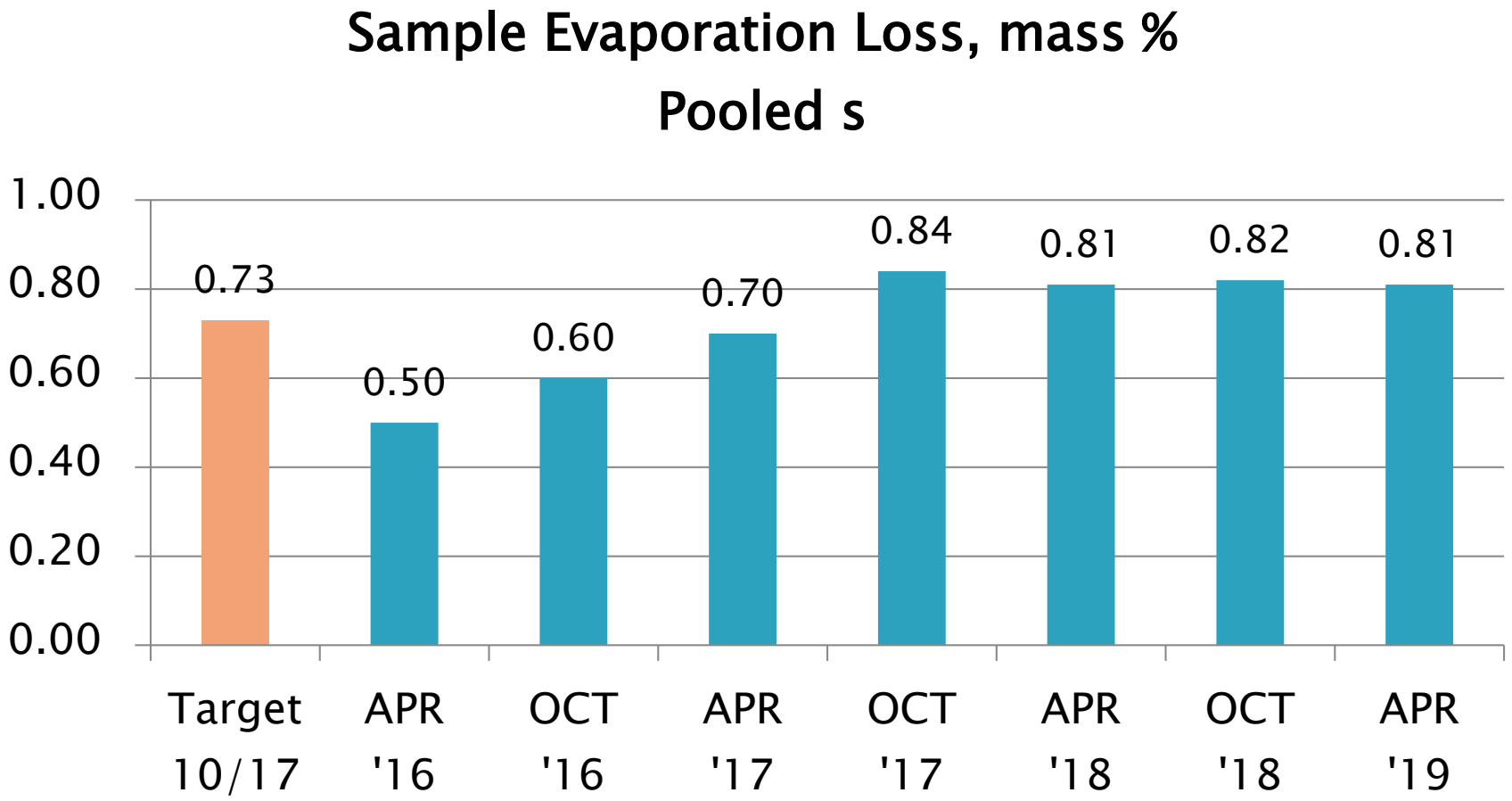
Sample Evaporation Loss, Mass %

	n	df	Pooled s	Mean Δ/s
Procedure B	120	117	0.67	0.80
Procedure C	3	1	1.63	-1.15
Procedure D	28	25	0.62	-0.58

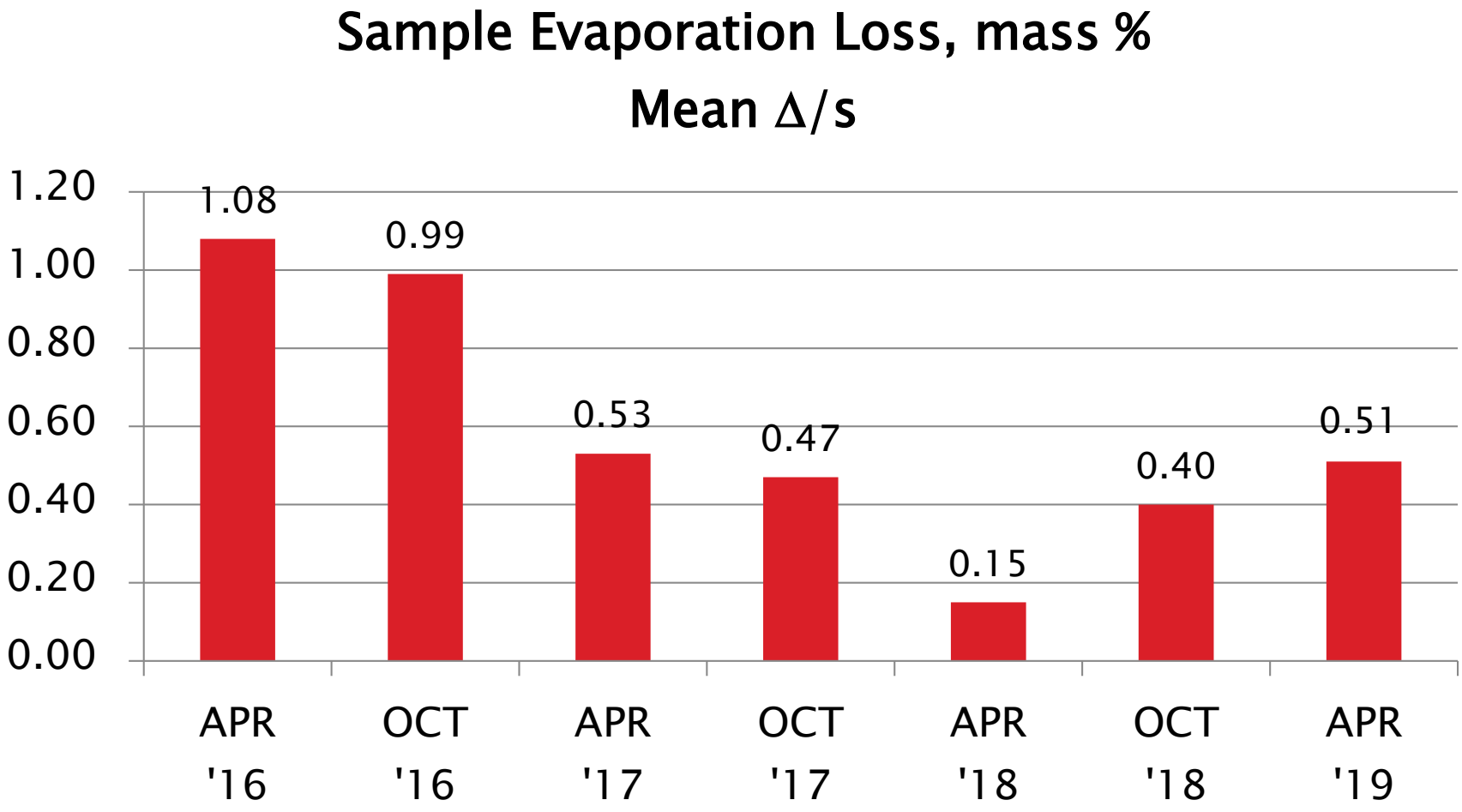
Model	n	df	Pooled s	Mean Δ/s
NCK2	10	7	0.31	0.00
NCK25G	110	107	0.66	0.87
NS2	28	25	0.62	-0.58
SVT1	3	1	1.63	-1.15

2 Procedure B NCK2 Rigs
23 Procedure B NCK25G Rigs
6 Procedure D NS2 Rigs
1 Procedure C SVT1 Rigs

D5800 Precision Estimates



D5800 Severity Estimates



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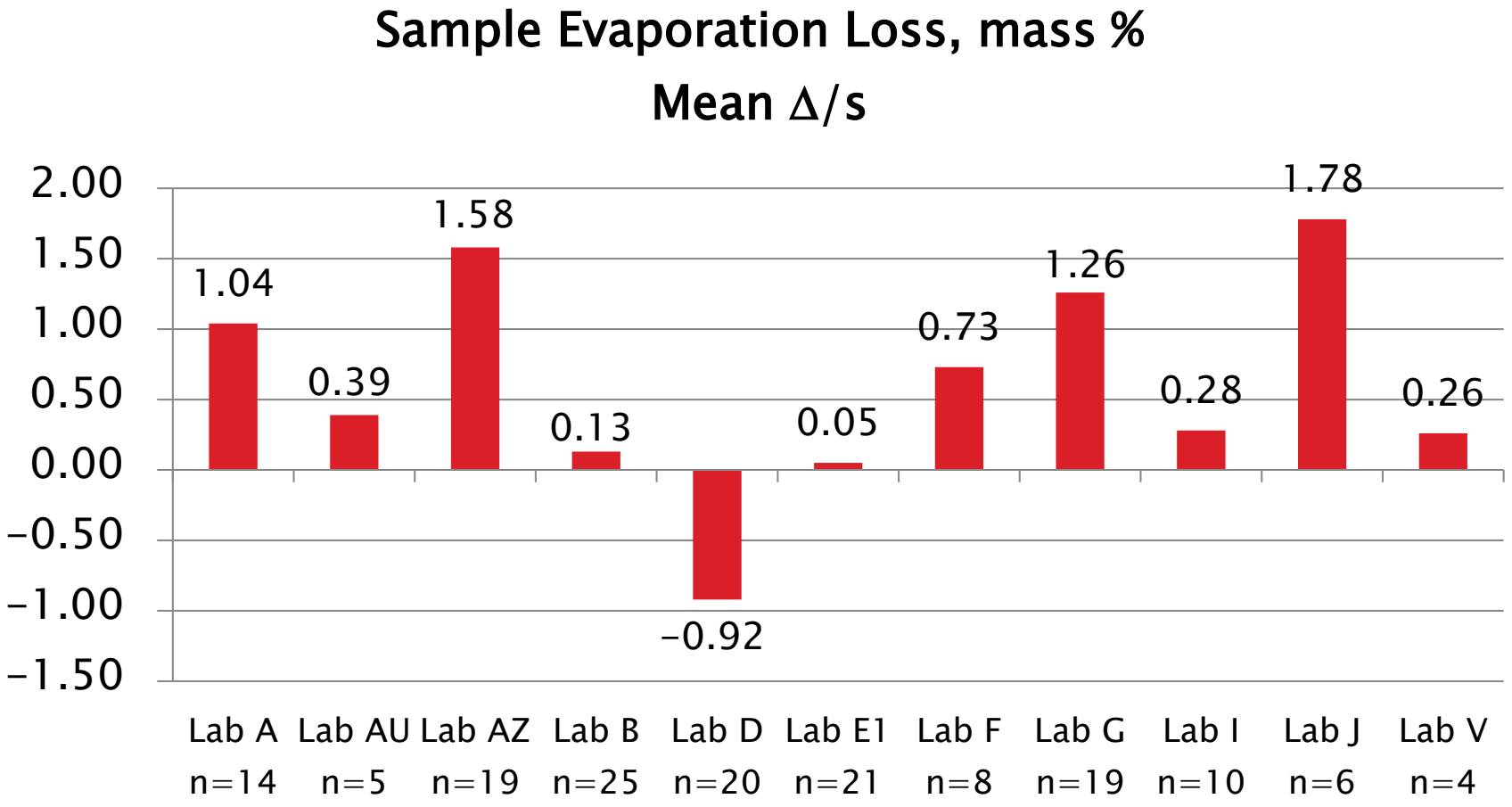
D5800: Evaporation Loss of Lubricating Oil by Noack Method

Current Period Severity Estimates by Lab
Sample Evaporation Loss, mass %

Lab	n	Mean Δ/s	Lab	n	Mean Δ/s
Lab A	14	1.04	Lab F	8	0.73
Lab AU	5	0.39	LAB G	19	1.26
Lab AZ	19	1.58	Lab I	10	0.28
Lab B	25	0.13	Lab J	6	1.78
Lab D	20	-0.92	Lab V	4	0.26
Lab E1	21	0.05			

D5800 Lab Severity Estimates



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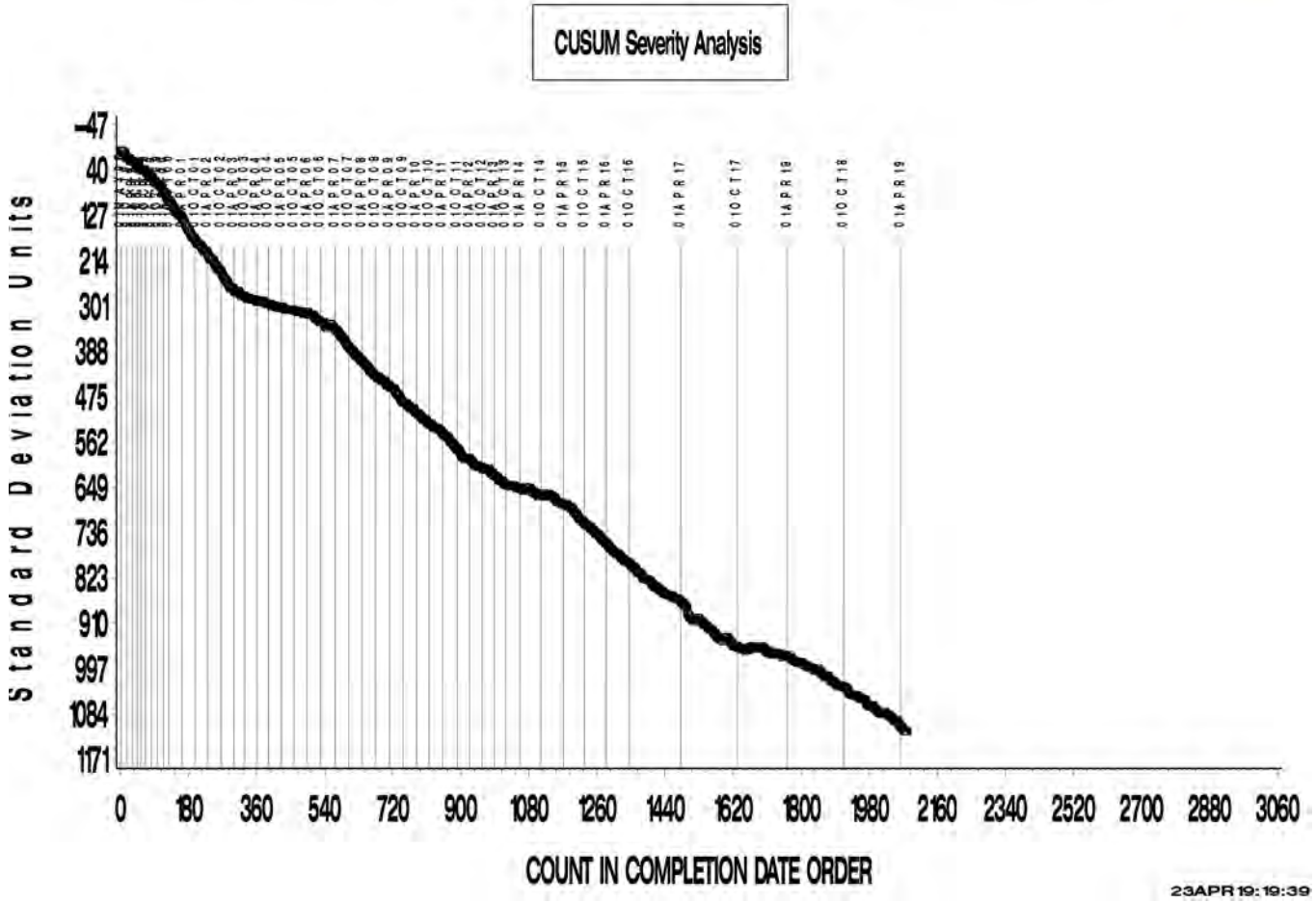
D5800: Evaporation Loss of Lubricating Oil by Noack Method

- Precision (Pooled s) is less precise than the target LTMS pooled precision of 0.73 mass %, but comparable to the prior report period.
- Performance (Mean Δ/s) is 0.51 s severe.
- All operationally valid tests (AC & OC) reported this period were within $\pm$ 3 s of targets, no significant outliers.
- Fail rate of operationally valid tests (AC & OC) has increased to 7% this period, slightly more than 5%. The fail rate had dropped to 5% or less for the prior four report periods using EWMA LTMS, compared to approximately 26% under the Shewhart severity only system.
- CUSUM plot shows a continuing overall severe trend with reference testing.

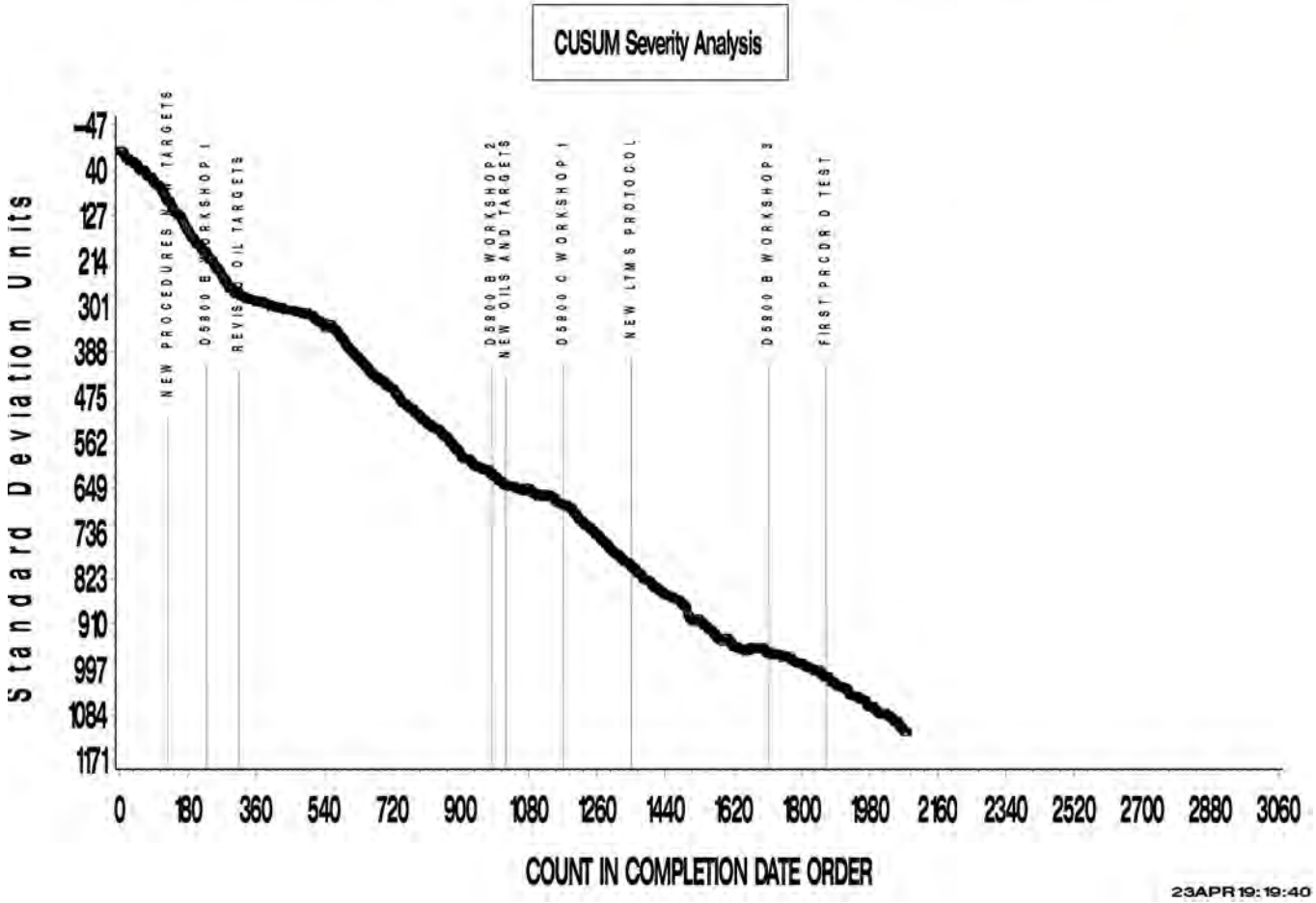
D5800 VOLATILITY BY NOACK INDUSTRY OPERATIONALLY VALID DATA

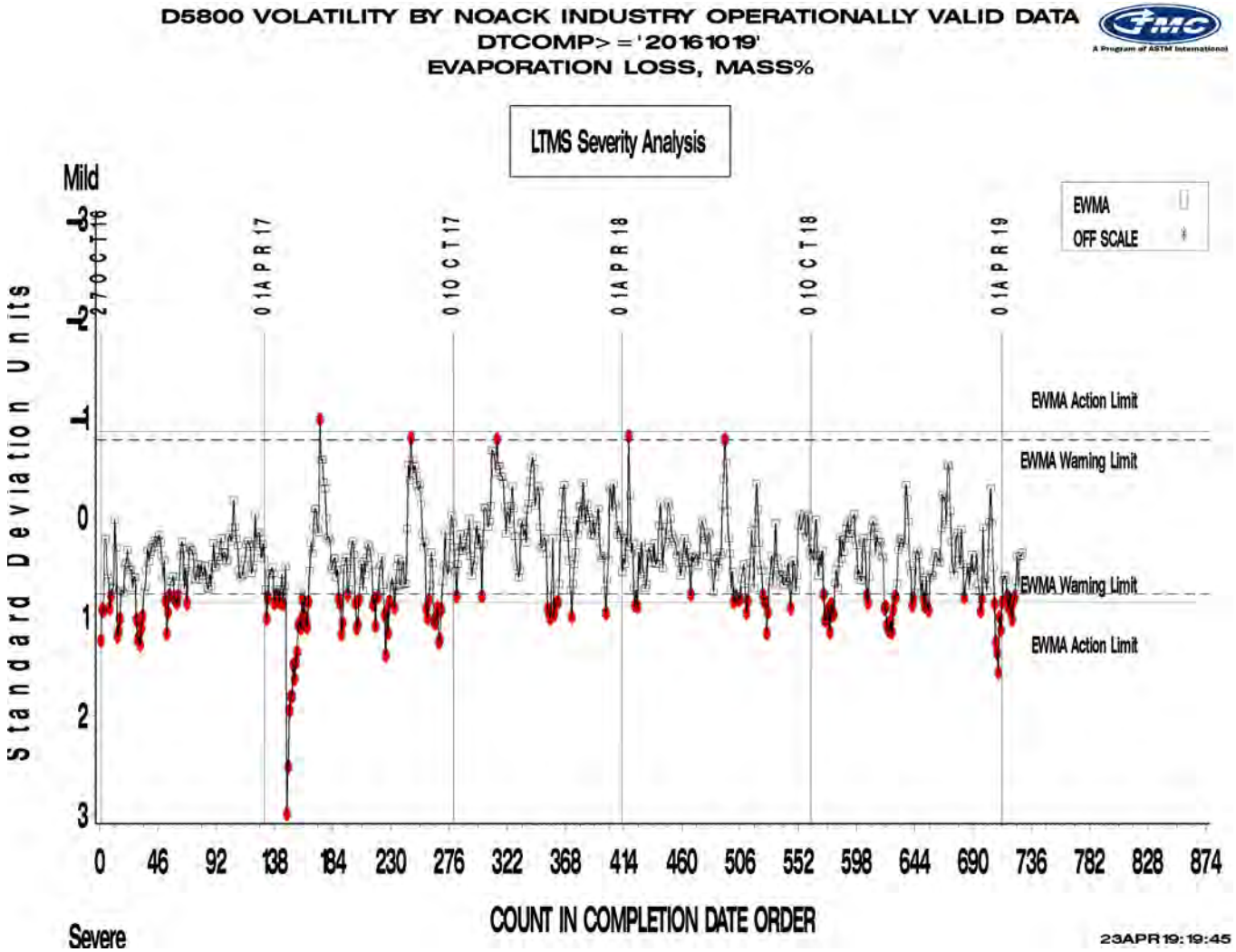
EVAPORATION LOSS, MASS%



D5800 VOLATILITY BY NOACK INDUSTRY OPERATIONALLY VALID DATA

EVAPORATION LOSS, MASS%




D5800 VOLATILITY BY NOACK INDUSTRY OPERATIONALLY VALID DATA
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EVAPORATION LOSS, MASS%
LTMS Severity Analysis
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Severe
Standard Deviation Units
EWMA
OFF SCALE
EWMA Action Limit
EWMA Warning Limit
EWMA Warning Limit
EWMA Action Limit
27OCT16
01APR17
01OCT17
01APR18
01OCT18
01APR19
3
2
1
0
1
2
3
0
46
92
138
184
230
276
322
368
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460
506
552
598
644
690
736
782
828
874
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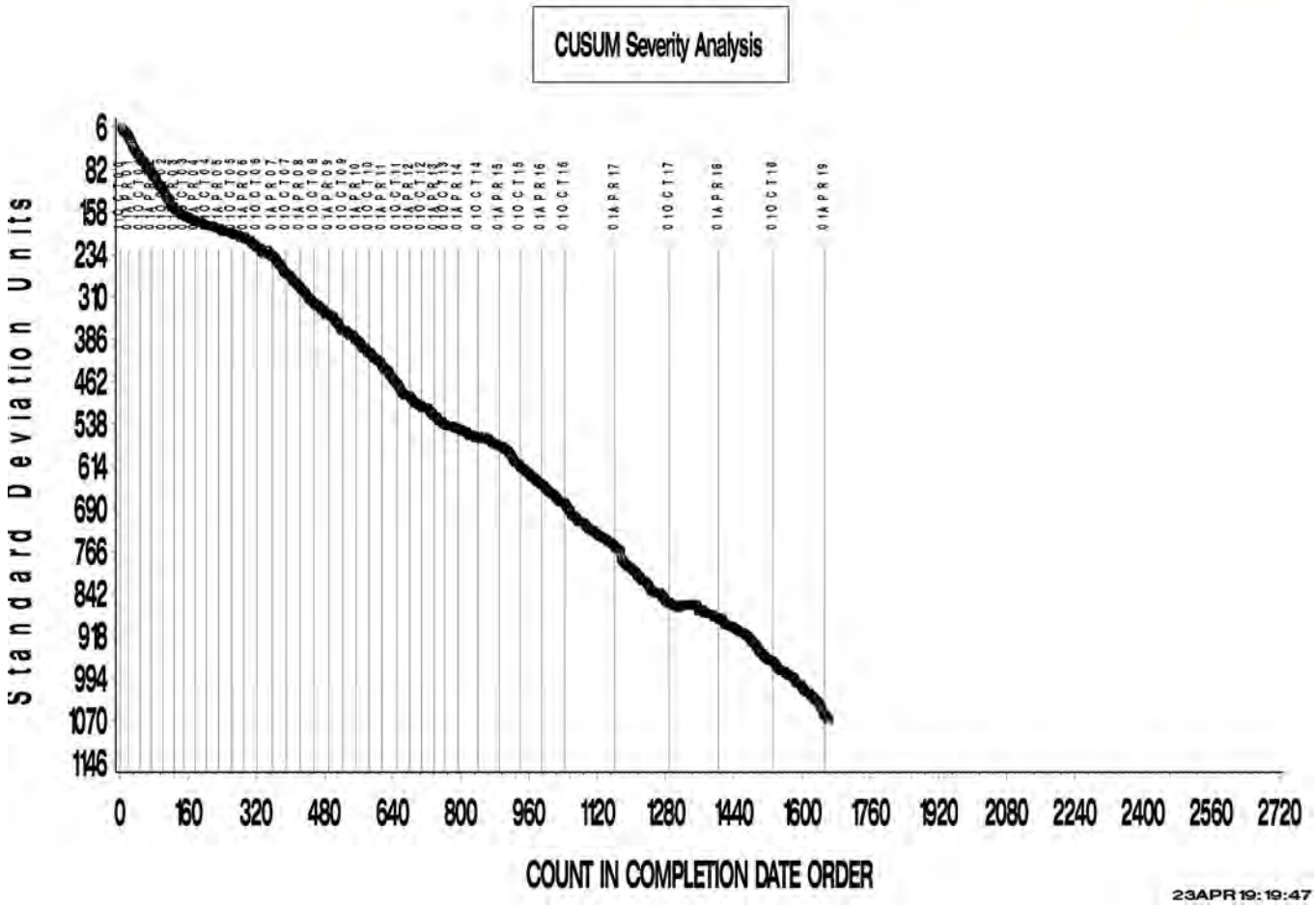
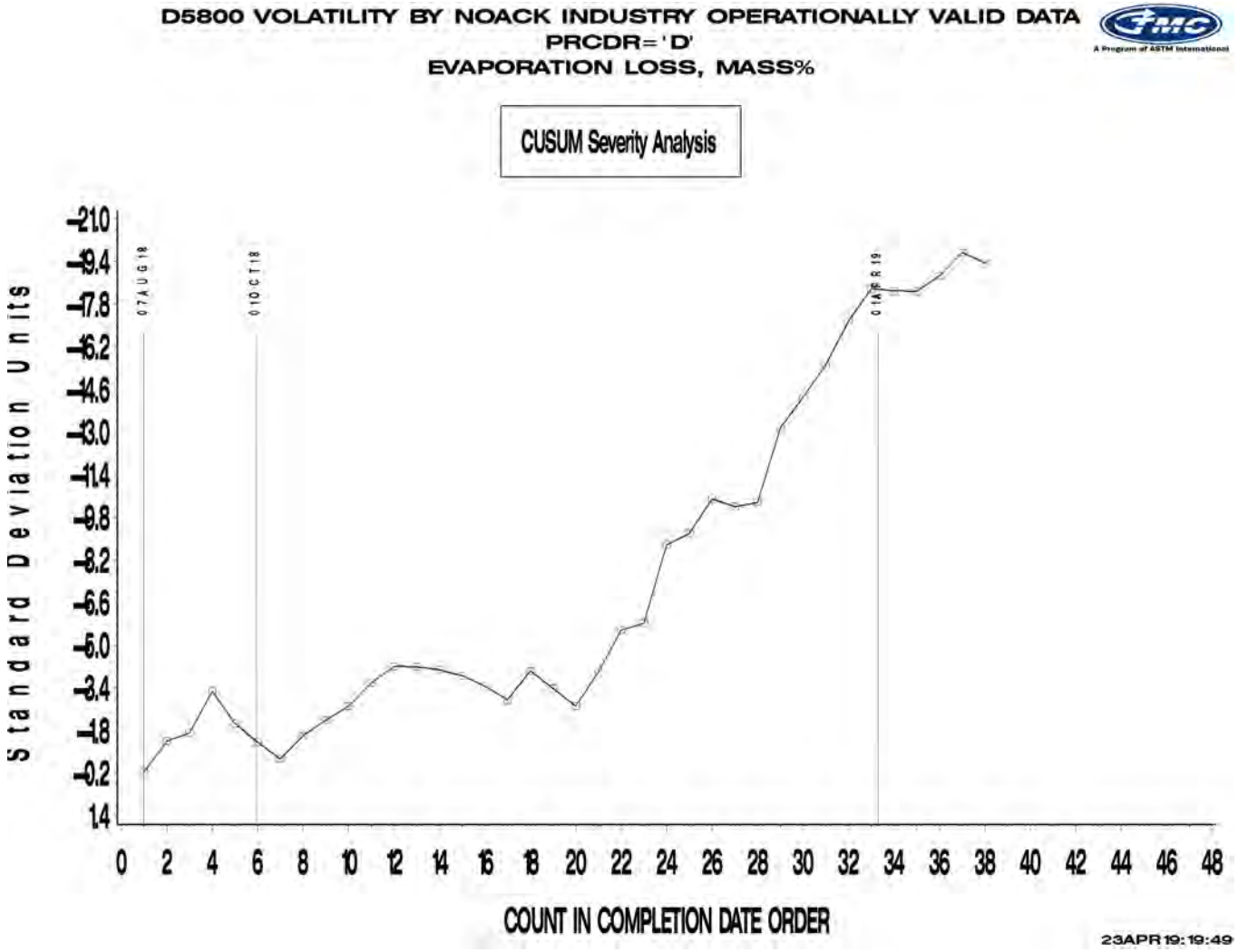
D5800 VOLATILITY BY NOACK INDUSTRY OPERATIONALLY VALID DATA
PRCDR='B'
EVAPORATION LOSS, MASS%



D5800 VOLATILITY BY NOACK INDUSTRY OPERATIONALLY VALID DATA
PRCDR='C'
EVAPORATION LOSS, MASS%

CUSUM Severity Analysis

23APR19:19:48


D5800 VOLATILITY BY NOACK INDUSTRY OPERATIONALLY VALID DATA
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EVAPORATION LOSS, MASS%
CUSUM Severity Analysis
Standard Deviation Units
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16.2
14.6
13.0
11.4
9.8
8.2
6.6
5.0
3.4
1.8
0.2
1.4
07AUG18
01OCT18
01APR19
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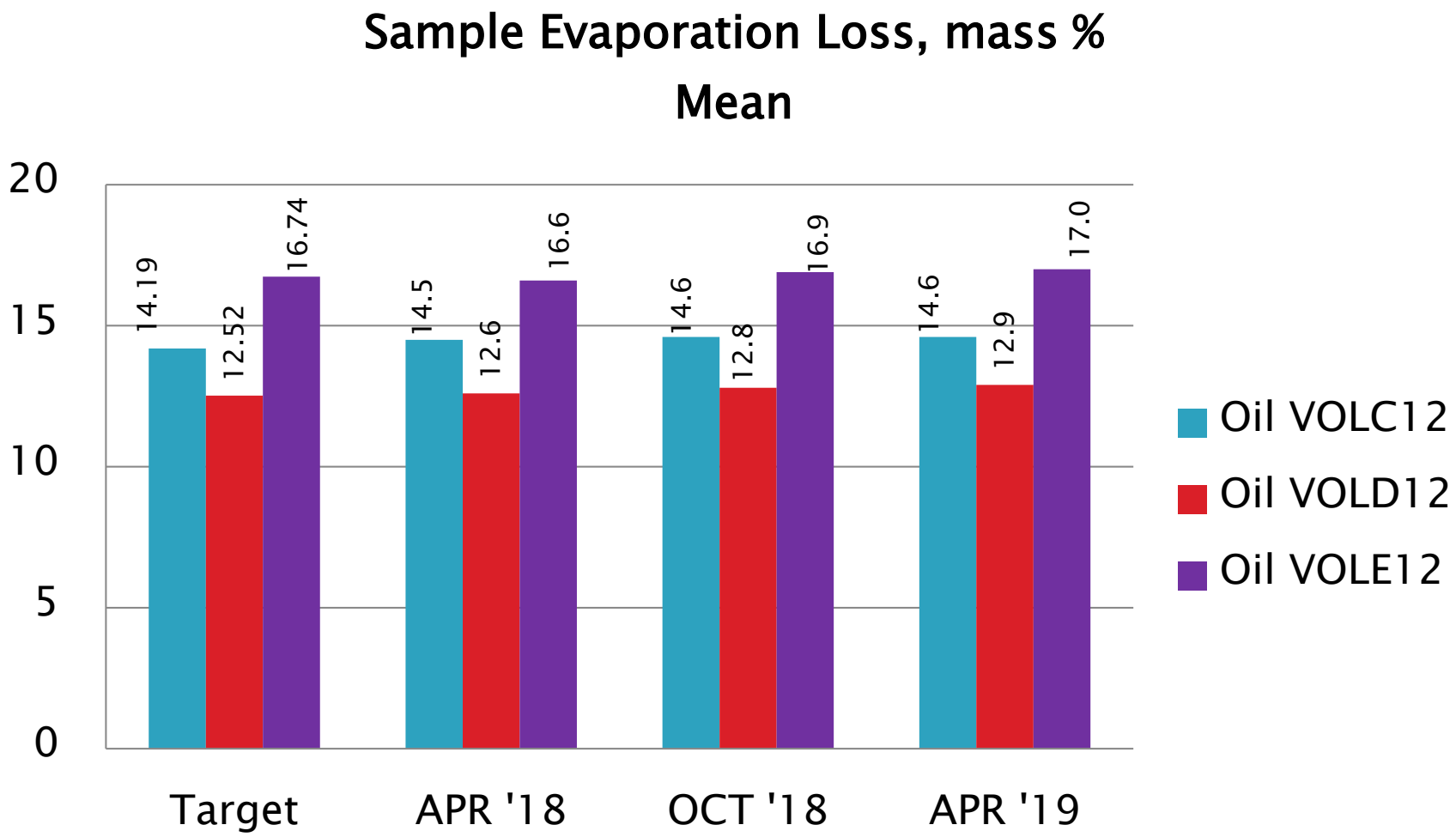
COUNT IN COMPLETION DATE ORDER
23APR19:19:49

D5800: Evaporation Loss of Lubricating Oil by Noack Method

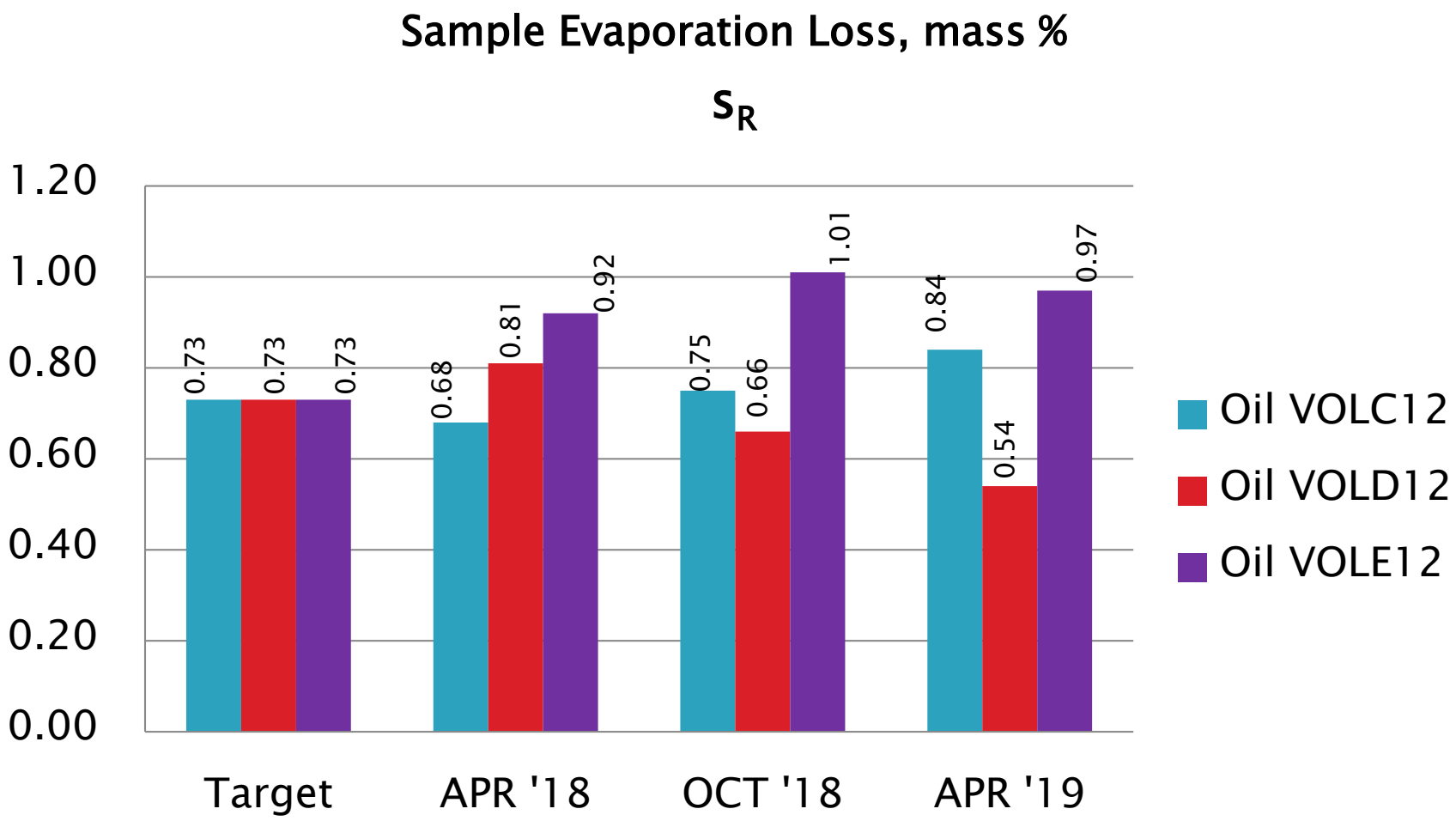
Sample Evaporation Loss, mass %
Performance by Oil

	Targets			10/1/17– 3/31/18				4/1/18 – 9/30/18				10/1/18– 3/31/19			
Oil Code	n	Mean	s_R	n	Mean	s_R	Mean Δ/s	n	Mean	s_R	Mean Δ/s	n	Mean	s_R	Mean Δ/s
VOLC12	24	14.19	0.73	44	14.5	0.68	0.43	52	14.6	0.75	0.54	48	14.6	0.84	0.58
VOLD12	27	12.52	0.73	45	12.6	0.81	0.15	46	12.8	0.66	0.45	48	12.9	0.54	0.54
VOLE12	27	16.74	0.73	44	16.6	0.92	-0.13	51	16.9	1.01	0.22	55	17.0	0.97	0.41

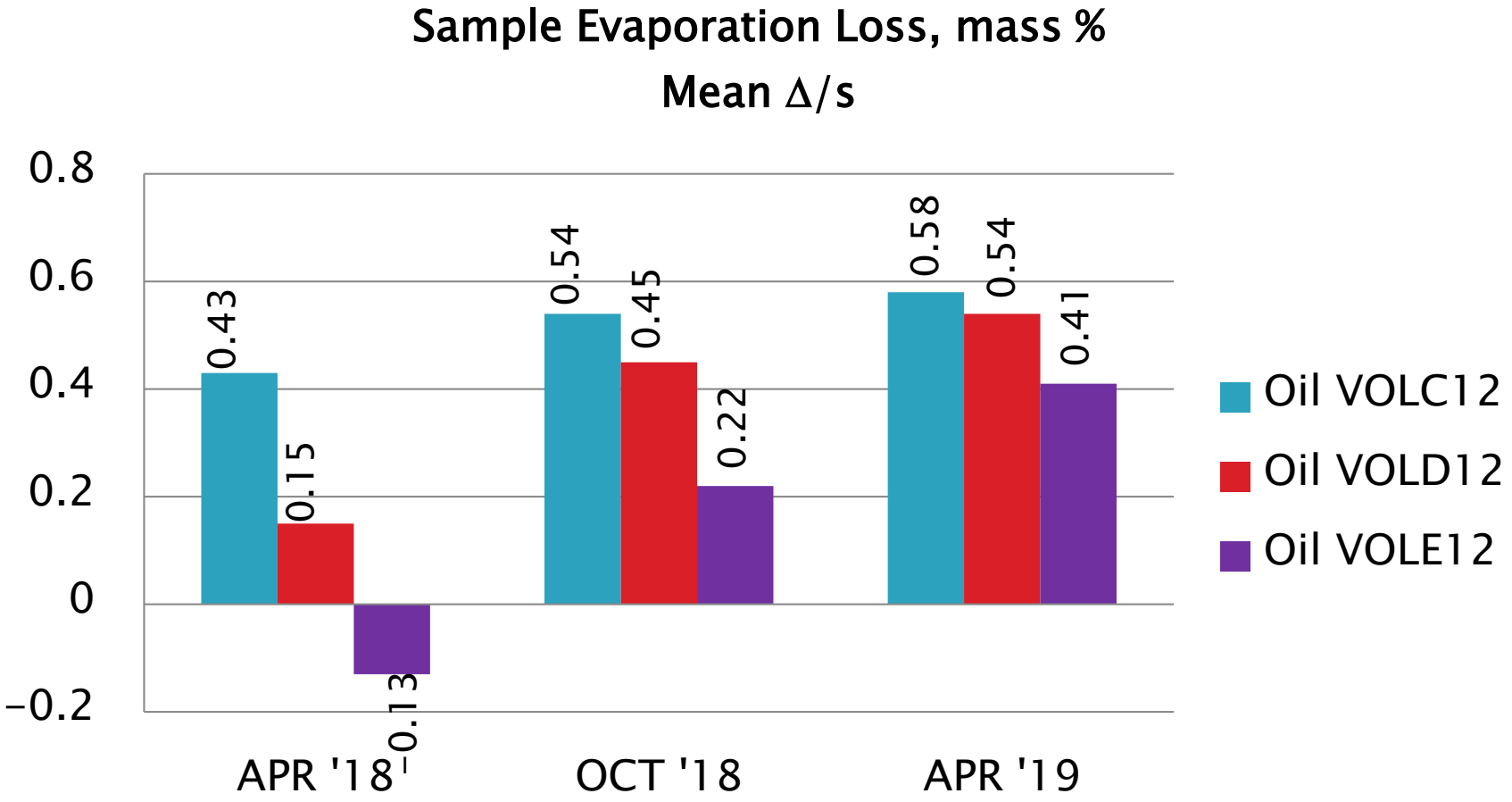
D5800 Performance by Oil



D5800 Performance by Oil



D5800 Performance by Oil



Return to Executive Summary

D5133: Gelation Index

Test Status	Validity Code	No. Tests
Acceptable Calibration Test	AC	27
Failed Calibration Test	OC	0
Operationally Invalidated by Lab	LC, XC	5
Operationally Invalidated After Initially Reported as Valid	RC	0
Non-Blind Instrument Shakedown	NN	2
Total		**34**

Number of Labs Reporting Data: 8
(7 labs with operationally valid calibration tests to report)
Fail Rate of Operationally Valid Tests: 0%

D5133: Gelation Index

Statistically Unacceptable Tests (OC)	No. Of Tests
Gelation Index Mild	0
Gelation Index Severe	0

- Five operationally invalid calibration runs reported this period:
  - Two aborted due to power failure (XC)
  - Three aborted because software appears to have aborted unexpectedly mid-run (XC), at 3 different labs.

- Two non-blind shakedown runs to troubleshoot one instrument (NN).

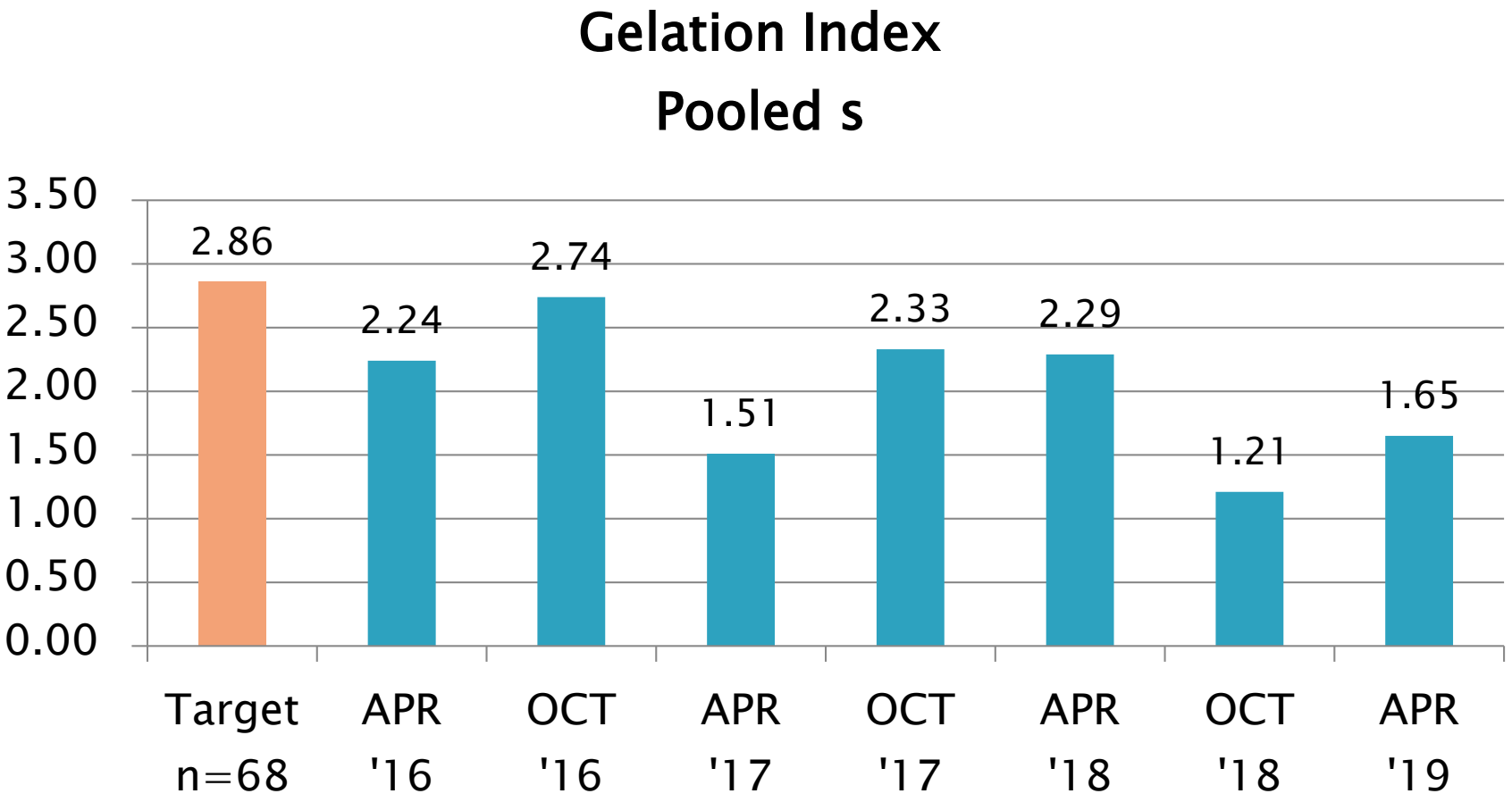
D5133: Gelation Index

Period Precision and Severity Estimates

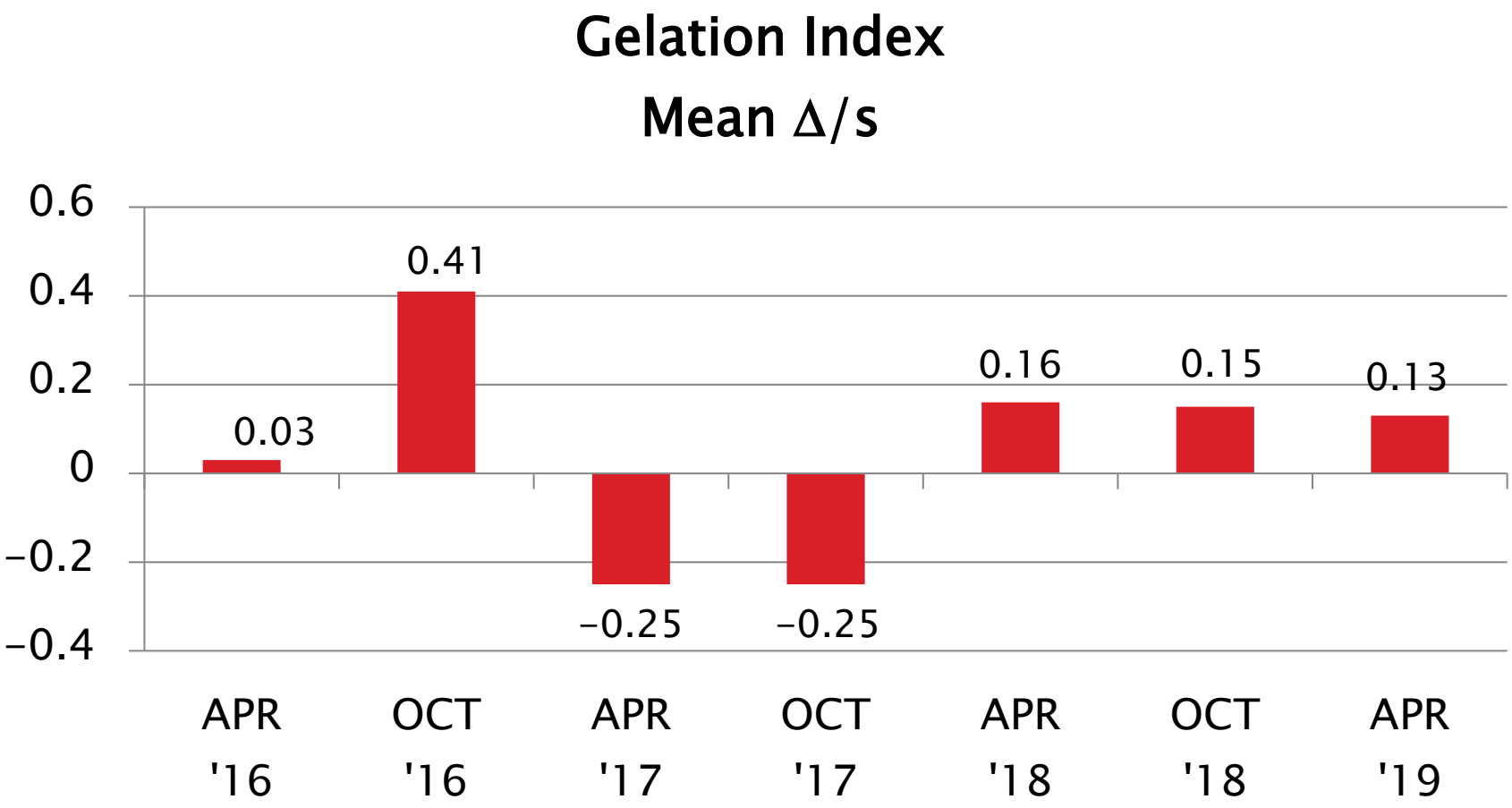
Gelation Index	n	df	Pooled s	Mean Δ/s
Current Targets 7/15/2003	68	65	2.86	-----
4/1/16 through 9/30/16	31	28	2.74	0.41
10/1/16 through 3/31/17	35	32	1.51	-0.25
4/1/17 through 9/30/17*	30	27	4.69	-0.08
4/1/17 through 9/30/17*	29	26	2.33	-0.25
10/1/17 through 3/31/18	36	33	2.29	0.16
4/1/18 through 9/30/18*	32	29	1.21	0.15
4/1/18 through 9/30/18*	31	28	1.03	-0.02
10/1/18 through 3/31/19	27	24	1.65	0.13

*Extreme OC result included and excluded

D5133 Precision Estimates



D5133 Severity Estimates



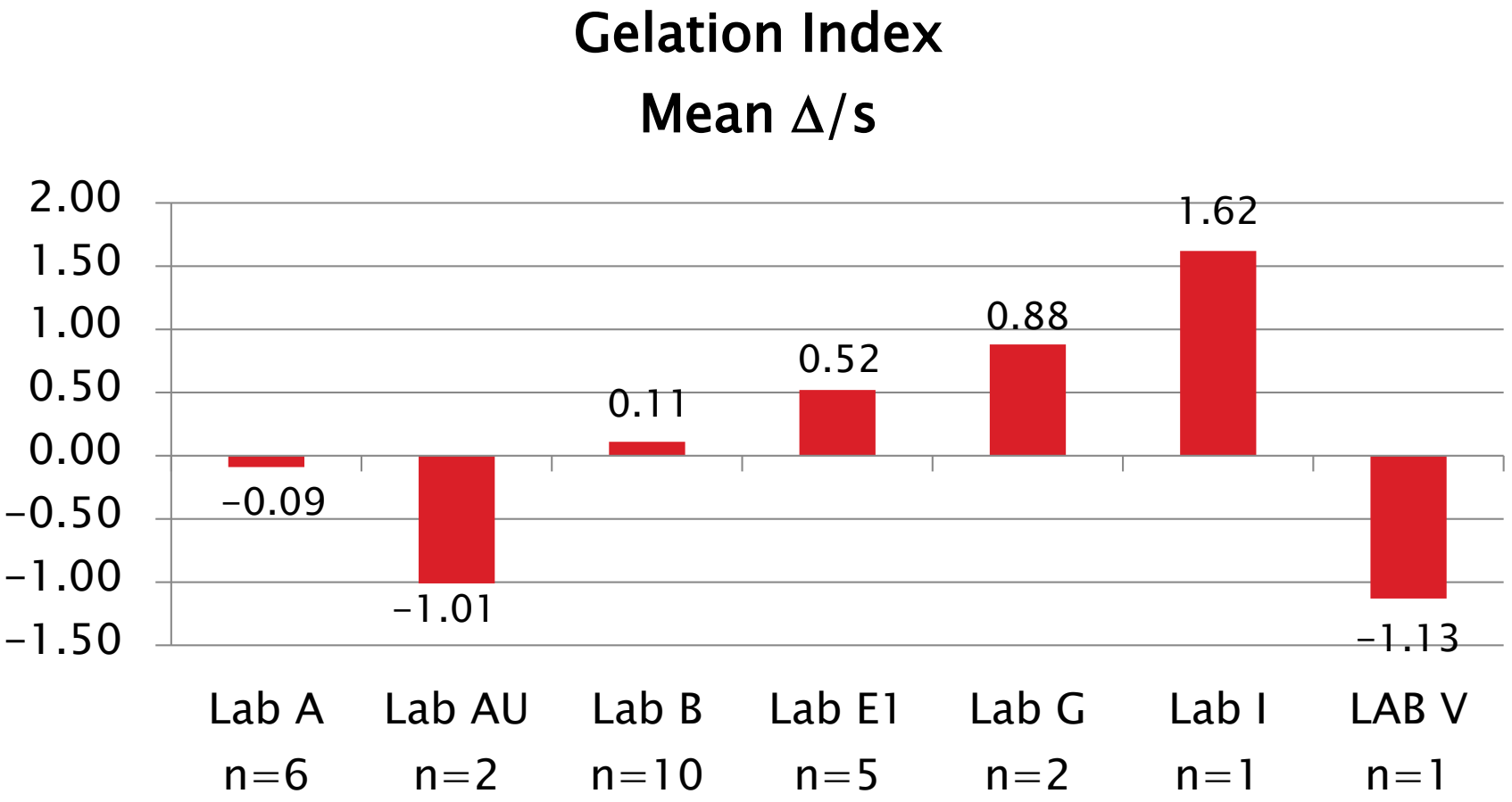
D5133: Gelation Index

Current Period Severity Estimates by Lab

Gelation Index

	n	Mean Δ/s
Lab A	6	-0.09
Lab AU	2	-1.01
Lab B	10	0.11
Lab E1	5	0.52
Lab G	2	0.88
Lab I	1	1.62
Lab V	1	-1.13

D5133 Lab Severity Estimates



D5133: Gelation Index

- Fail rate of operationally valid tests is 0% this period. Historic period fail rates have ranged between 6% and 26%.
- Performance (Mean Δ/s) is 0.13 s severe
  - Comparable to last two periods.
- Precision (Pooled s) is more precise than target precision.
- All operationally valid tests (AC & OC) reported this period were within $\pm$ 3 s of targets, no significant outliers.
- Oil GIA17 was approved by panel vote as a severe performing reference oil replacement for oil 62, which is in low supply.

D5133: Gelation Index

- While performance and precision this period is good, prior erratic calibration performance of certain heads should raise concerns about the adequacy of the current 'single-test' Shewhart monitoring system to catch severe or mild performing instruments or heads in a timely manner. And, whether those instruments demonstrating multiple failing results should be considered properly calibrated based on just one passing Shewhart test result on just one viscometer head.
  - While the panel has recently been considering proposals for a head-based Shewhart calibration system, industry might be better served if an LTMS EWMA based monitoring system was considered for this test, much like what is currently done in D5800. Capturing data on a head based calibration system, over time, should provide additional data for consideration.

- Severe performing GI reference oil 62 is in low supply. On March 26, 2019, the panel approved a replacement oil GIA17 with preliminary targets from a round robin study.

D5133 GELATION INDEX INDUSTRY OPERATIONALLY VALID DATA

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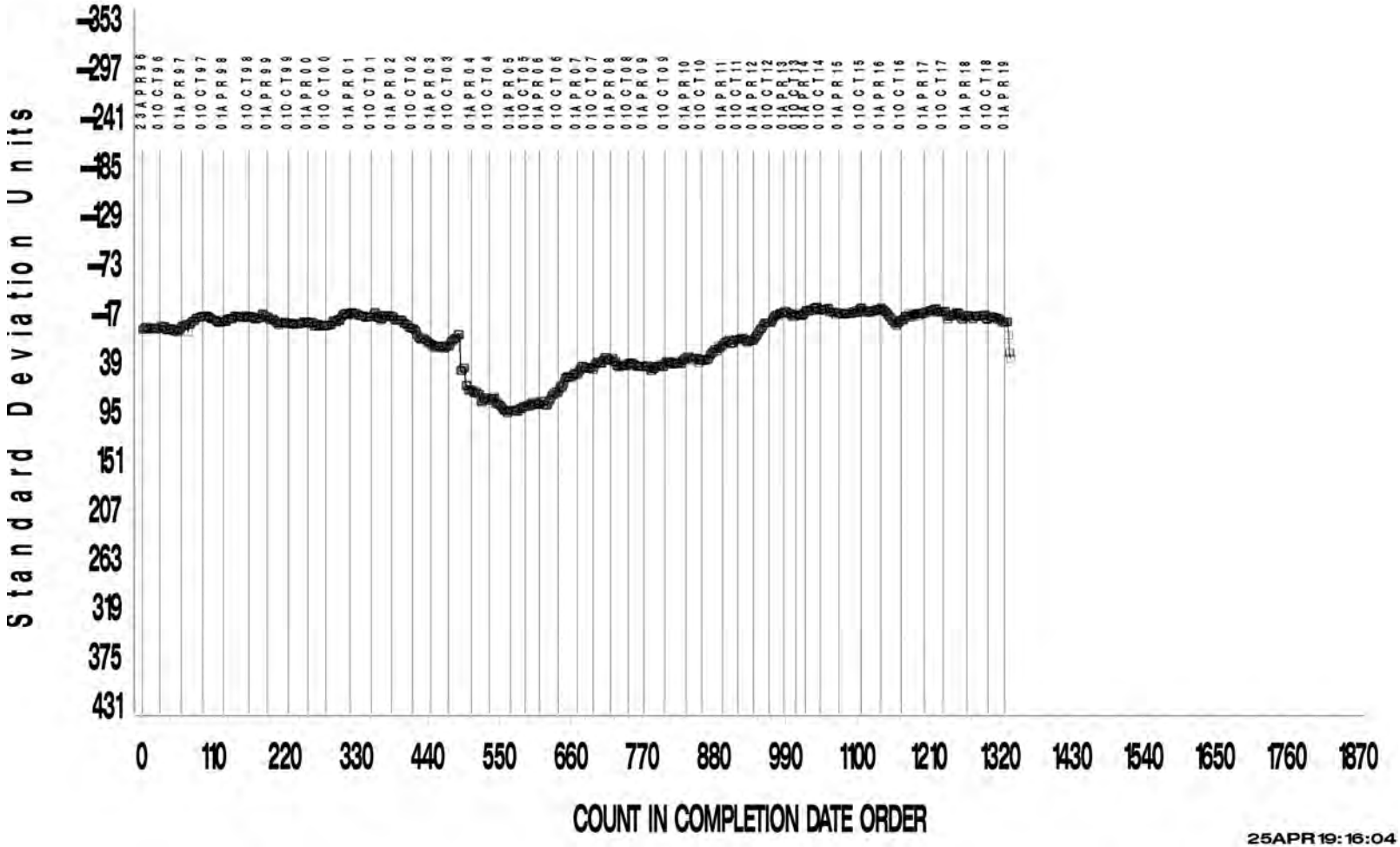
GELATION INDEX

CUSUM Severity Analysis



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D5133 GELATION INDEX INDUSTRY OPERATIONALLY VALID DATA

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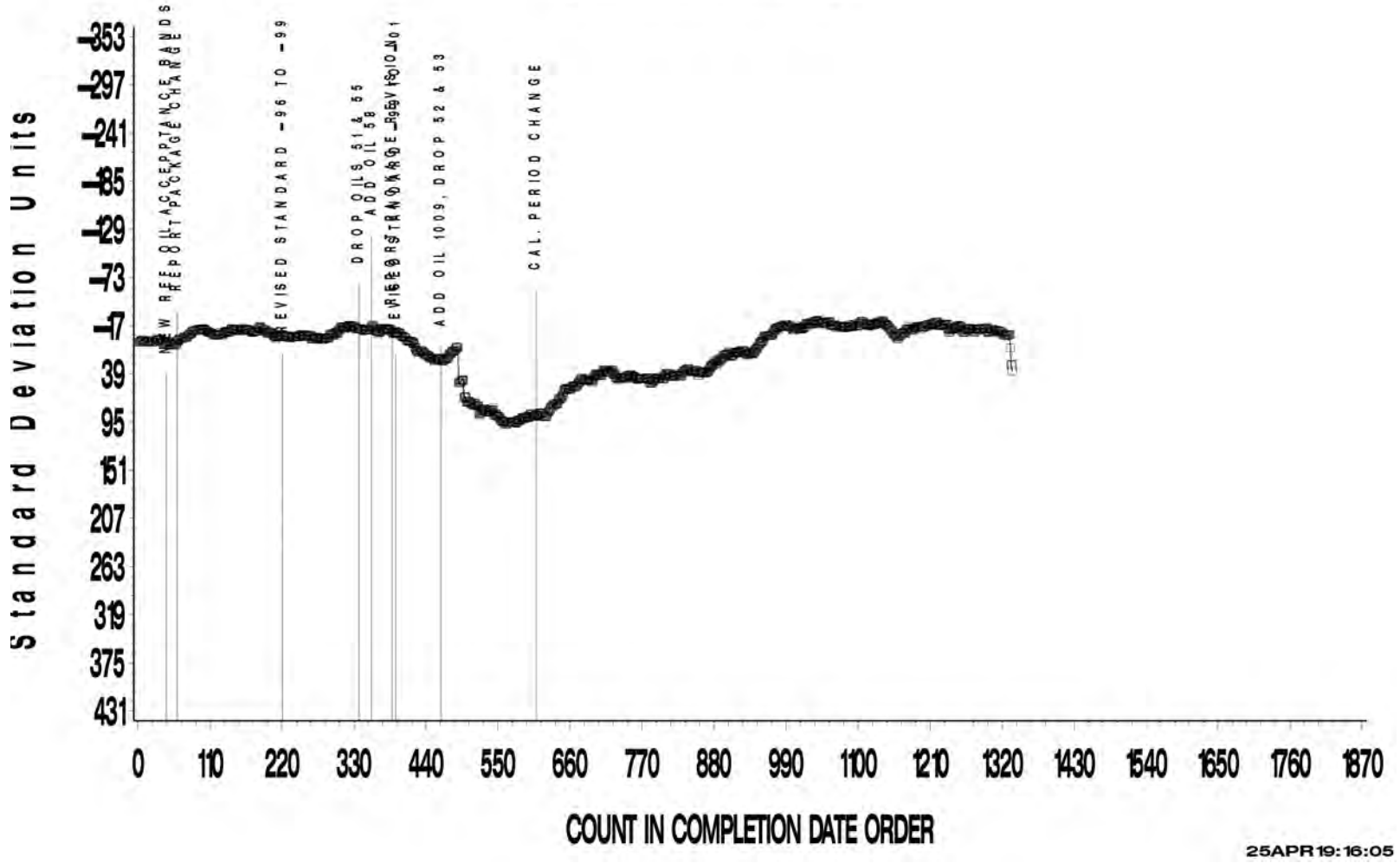
GELATION INDEX

CUSUM Severity Analysis



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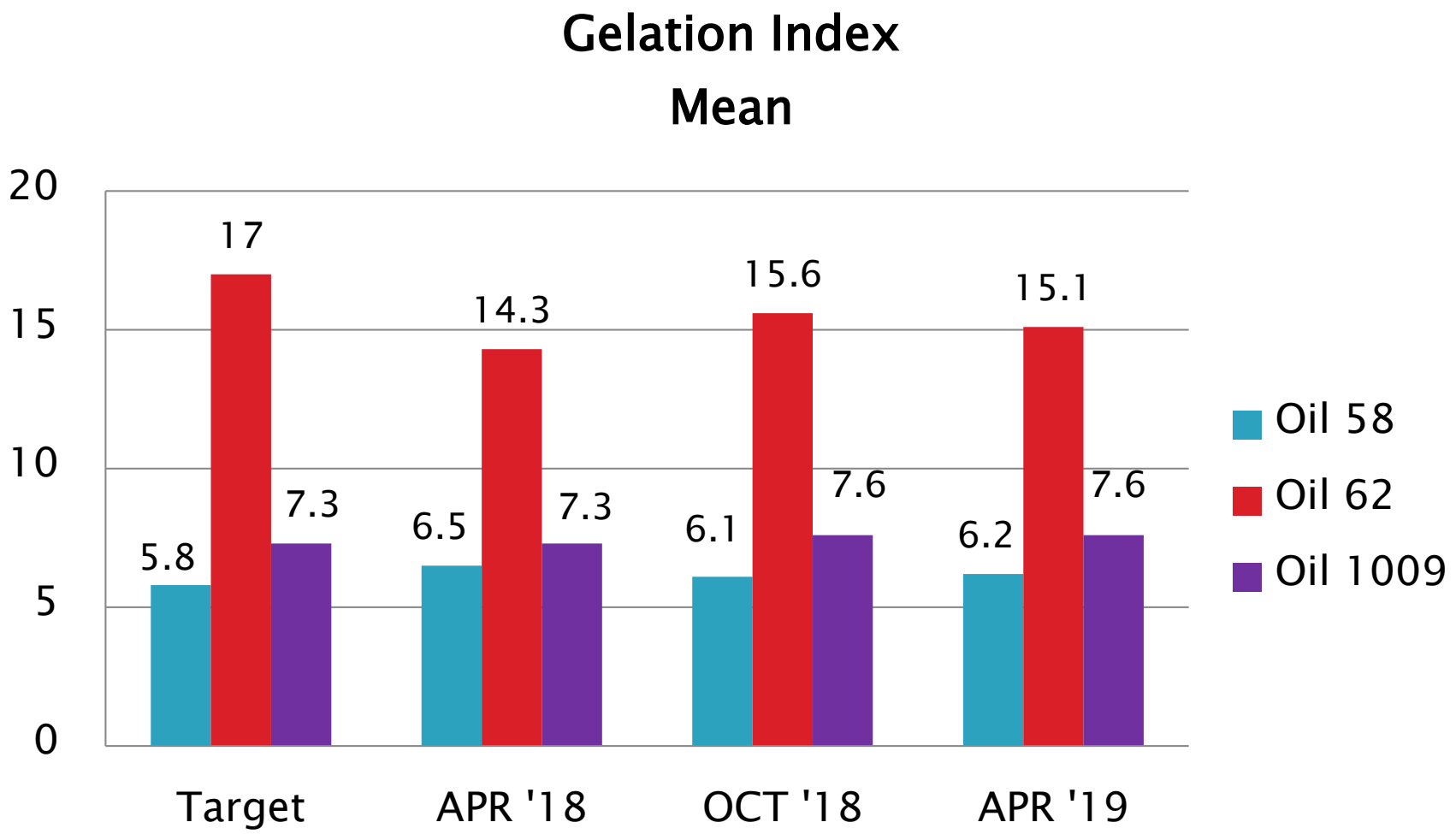
D5133 Performance by Oil

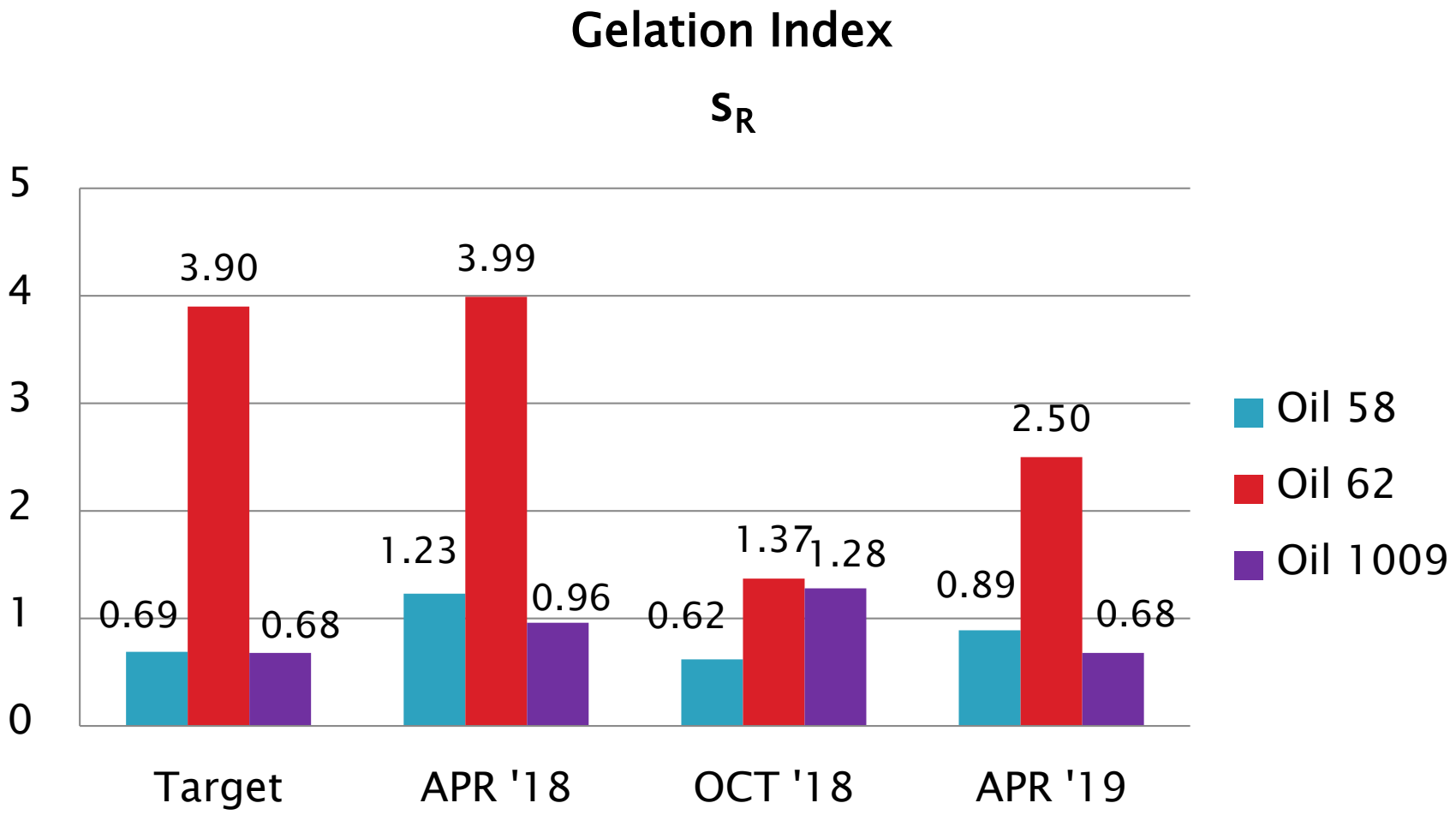
Gelation Index
Performance by Oil

	Targets			10/1/17– 3/31/18				4/1/18– 9/30/18				10/1/18– 3/31/19			
Oil Code	n	Mean	s_R	n	Mean	s_R	Mean Δ/s	n	Mean	s_R	Mean Δ/s	n	Mean	s_R	Mean Δ/s
58	17	5.8	0.69	13	6.5	1.23	1.00	7	6.1	0.62	0.41	9	6.2	0.89	0.52
62	35	17.0	3.90	10	14.3	3.99	-0.69	11	15.6	1.37	-0.35	10	15.1	2.50	-0.49
1009	16	7.30	0.68	13	7.3	0.96	-0.02	14	7.6	1.28	0.41	8	7.6	0.68	0.46

D5133 Performance by Oil



D5133 Performance by Oil



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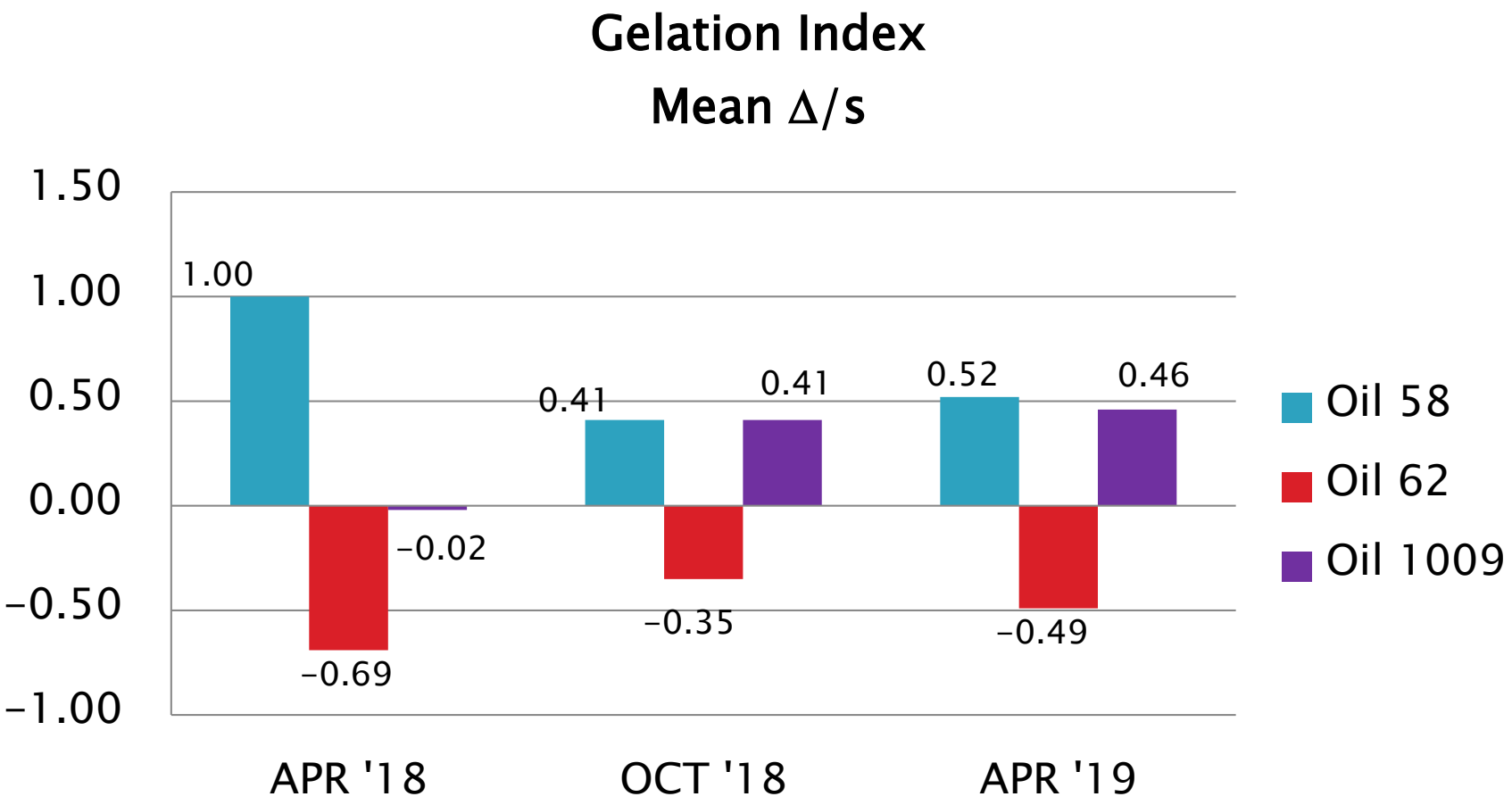
D5133 Performance by Oil



Return to Executive Summary

D6335: Deposits by TEOST-33C

Test Status	Validity Code	No. Tests
Acceptable Calibration Test	AC	20
Failed Calibration Test	OC	5
Operationally Invalidated by Lab	LC, XC	1
Operationally Invalidated After Initially Reported as Valid	RC	0
Excluded from statistics (two-test fail on new rig)	MC	2
Total		**28**

Number of Labs Reporting Data: 8
Fail Rate of Operationally Valid Tests: 20%

D6335: Deposits by TEOST-33C

Statistically Unacceptable Tests (OC)	No. Of Tests
Total Deposits Mild	2
Total Deposits Severe	3

- Two consecutive mild failing runs were reported on the same instrument (B8). Three severe failing runs on three separate rigs, three labs.
  - All five OC fails this period were on mild performing oil 435-2.
  - Precision on 435-2 is unusually poor this period as a result.

- One aborted run (XC) reported due to incorrect pump speed setting.

- Initial two-test sequence on new rig (D4) excluded from statistics (validity MC) because 2nd test failed mild, instrument failed to demonstrate an initial passing calibration. Rig subsequently passed calibration.

- Calibration requirement updates are issued as LTMS document updates.

D6335: Deposits by TEOST-33C

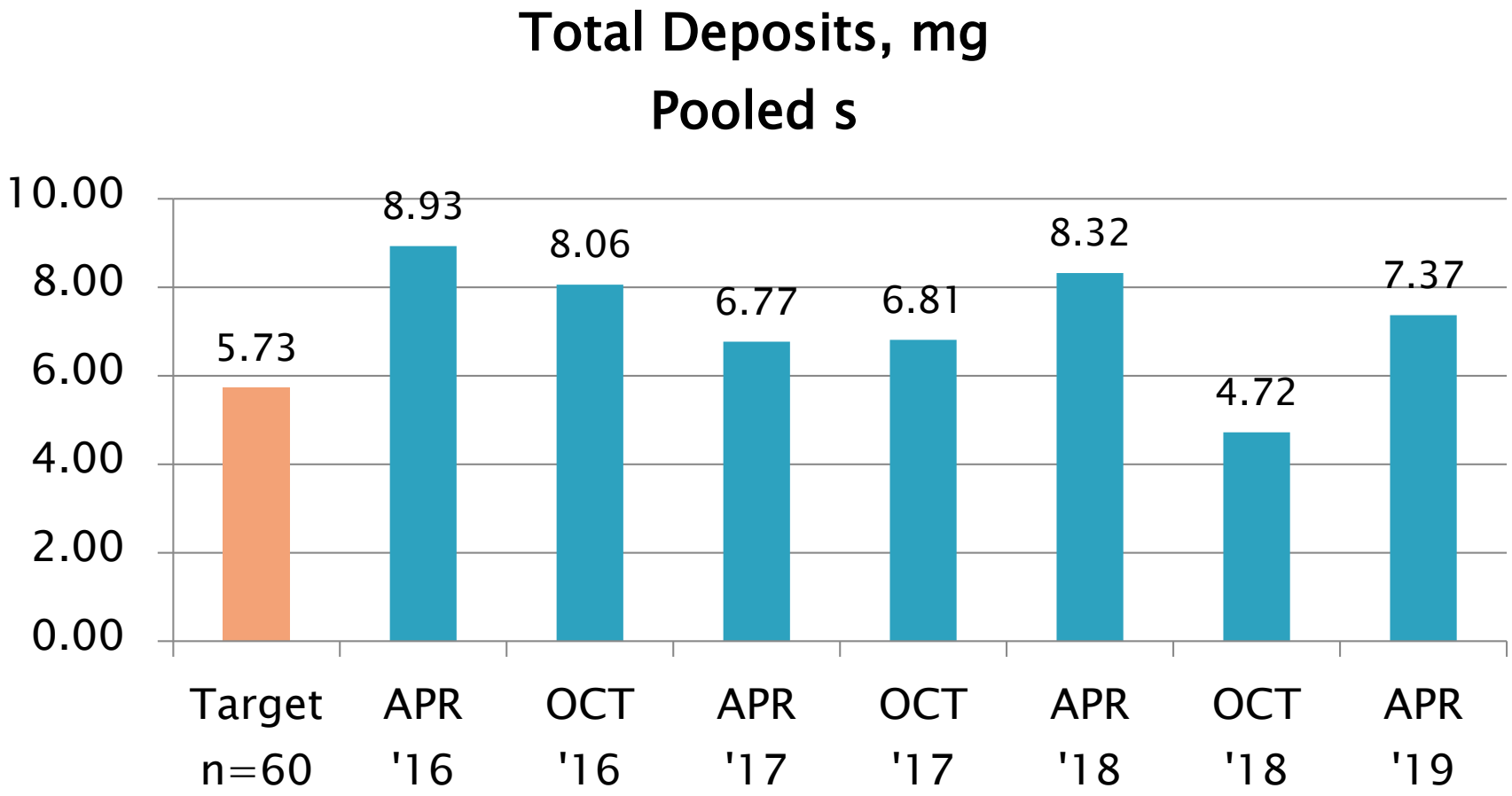
Period Precision and Severity Estimates

Total Deposits, mg	n	df	Pooled s	Mean Δ/s
Updated Targets 20130415	60	58	5.73	-----
10/1/15 through 3/31/16	21	19	8.93	-0.43
4/1/16 through 9/30/16	21	19	8.06	-0.68
10/1/16 through 3/31/17	21	19	6.77	-0.14
4/1/17 through 9/30/17*	26	24	6.81	0.00
4/1/17 through 9/30/17*	23	21	5.19	-0.28
10/1/17 through 3/31/18**	27	25	8.32	-0.61
10/1/17 through 3/31/18**	26	24	6.43	-0.45
4/1/18 through 9/30/18	21	19	4.72	-0.33
10/1/18 through 3/31/19	25	23	7.37	0.11

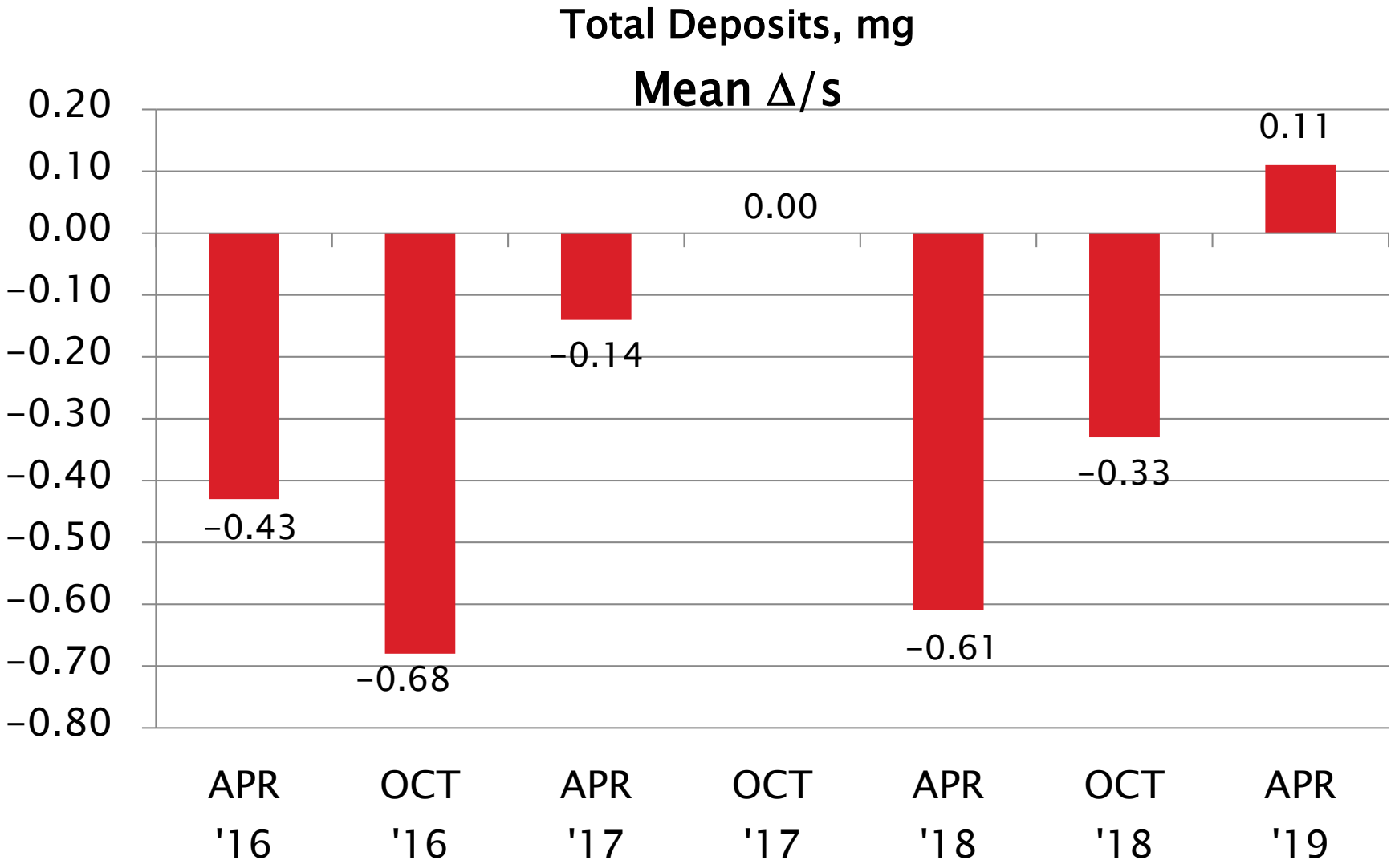
*Three consecutive OC results on same rig included and excluded.

**Single result of -4.6 s mild included and excluded

D6335 Precision Estimates



D6335 Severity Estimates



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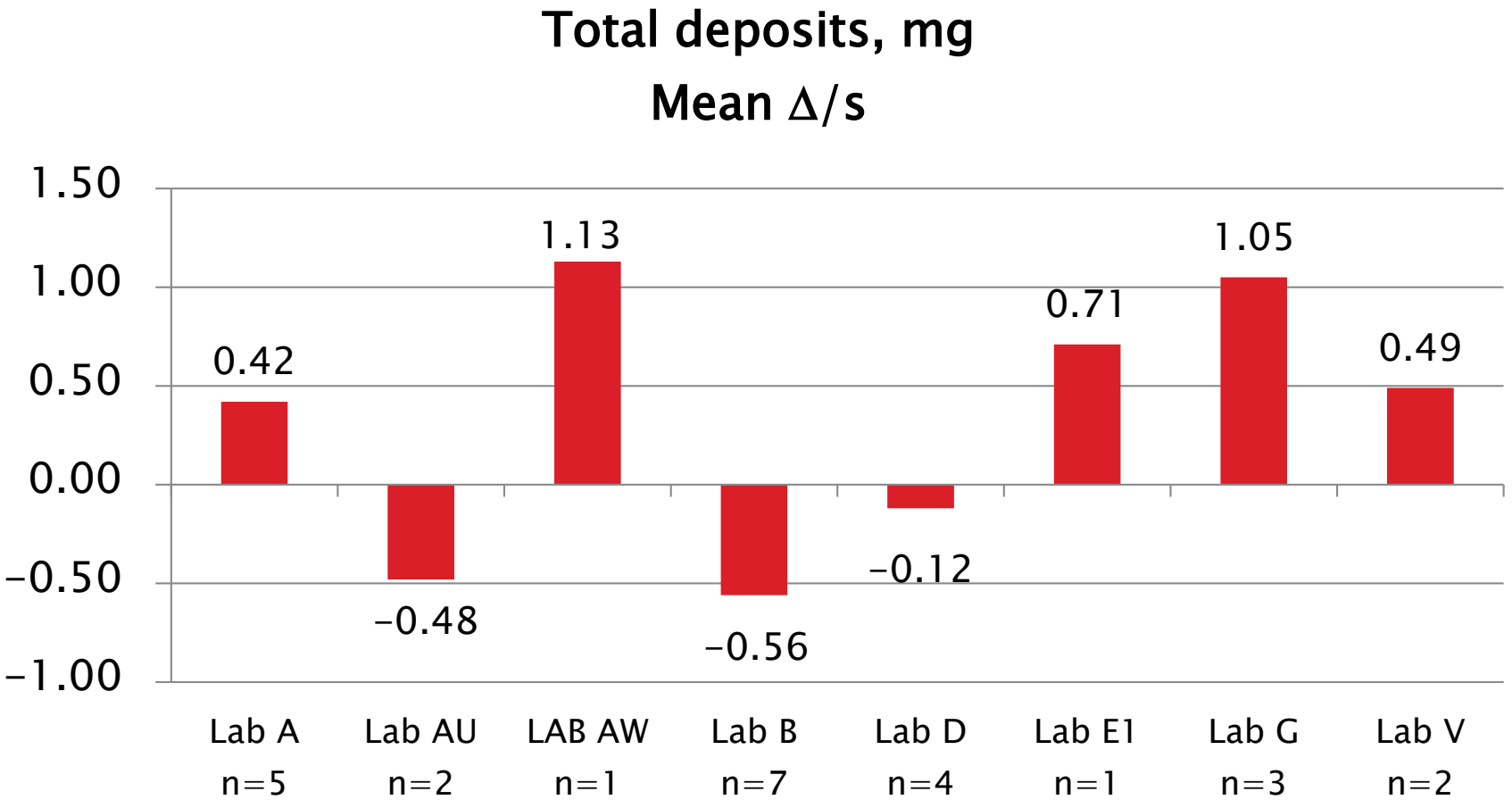
D6335: Deposits by TEOST-33C

Current Period Severity Estimates by Lab
Total Deposits, mg

	n	Mean Δ/s
Lab A	5	0.42
Lab AU	2	-0.48
Lab AW	1	1.13
Lab B	7	-0.56
Lab D	4	-0.12
Lab E1	1	0.71
Lab G	3	1.05
Lab V	2	0.49

D6335 Lab Severity Estimates



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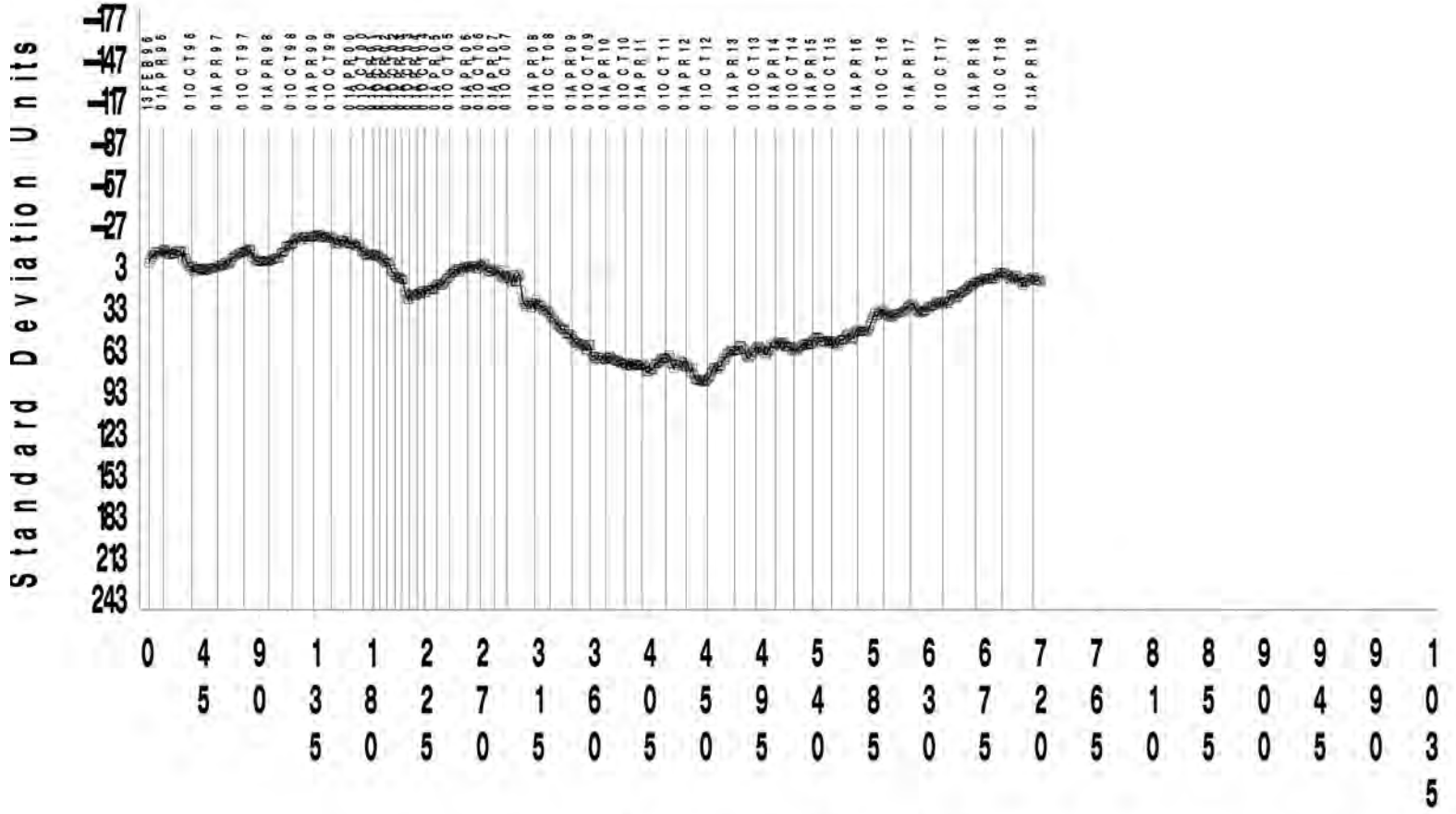
D6335: Deposits by TEOST-33C

- Precision (Pooled s) is less precise than prior period, and less precise than target precision.
  - All five OC fails this period were on mild performing oil 435-2.
  - Precision on 435-2 is unusually poor this period as a result.
- Performance (Mean Δ/s) is 0.11 s severe.
- Fail rate of 20% is unusually high for the period.
- All tests this period report using Rod Batch M.
- Oil 75-1 (reblend) was approved on 20190404 to replace severe performing reference oil 75, which is in low supply.

TEOST –33C INDUSTRY OPERATIONALLY VALID DATA

TOTAL DEPOSITS MG

CUSUM Severity Analysis



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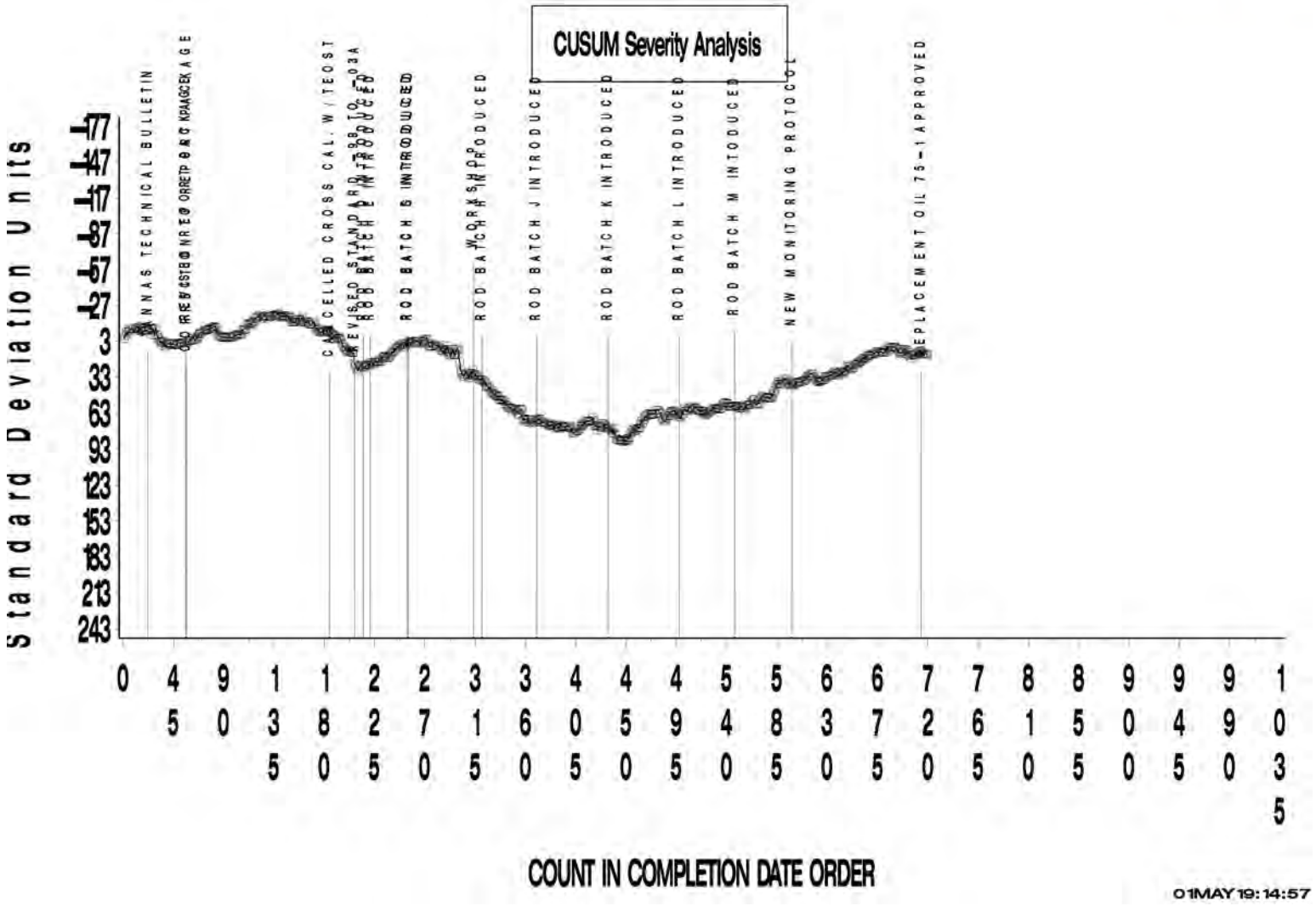
TEOST –33C INDUSTRY OPERATIONALLY VALID DATA

TOTAL DEPOSITS MG



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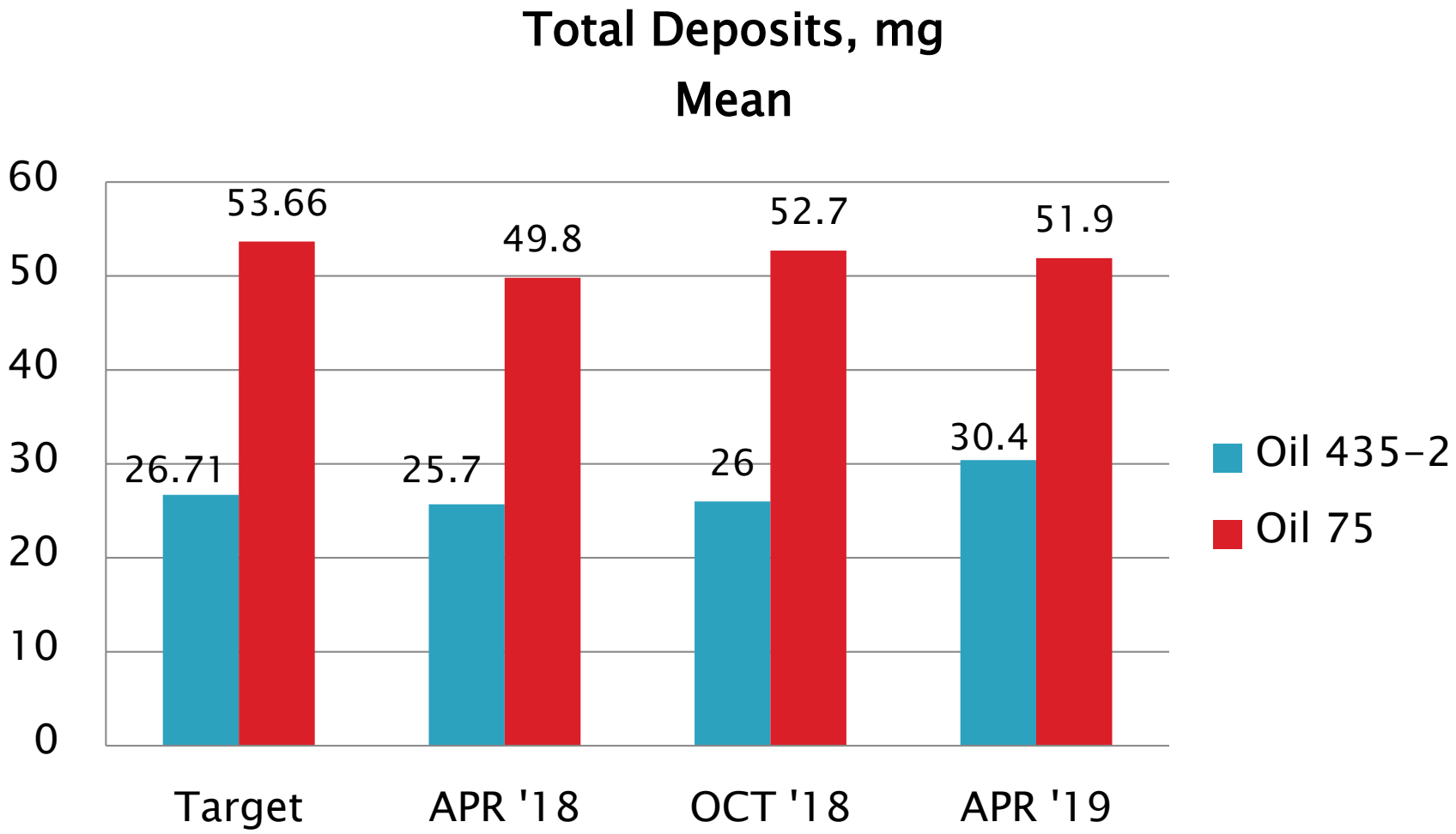
D6335 Performance by Oil

Total Deposits, mg
Performance by Oil

	Targets 20130415			10/1/17 – 3/31/18				4/1/18– 9/30/18				10/1/18 – 3/31/19			
Oil Code	n	Mean	s_R	n	Mean	s_R	Mean Δ/s	n	Mean	s_R	Mean Δ/s	n	Mean	s_R	Mean Δ/s
435-2	30	26.71	4.76	11	25.7	5.24	-0.64	9	26.0	3.38	-0.57	15	30.4	8.62	0.36
75	30	53.66	6.56	16	49.8	9.85	-0.58	12	52.7	5.50	-0.15	10	51.9	4.82	-0.27

D6335 Performance by Oil



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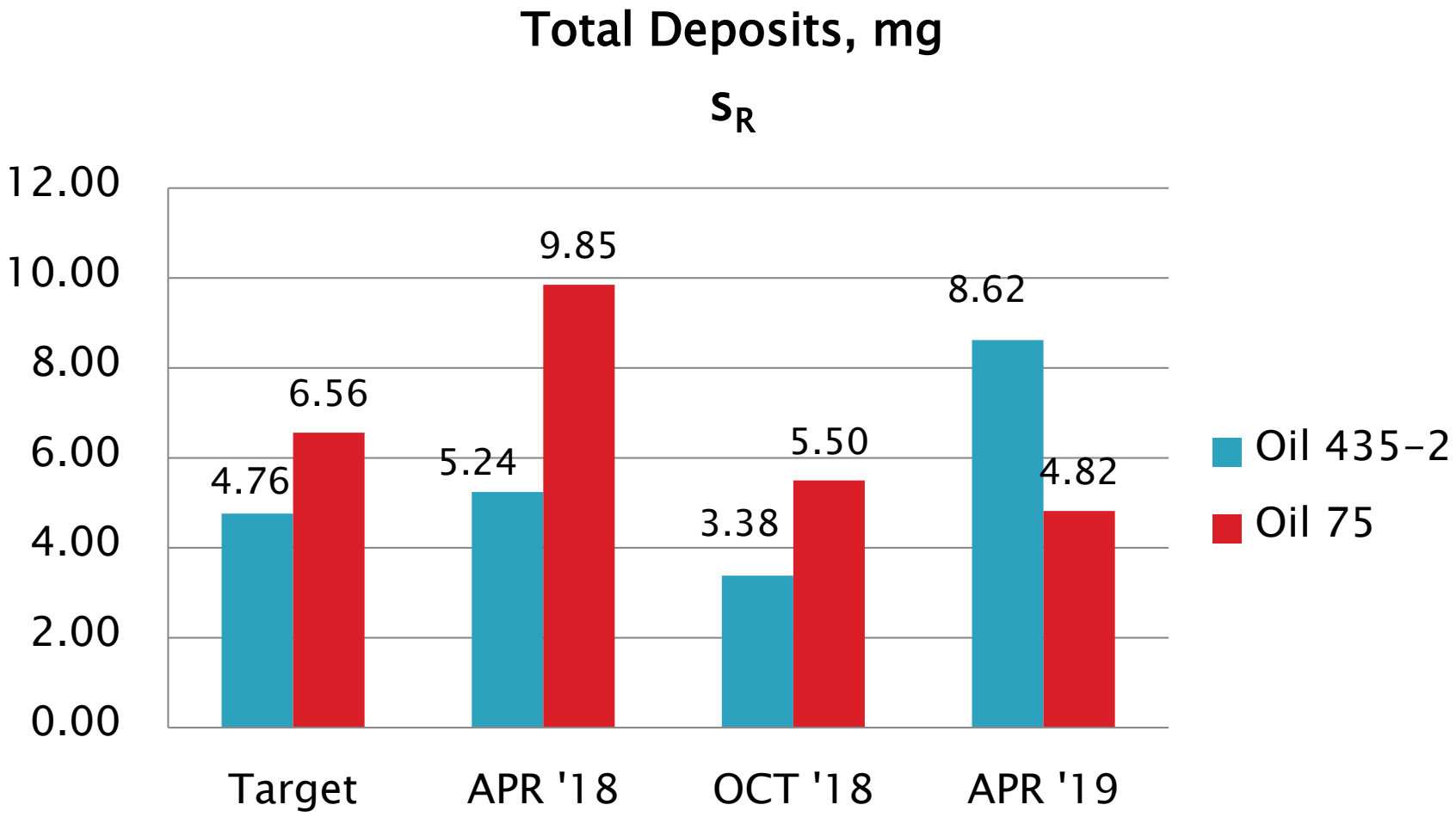
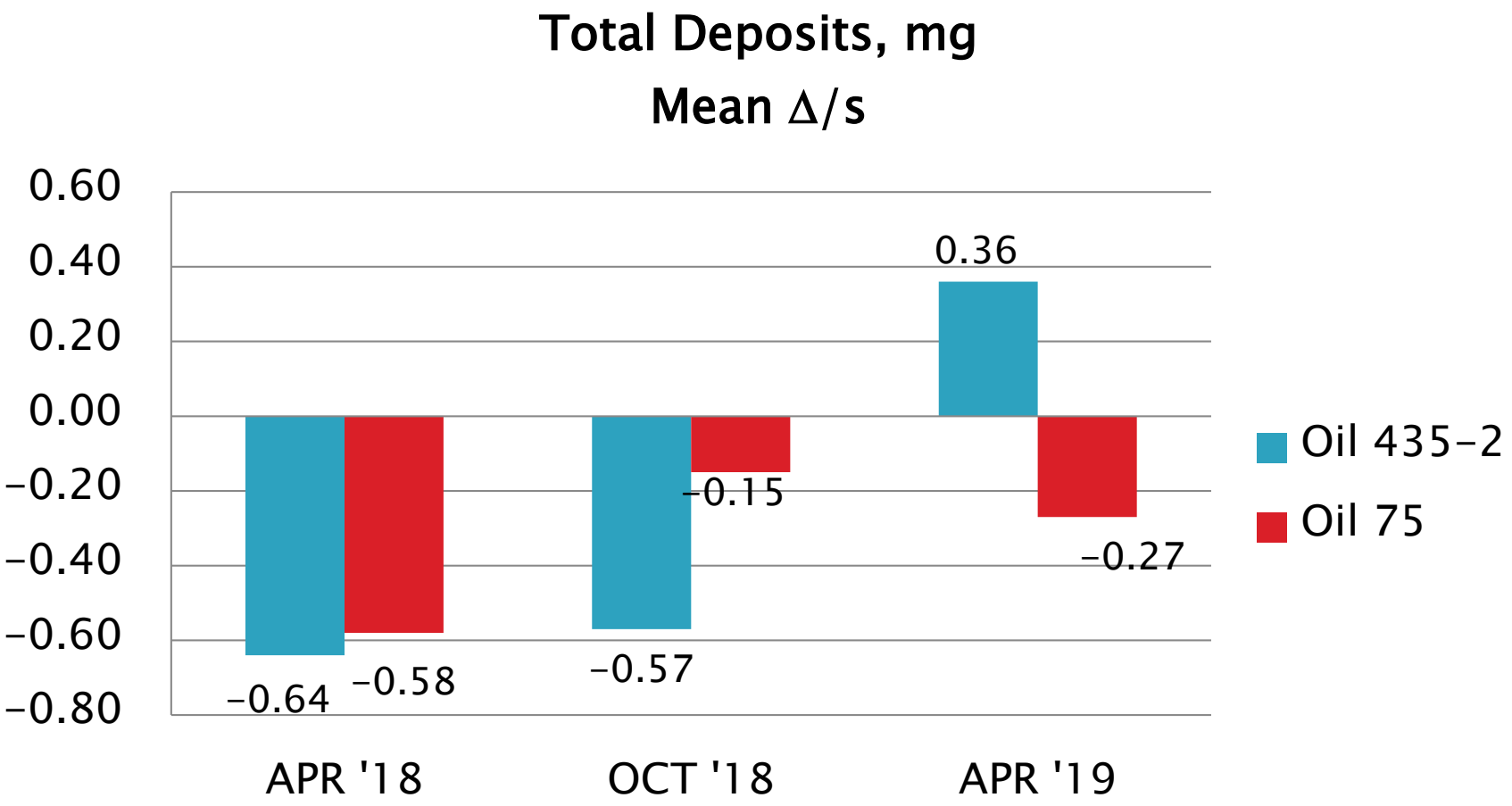
D6335 Performance by Oil



D6335 Performance by Oil



Return to Executive Summary

D7097: Deposits by MHT TEOST

Test Status	Validity Code	No. Tests
Acceptable Calibration Test	AC	94
Failed Calibration Test	OC	3
Operationally Invalidated by Lab	LC, XC	5
Operationally Invalidated After Initially Reported as Valid	RC	2
Total		**104**

Number of Labs Reporting Data: 12
Fail Rate of Operationally Valid Tests: 3%

D7097: Deposits by MHT TEOST

Statistically Unacceptable Tests (OC)	No. Of Tests
Total Deposits Mild	0
Total Deposits Severe	3

- Seven operationally invalid calibration test reported this period:
  - 4 test sample leak (XC)
  - 2 initial sample weight off-spec (LC, RC)
  - 1 catalyst weight off-spec (RC)

- Calibration requirement updates are issued as LTMS document updates.

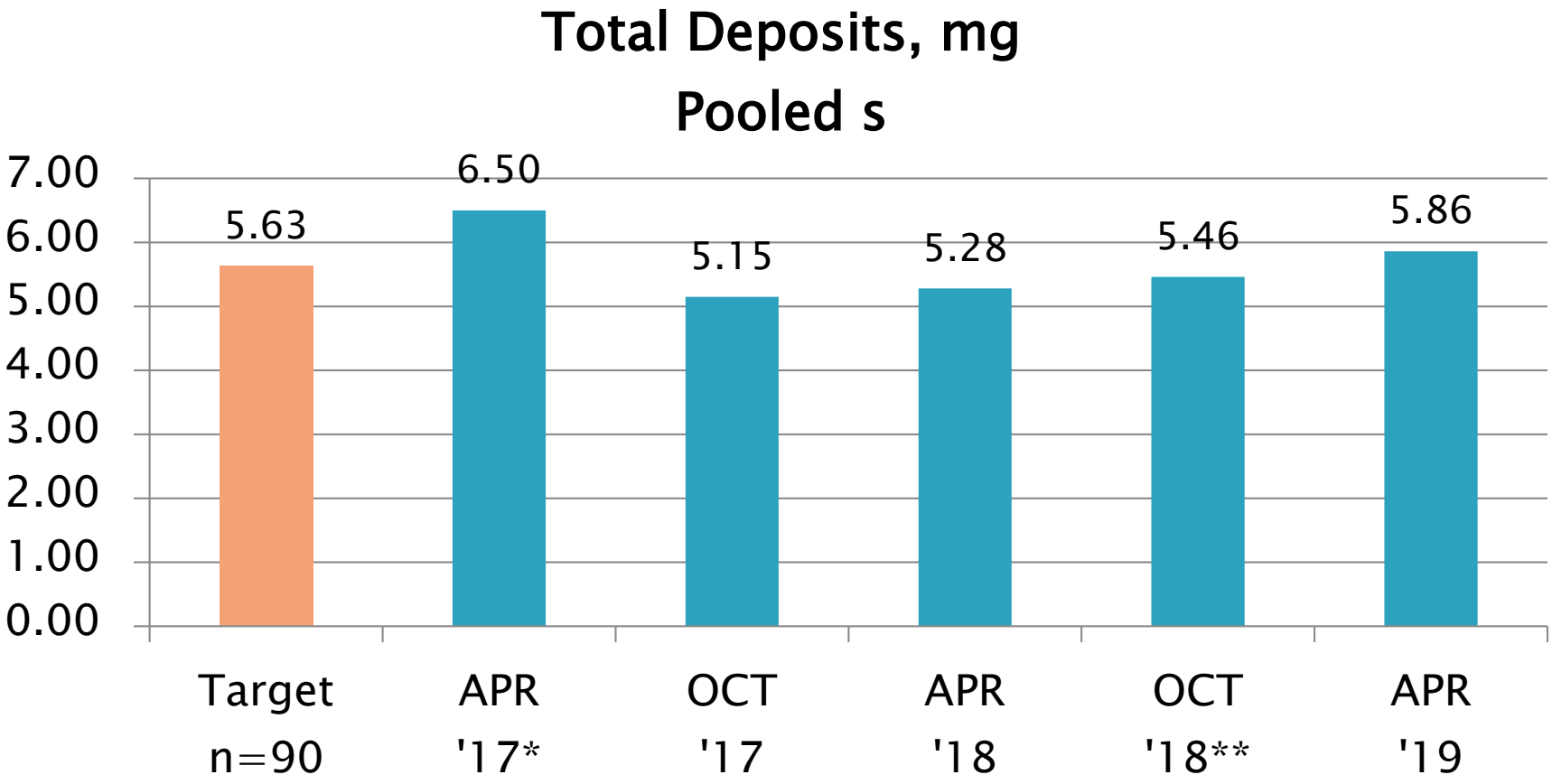
D7097: Deposits by MHT TEOST

Period Precision and Severity Estimates

Total Deposits, mg	n	df	Pooled s	Mean Δ/s
Current Targets 7/31/2006	90	87	5.63	-----
10/1/16 through 3/31/17*	105	103	7.11	0.17
10/1/16 through 3/31/17*	97	95	6.50	0.03
4/1/17 through 9/30/17	83	81	5.15	0.14
10/1/17 through 3/31/18	88	86	5.28	0.33
4/1/18 through 9/30/18**	95	93	6.69	0.29
4/1/18 through 9/30/18**	94	92	5.46	0.20
10/1/18 through 3/31/19	97	95	5.86	-0.14

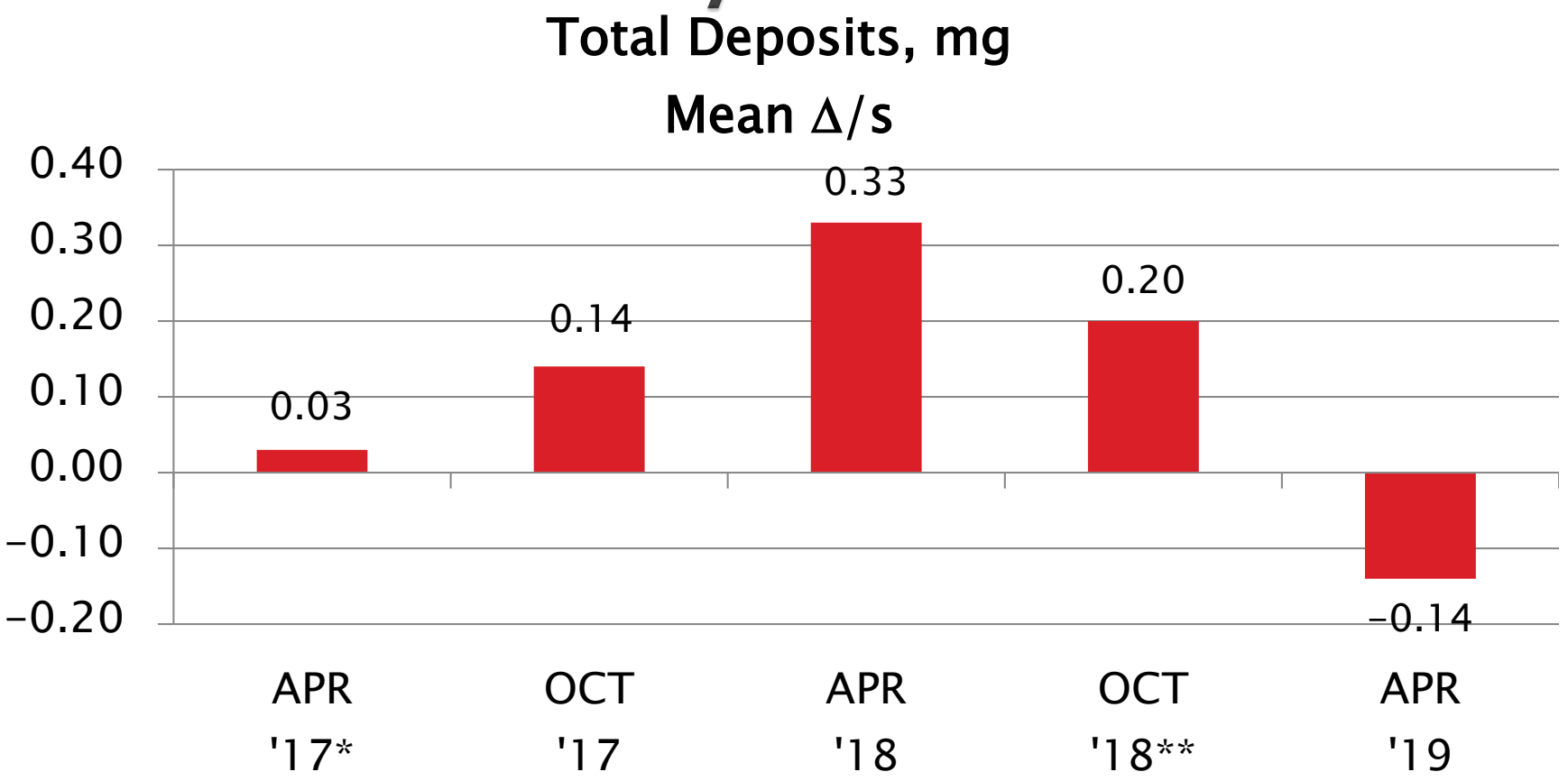
*Eight 2TESTCAL tests from instrument J2 included and excluded
**One severe OC test from instrument G5 included and excluded (8.9 s)

D7097 Precision Estimates



*Eight tests instrument J2 excluded (failed to calibrate)
**One severe OC test from instrument G5 excluded (8.9 s)

D7097 Severity Estimates



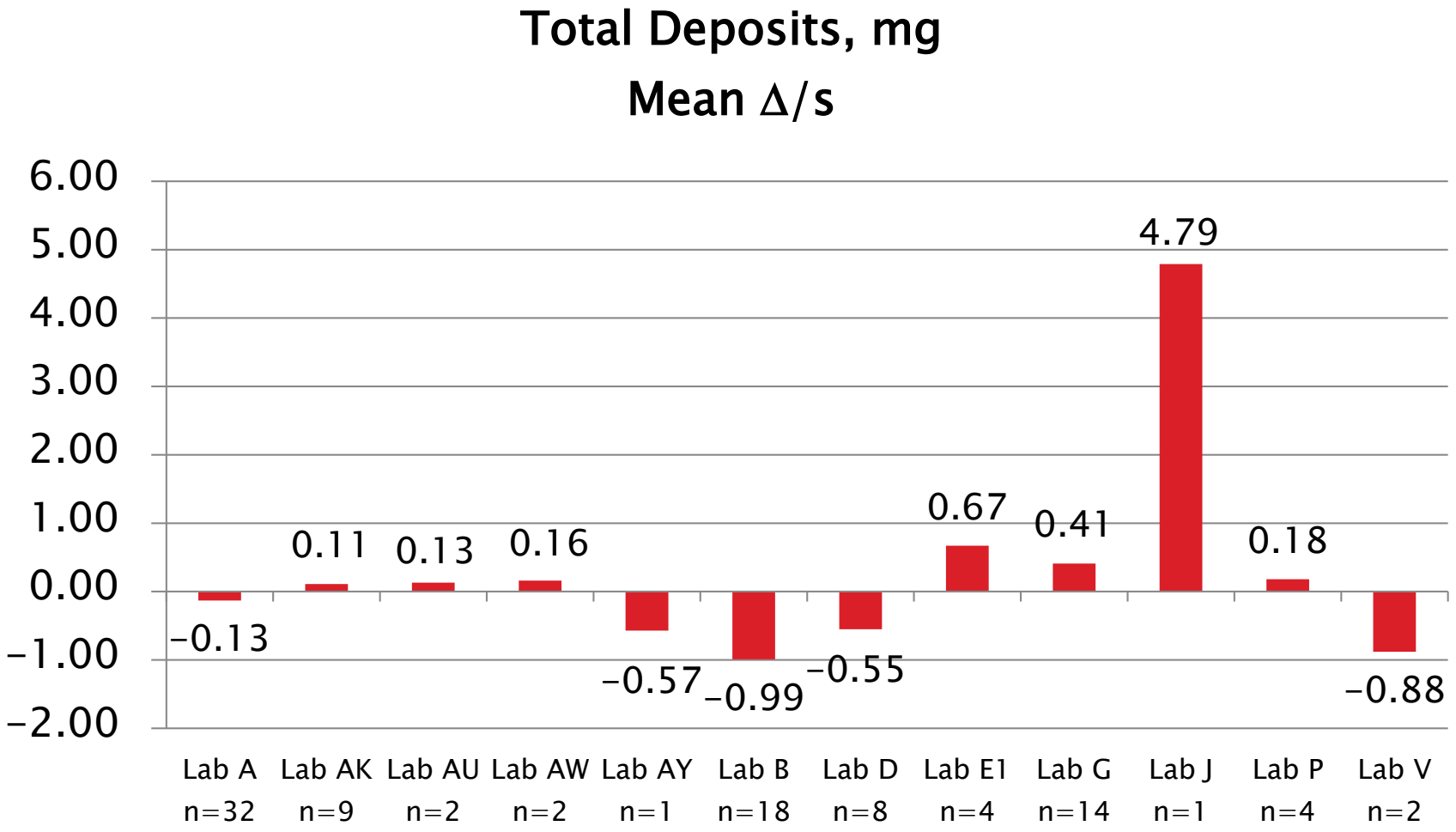
*Eight tests instrument J2 excluded (failed to calibrate)
**One severe OC test from instrument G5 excluded (8.9 s)

D7097: Deposits by MHT TEOST

Current Period Severity Estimates by Lab
Total Deposits, mg

Lab	n	Mean Δ/s	Lab	n	Mean Δ/s
Lab A	32	-0.13	Lab D	8	-0.55
Lab AK	9	0.11	Lab E1	4	0.67
Lab AU	2	0.13	Lab G	14	0.41
Lab AW	2	0.16	Lab J	1	4.79
Lab AY	1	-0.57	Lab P	4	0.18
Lab B	18	-0.99	Lab V	2	-0.88

D7097 Lab Severity Estimates



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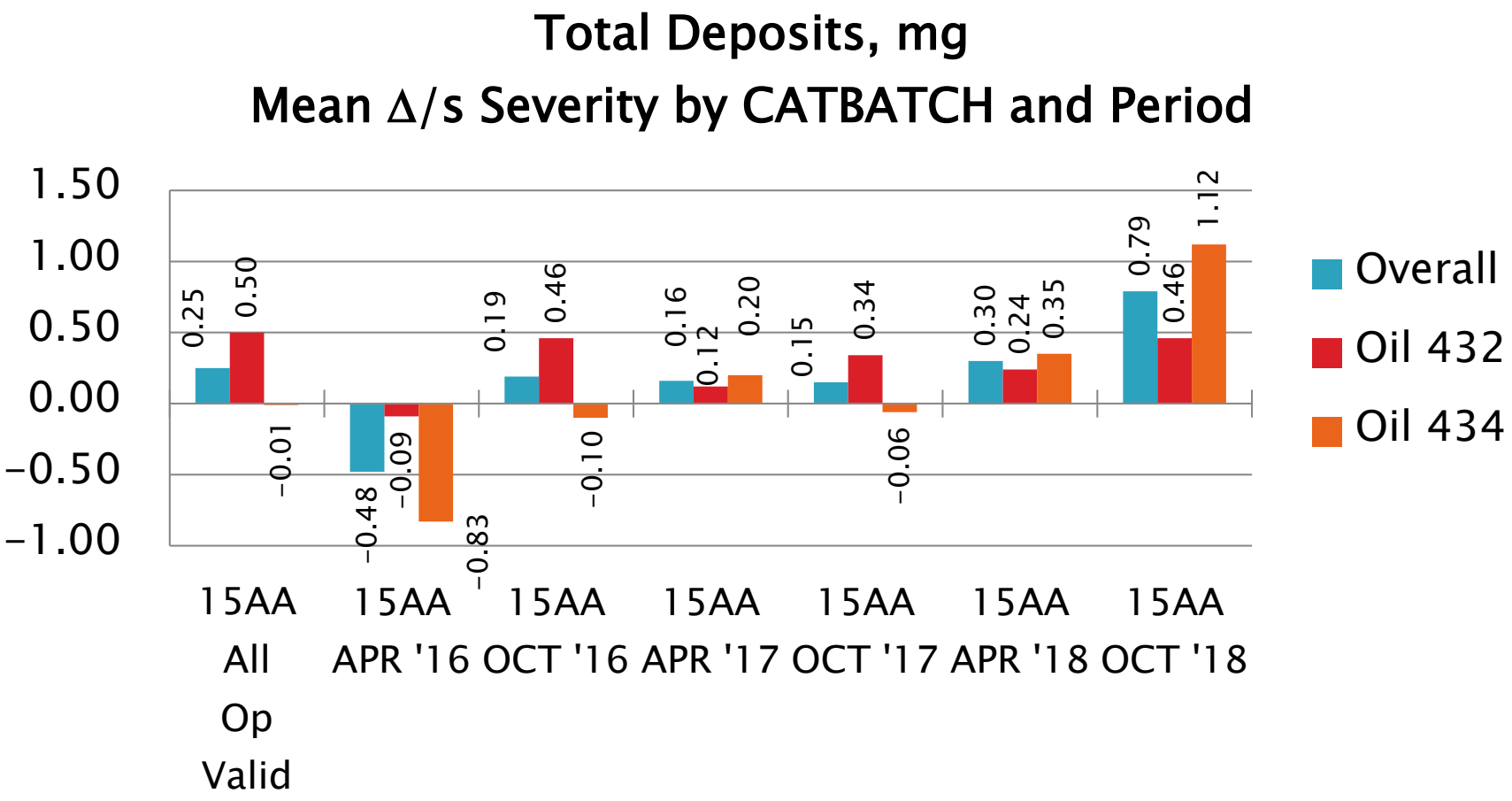
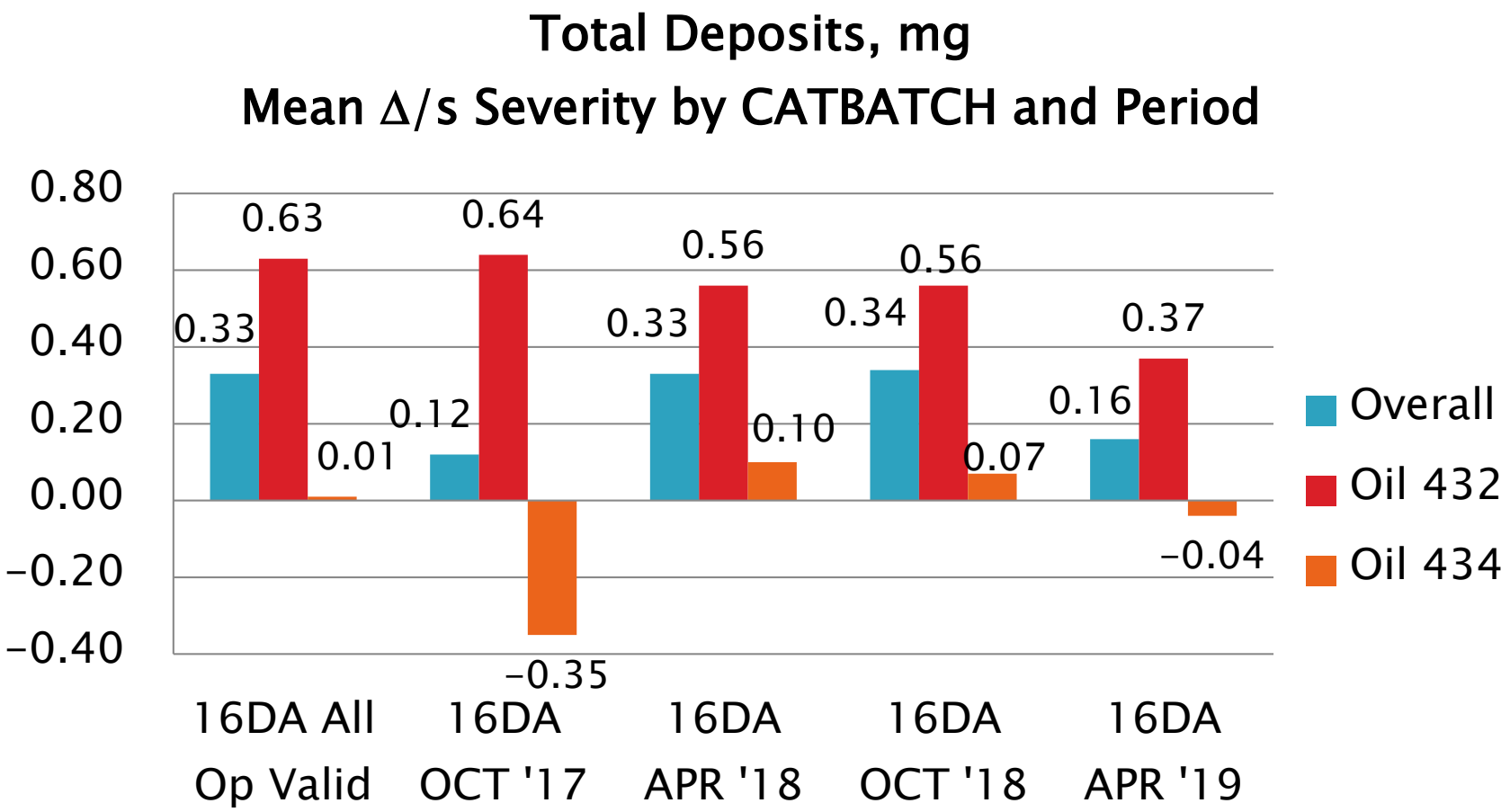
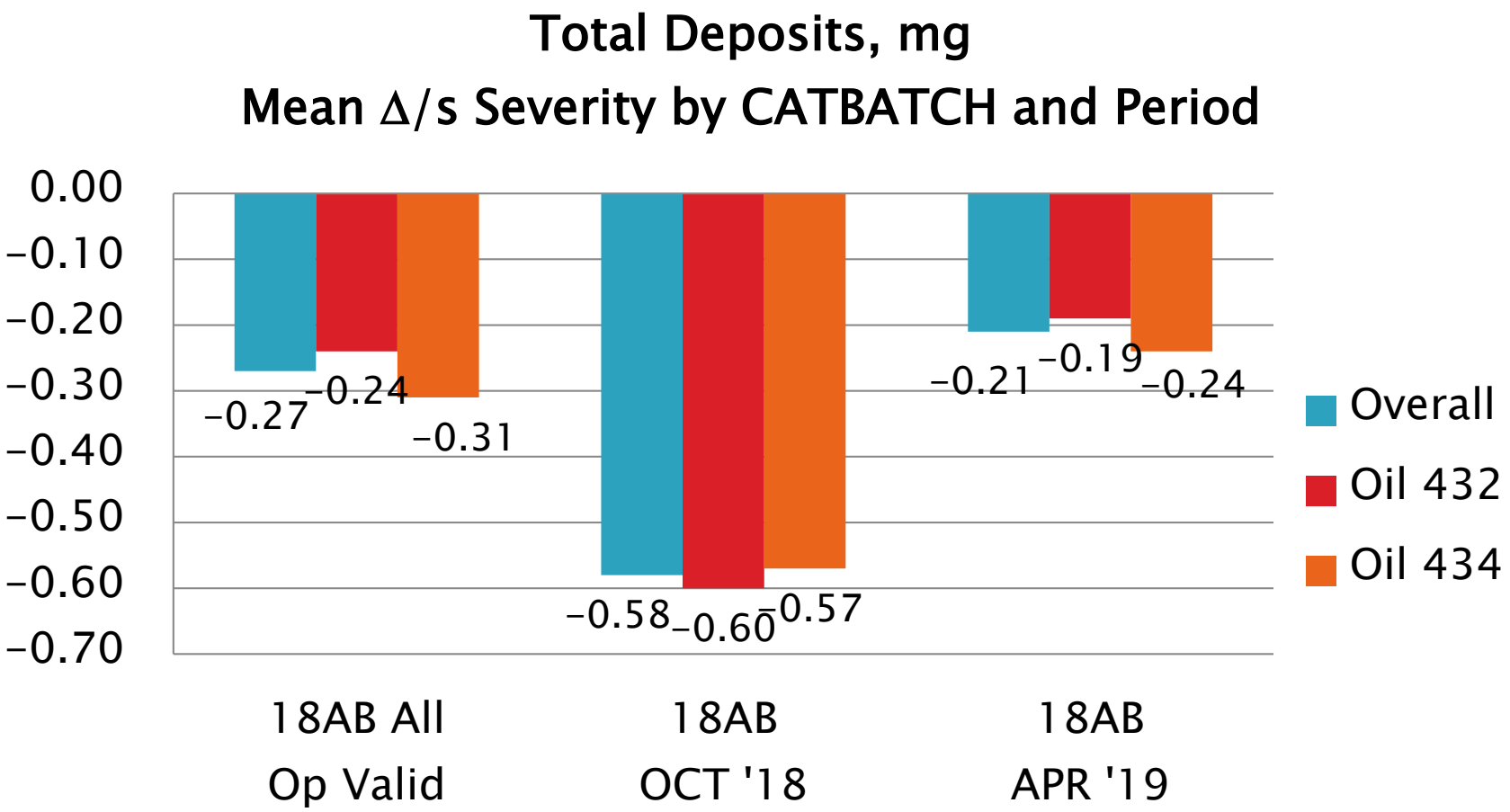
D7097: Deposits by MHT TEOST



D7097: Deposits by MHT TEOST



D7097: Deposits by MHT TEOST



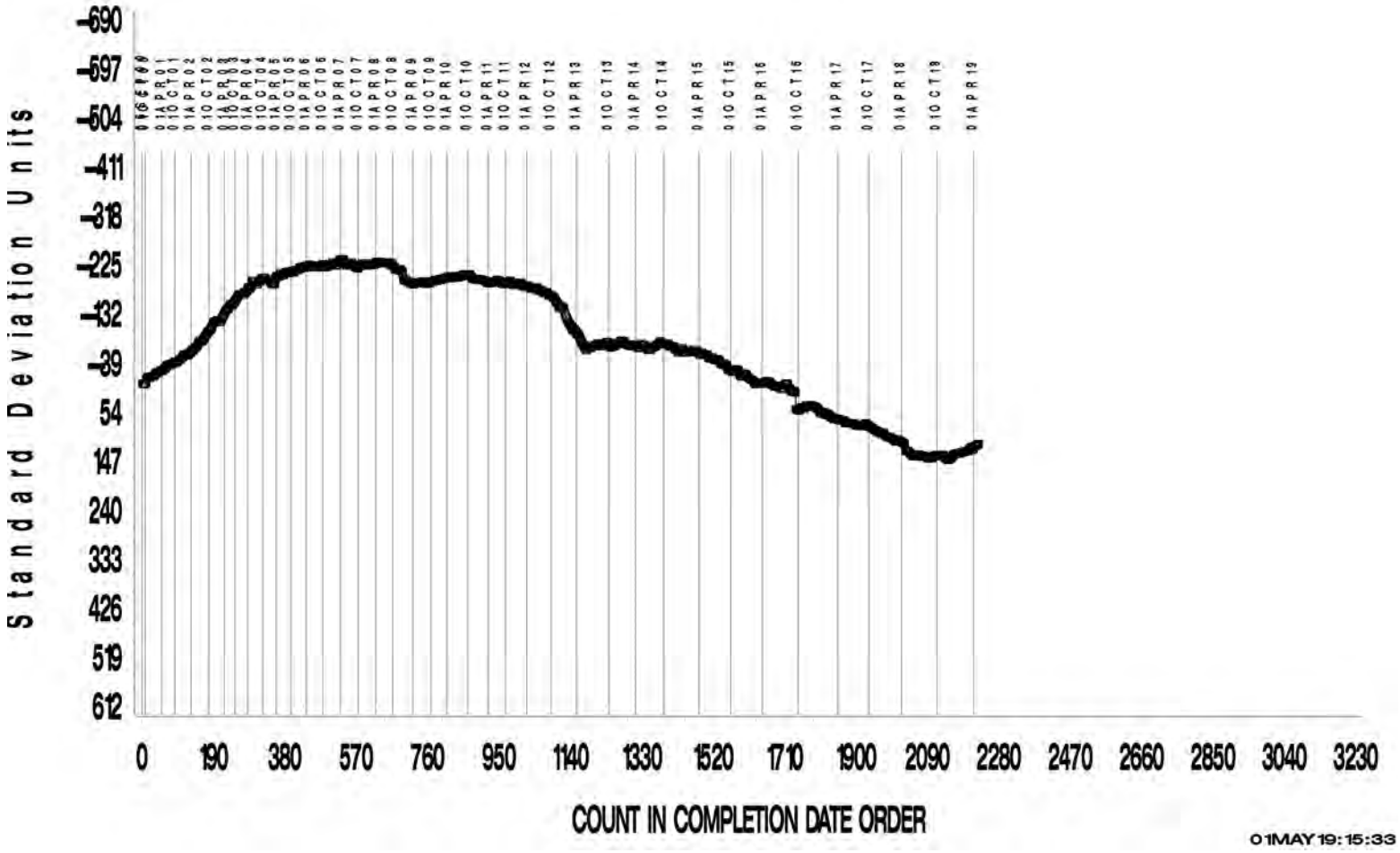
D7097: Deposits by MHT TEOST

- Precision (Pooled s) is comparable to last report period and comparable to target precision
  - Improved precision last four report periods, compared to prior report periods, is coincident with use of new end cap flask seals
- Performance (Mean Δ/s) is -0.14 s mild.
- All operationally valid tests this period report using Rod Batch M
- All operationally valid calibration tests this period report using Catalyst Batch 15AA (n=2), 16DA (n=18) or 18AB (n=77).
- Overall severity of the newest catalyst batch 18AB (n=92) appears to be about -0.3 s mild, and comparably mild on both reference oils.

MHT—4 TEOST INDUSTRY OPERATIONALLY VALID DATA

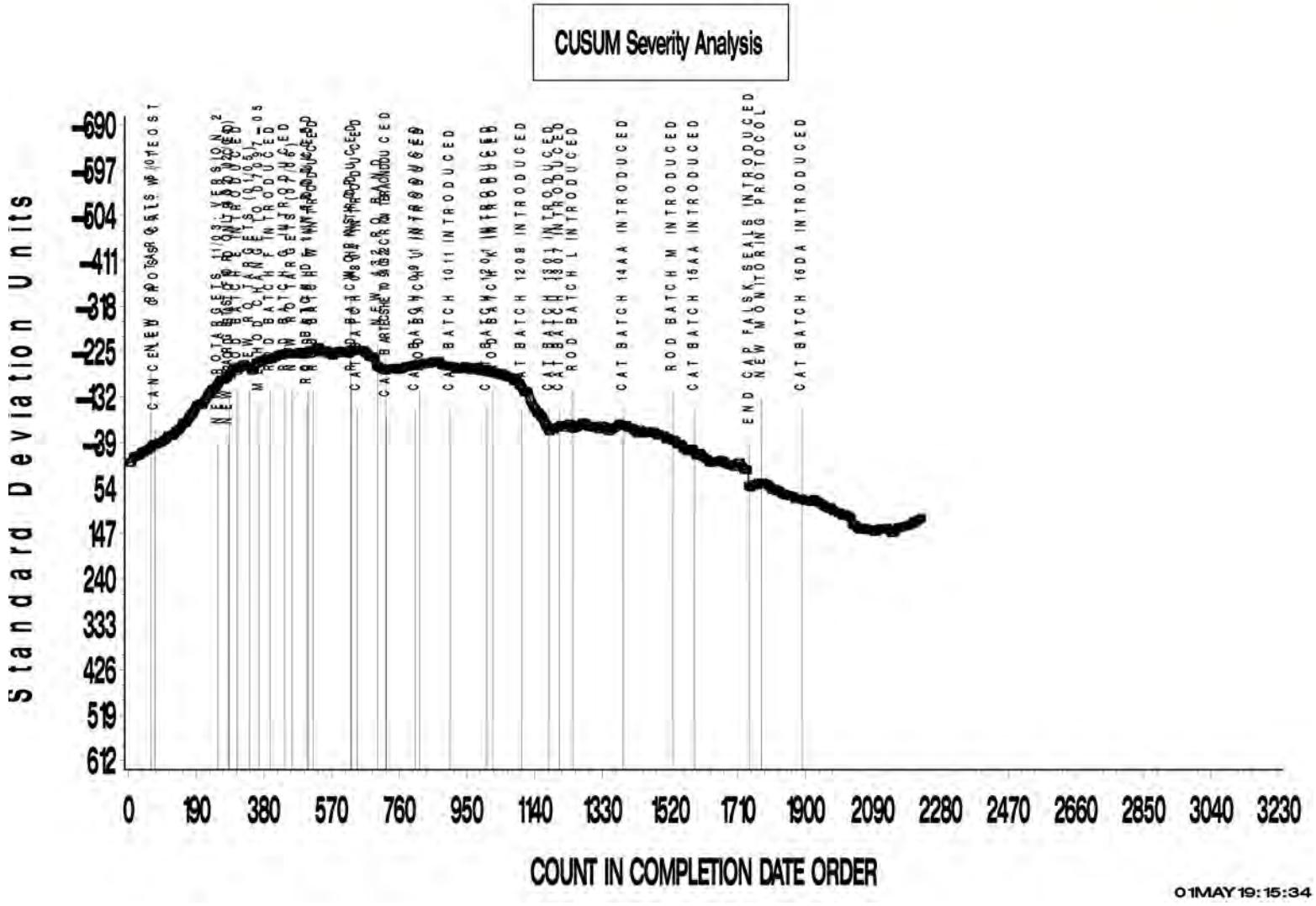
TOTAL DEPOSITS MG

CUSUM Severity Analysis



MHT—4 TEOST INDUSTRY OPERATIONALLY VALID DATA

TOTAL DEPOSITS MG

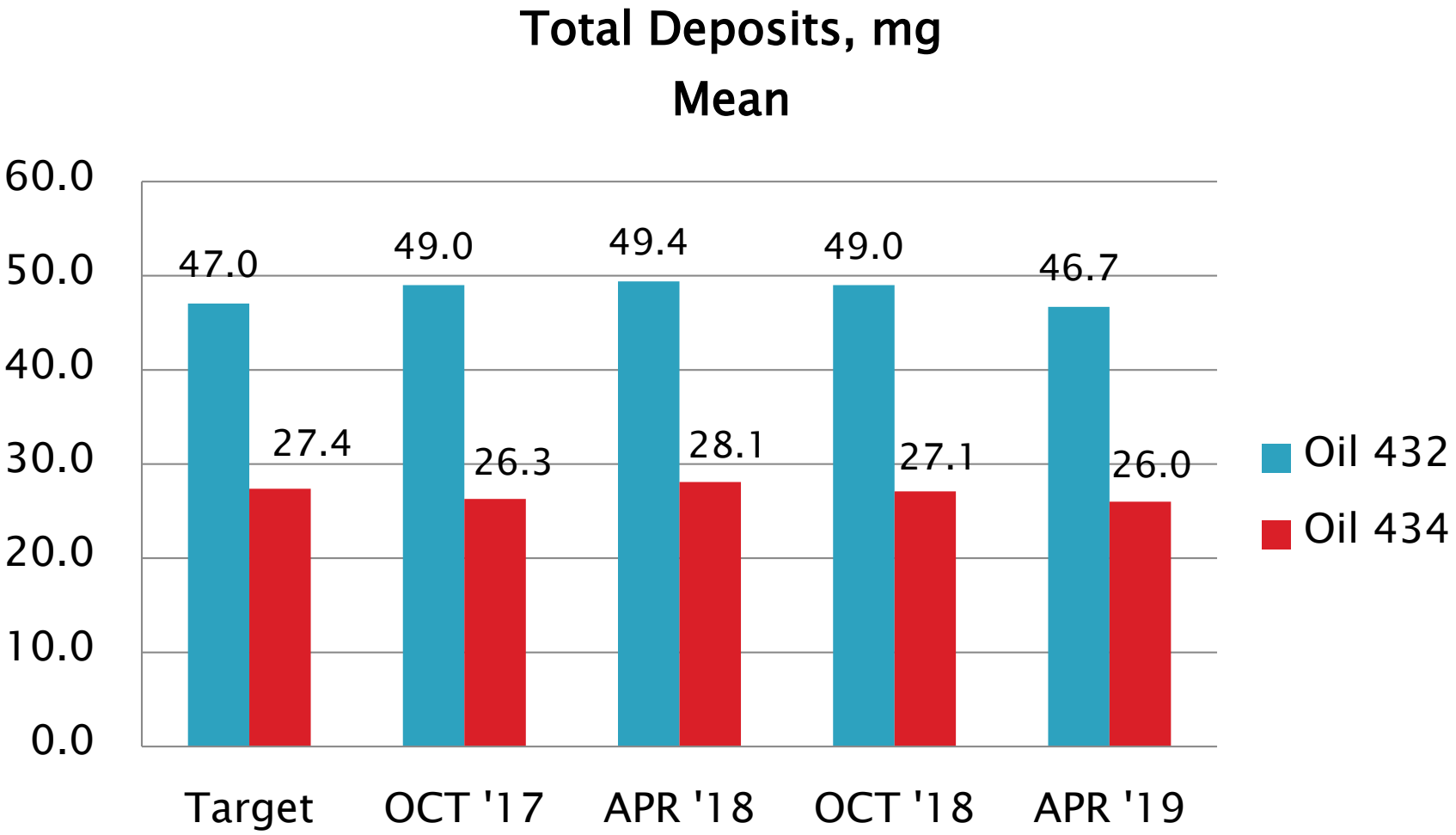


D7097 Performance by Oil

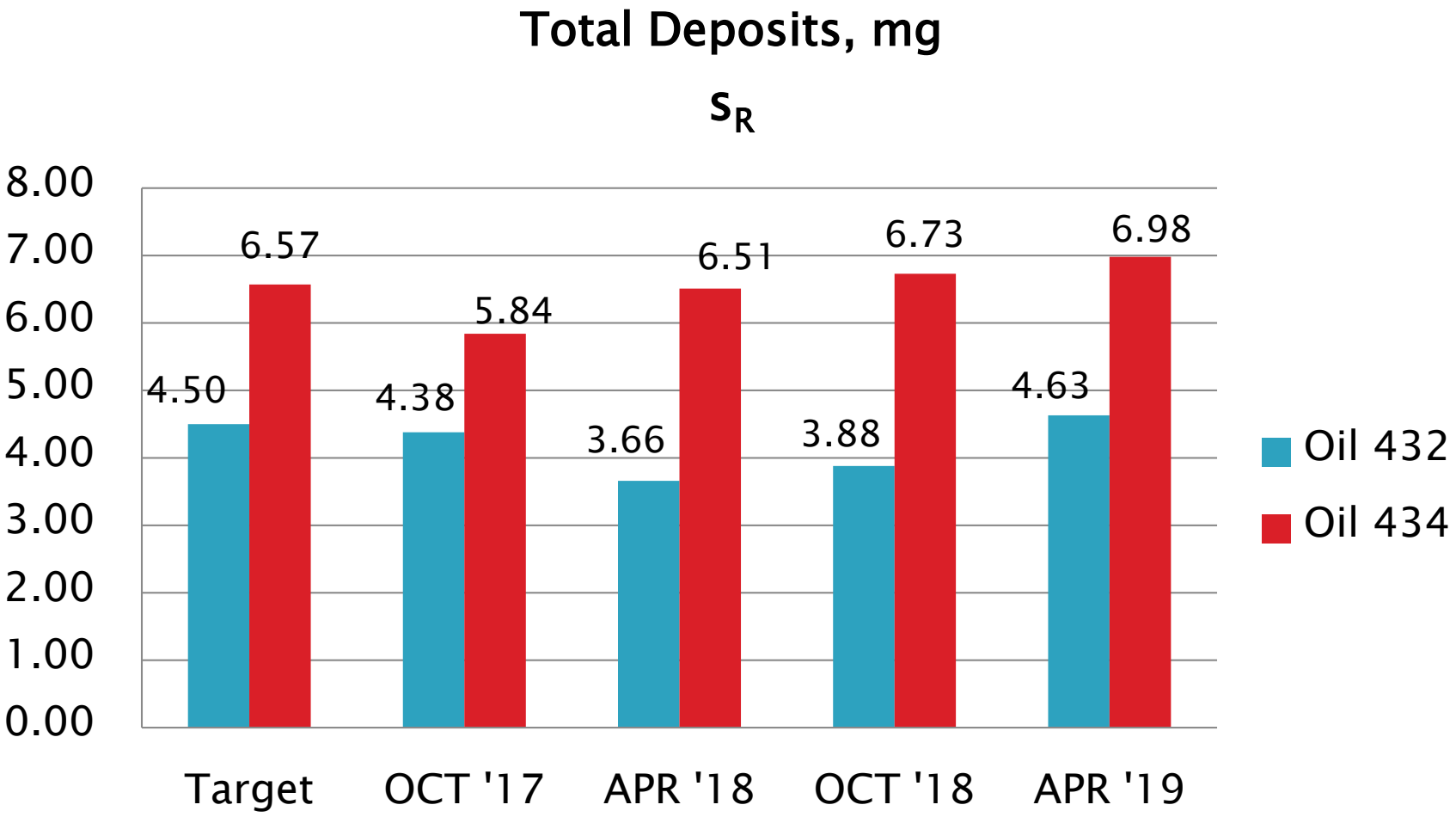
Total Deposits, mg
Performance by Oil

	Targets			10/1/17 – 3/31/18				4/1/18- 9/30/18				10/1/18 – 3/31/19			
Oil Code	n	Mean	s_R	n	Mean	s_R	Mean Δ/s	n	Mean	s_R	Mean Δ/s	n	Mean	s_R	Mean Δ/s
432	30	47.04	4.50	44	49.4	3.66	0.53	48	49.0	3.88	0.44	51	46.7	4.63	-0.07
434	30	27.37	6.57	44	28.1	6.51	0.12	46	27.1	6.73	-0.05	46	26.0	6.98	-0.21

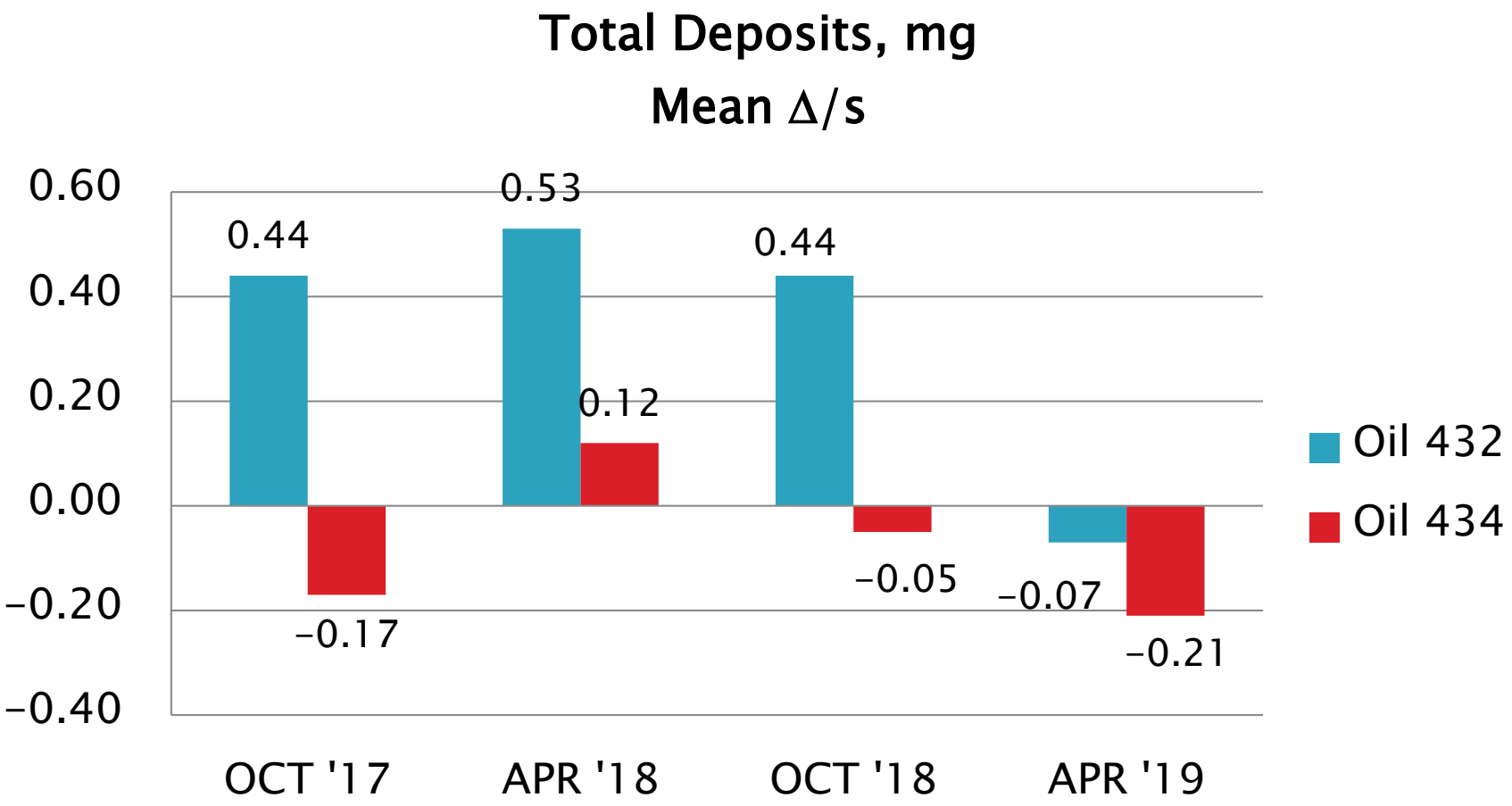
D7097 Performance by Oil



D7097: Deposits by MHT TEOST



D7097: Deposits by MHT TEOST



Return to Executive Summary

D6082: High Temperature Foam

Test Status	Validity Code	No. Tests
Acceptable Calibration Test	AC	14
Acceptable Discrimination Test	AS	6
Failed Statistically	OS	1
Operationally Invalidated by Lab	LC, LS	2
Operationally Invalidated After Initially Reported as Valid	RC	1
Total		**24**

Number of Labs Reporting Data: 6
Fail Rate of Operationally Valid Calibration Tests: 0%

D6082: High Temperature Foam

Statistically Unacceptable Tests (OC, OS)	No. Of Tests
Foam Tendency Mild	1
Foam Tendency Severe	0

- Six of seven severe oil discrimination runs (on TMC oil 66) demonstrated acceptable discrimination.
  - One discrimination run reported mild of lower limit of 100 ml foam tendency (validity OS), repeat run showed acceptable discrimination.
  - Discrimination runs are not evaluated for overall period precision or severity due to poor test precision above 100 ml foam tendency.

- Three operationally invalid runs reported this period.
  - All for not having run a discrimination oil concurrent with the calibration when due. All were re-run acceptably.

- Calibration requirement updates are issued as LTMS document updates.

D6082: High Temperature Foam

Period Precision and Severity Estimates Oils 1007

Foam Tendency, ml	n	Mean	Pooled s	Mean Δ/s
Current Targets	28	65.71	19.28	-----
4/1/15 through 9/30/15	11	59	16	-0.36
10/1/15 through 3/31/16	8	58	10	-0.45
4/1/16 through 9/30/16	12	59	18	-0.38
10/1/16 through 3/31/17	14	54	19	-0.62
4/1/17 through 9/30/17	12	69	10	0.17
10/1/17 through 3/31/18* 10/1/17 through 3/31/18*	14 13	66 62	17 11	-0.02 -0.19
4/1/18 through 9/30/18	14	65	9	-0.07
10/1/18 through 3/31/19	14	65	12	-0.07

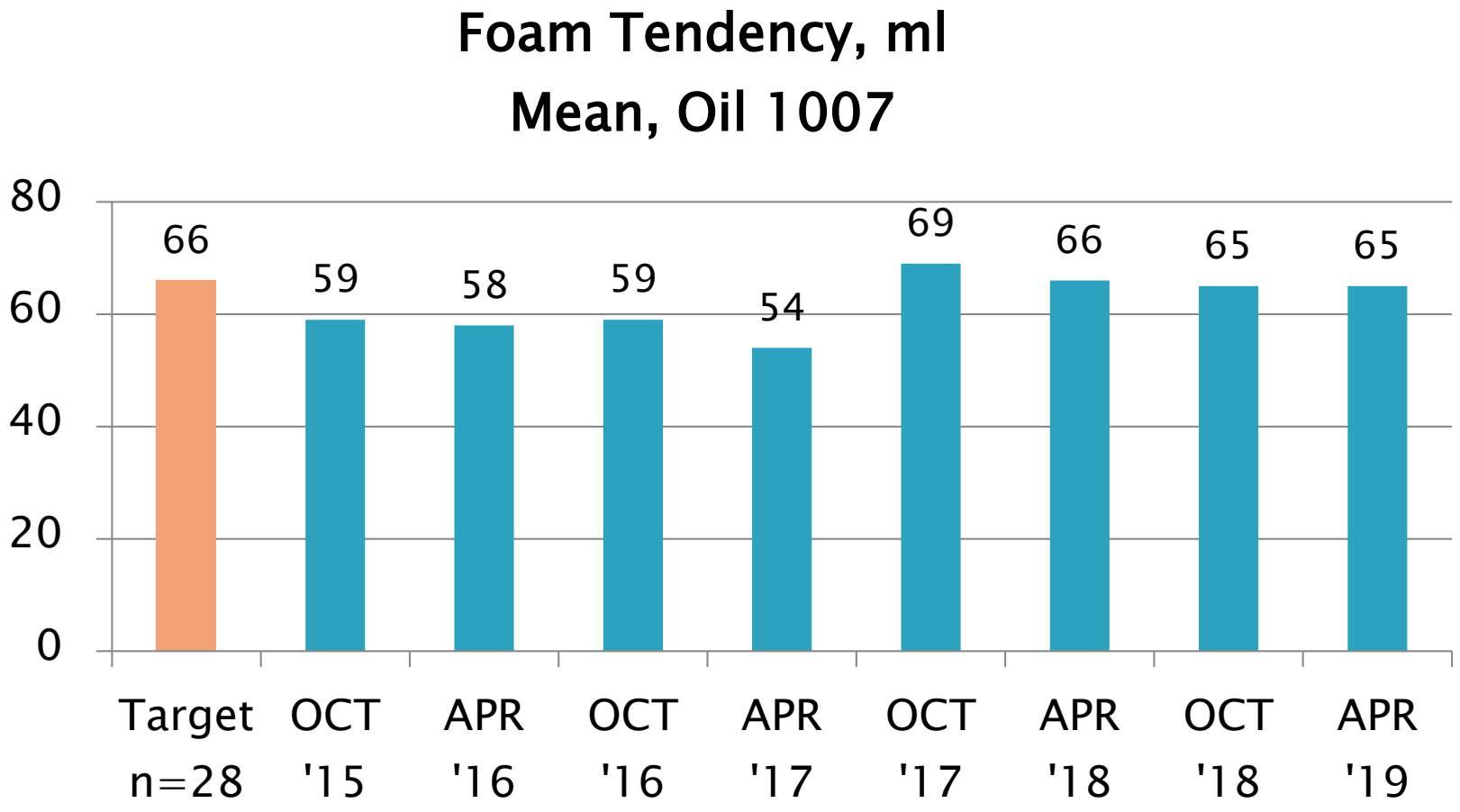
*Single OC result Yi=2.3 s severe included and excluded

D6082: High Temperature Foam

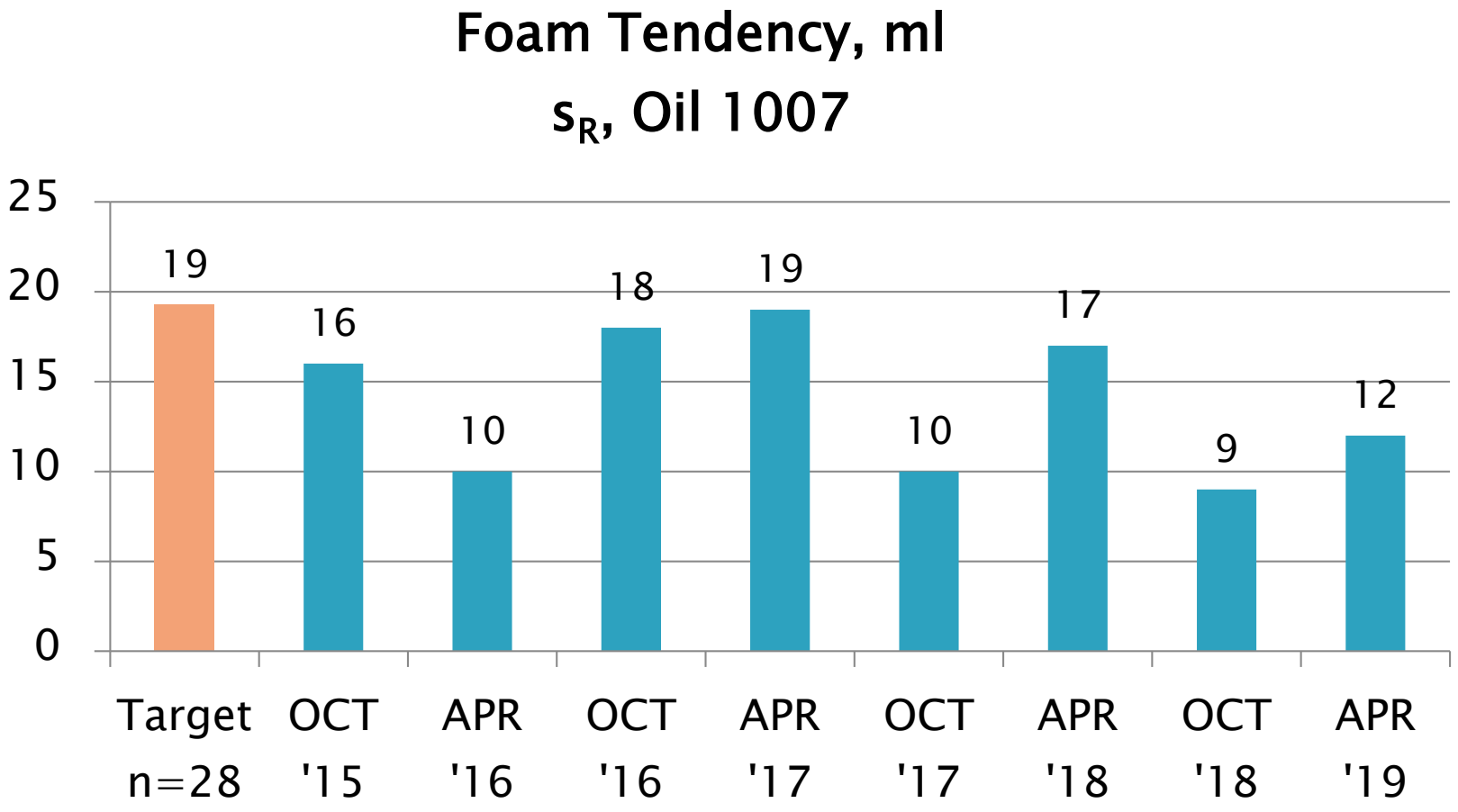
Period Precision and Severity Estimates Oil 1007

Foam Stability @ 1 min, ml	n	Mean	s
Current Targets	28	0.00	0.00
4/1/15 through 9/30/15	11	No non-zero occurrences	
10/1/15 through 3/31/16	8	No non-zero occurrences	
4/1/16 through 9/30/16	12	No non-zero occurrences	
10/1/16 through 3/31/17	14	No non-zero occurrences	
4/1/17 through 9/30/17	12	No non-zero occurrences	
10/1/17 through 3/31/18	14	No non-zero occurrences	
4/1/18 through 9/30/18	14	No non-zero occurrences	
10/1/18 through 3/31/19	14	No non-zero occurrences	

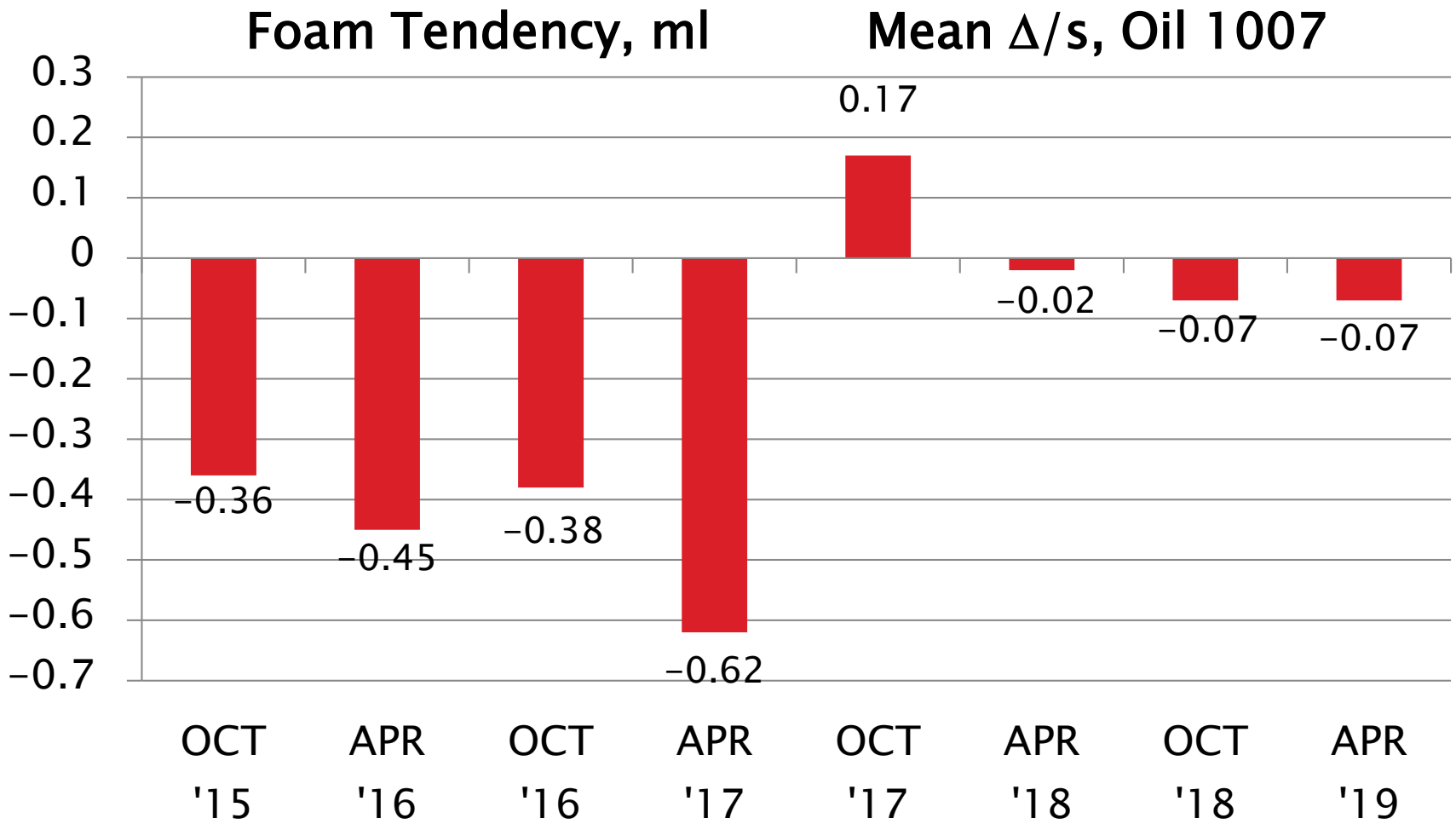
D6082: High Temperature Foam



D6082: High Temperature Foam



D6082: High Temperature Foam

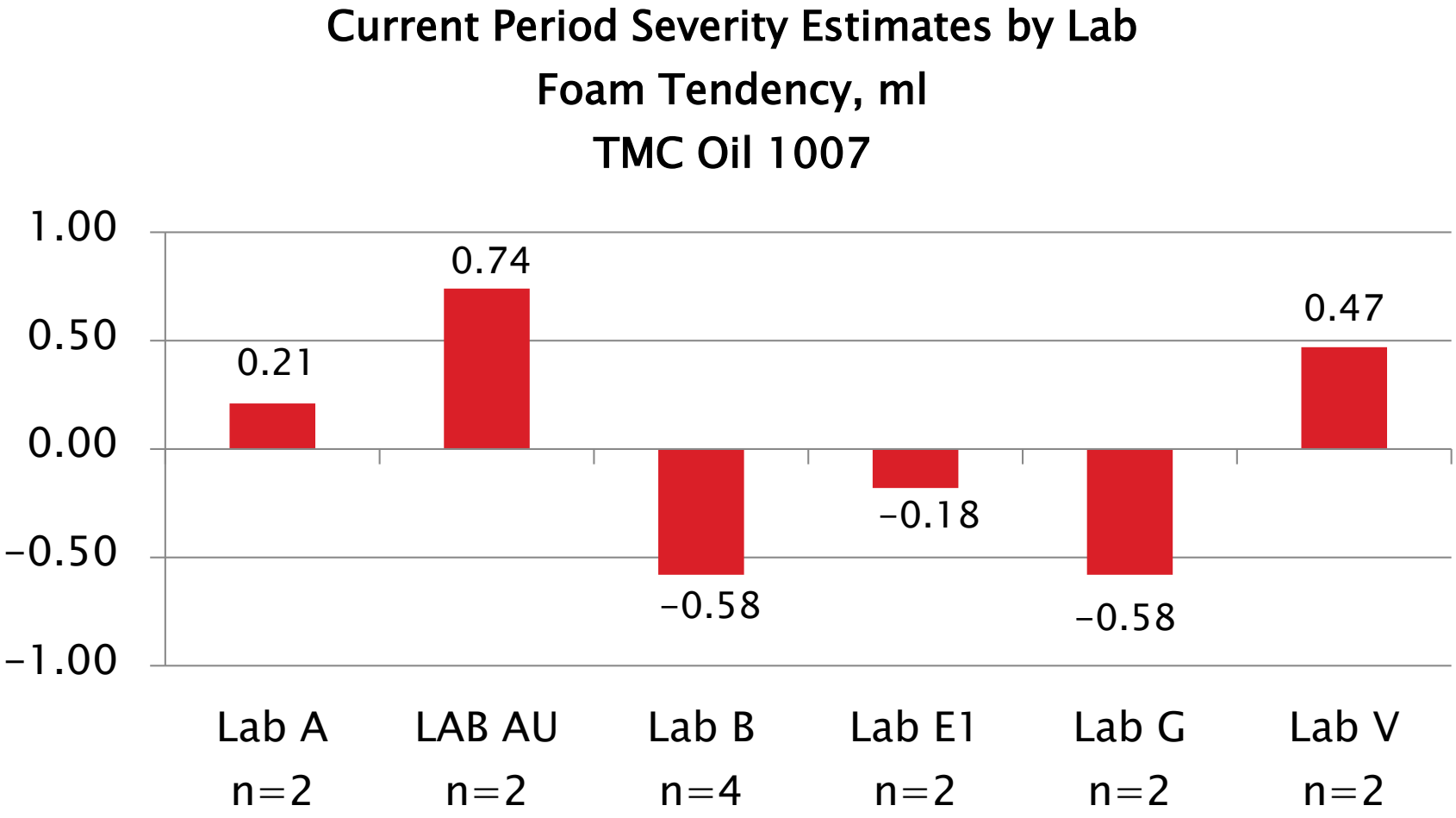


D6082: High Temperature Foam

Current Period Severity Estimates by Lab
Foam Tendency, ml
TMC Oil 1007

	n	Mean Δ/s
Lab A	2	0.21
Lab AU	2	0.74
Lab B	4	-0.58
Lab E1	2	-0.18
Lab G	2	-0.58
Lab V	2	0.47

D6082: High Temperature Foam



D6082: High Temperature Foam

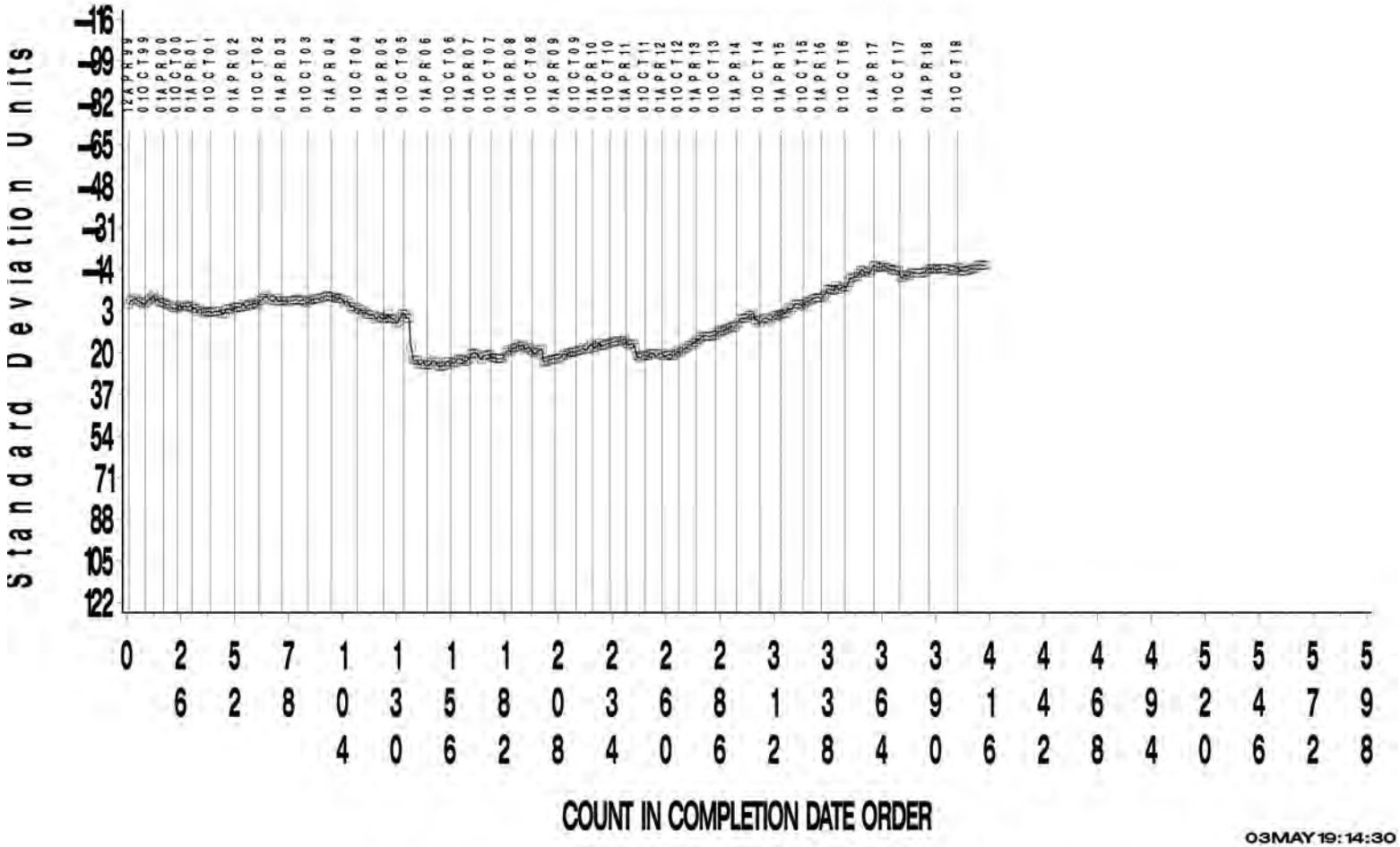
- Foam Tendency Precision (Pooled s) is less precise than the prior report period
  - More precise than target precision
- Performance (Mean Δ/s) is on target (slight mild bias)
- No non-zero occurrences of Foam Stability
  - Six of seven severe oil discrimination runs (on TMC oil 66) demonstrated acceptable discrimination.
    - One discrimination run reported mild of lower limit of 100 ml foam tendency (validity OS), repeat run showed acceptable discrimination.

D6082 HIGH TEMPERATURE FOAM INDUSTRY OPERATIONALLY VALID DA

IND= '1007'

FOAM TENDENCY

CUSUM Severity Analysis



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Return to Executive Summary

D874: Sulfated Ash

Test Status	Validity Code	No. Tests
Acceptable Calibration Test	AC	8
Failed Calibration Test	OC	0
Operationally Invalidated by Lab	LC, XC	1
Operationally Invalidated After Initially Reported as Valid	RC	0
Total		**9**

Number of Labs Reporting Data: 4
Fail Rate of Operationally Valid Tests: 0%

D874: Sulfated Ash

Statistically Unacceptable Tests (OC)	No. Of Tests
Sulfated Ash Mild	0
Sulfated Ash Severe	0

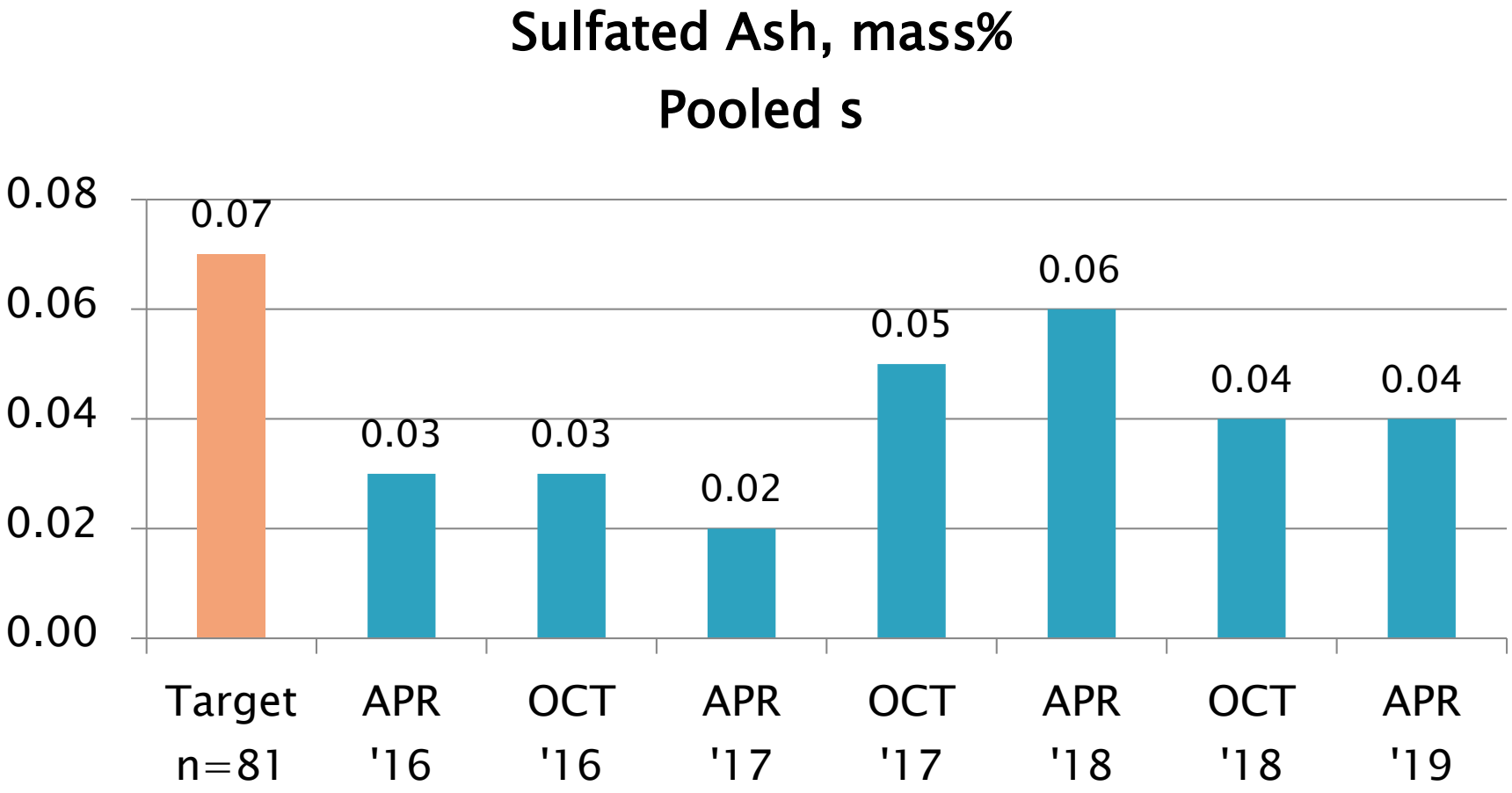
- No statistically invalid tests reported this period
- One operationally invalid test reported this period:
  - Failed expected result on control sample (LC)
- No TMC technical updates issued this period

D874: Sulfated Ash

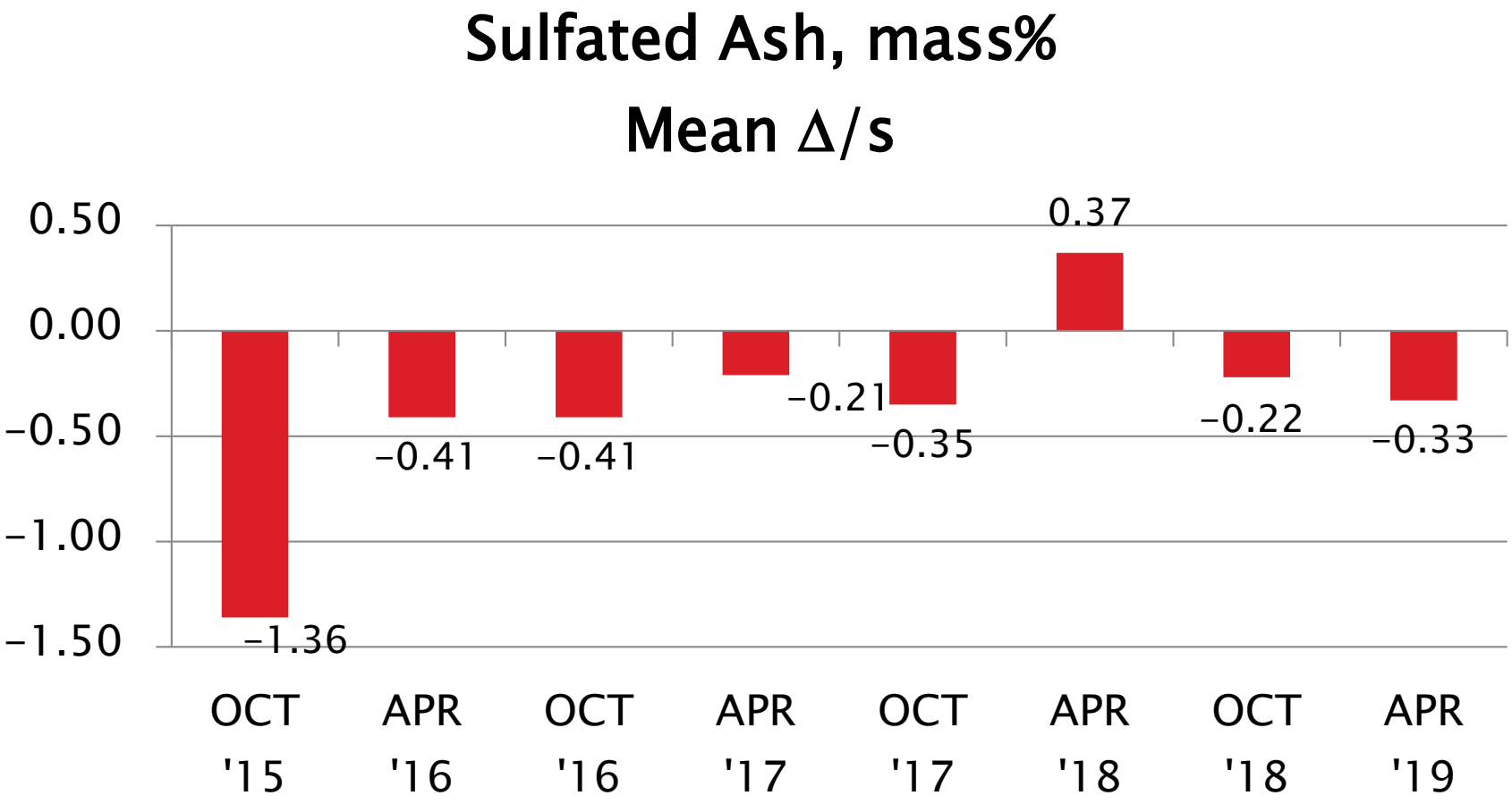
Period Precision and Severity Estimates

Total Deposits, mg	n	df	Pooled s	Mean Δ/s
Current Targets	81	78	0.07	-----
10/1/15 through 3/31/16	7	4	0.03	-0.41
4/1/16 through 9/30/16	6	3	0.03	-0.41
10/1/16 through 3/31/17	7	4	0.02	-0.21
4/1/17 through 9/30/17	8	5	0.05	-0.35
10/1/17 through 3/31/18	8	5	0.06	0.37
4/1/18 through 9/30/18	8	5	0.04	-0.22
10/1/18 through 3/31/19	8	5	0.04	-0.33

D874: Sulfated Ash



D874: Sulfated Ash

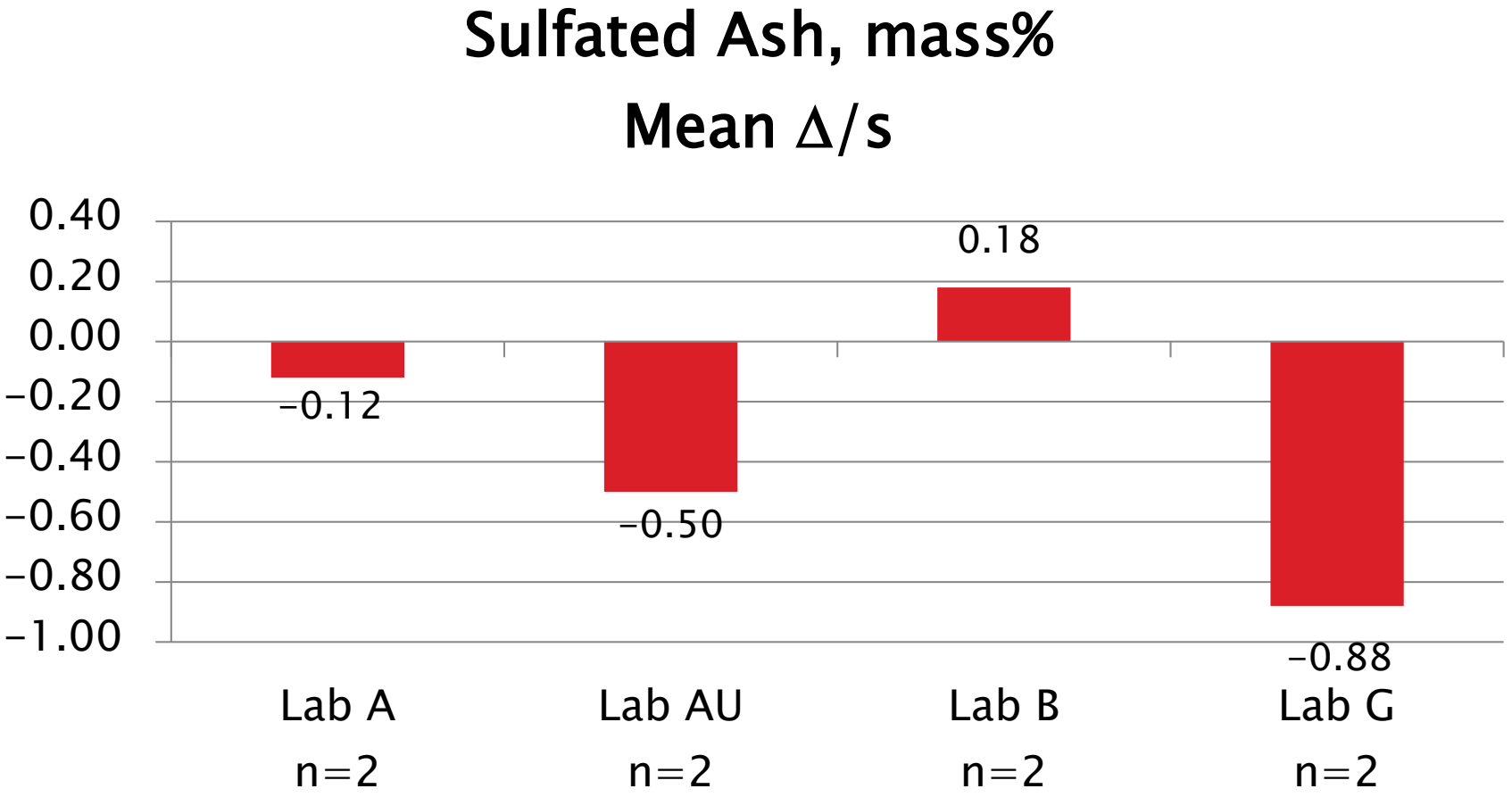


D874: Sulfated Ash

Current Period Severity Estimates by Lab
Sulfated Ash, mass%

	n	Mean Δ/s
Lab A	2	-0.12
Lab AU	2	-0.50
Lab B	2	0.18
Lab G	2	-0.88

D874: Sulfated Ash

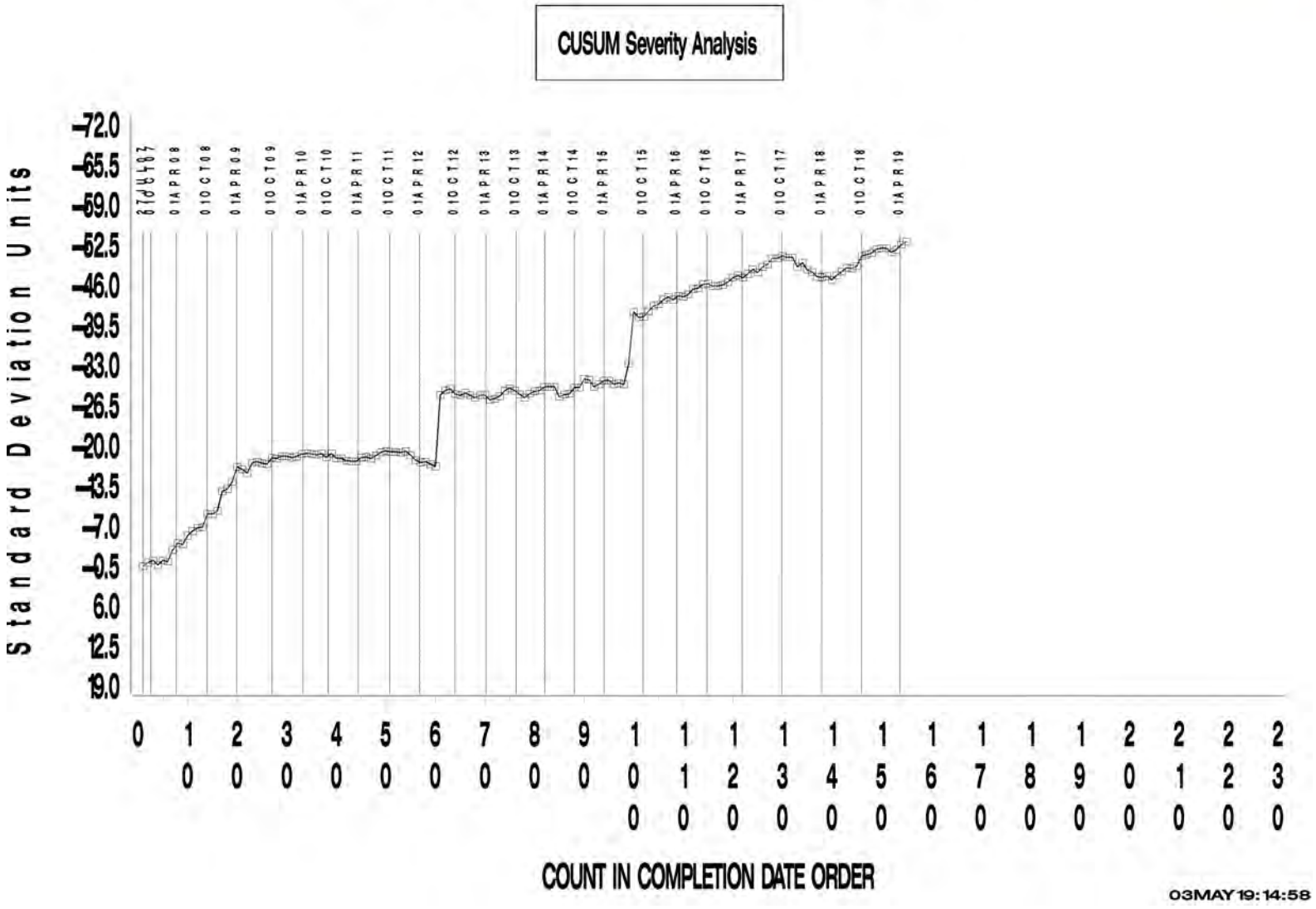


D874: Sulfated Ash

- Precision (Pooled s) is comparable to prior periods
  - More precise than target precision
- Performance (Mean Δ/s) is -0.33 s mild

D874 INDUSTRY OPERATIONALLY VALID DATA

TEST SAMPLE PERCENT SULFATED ASH

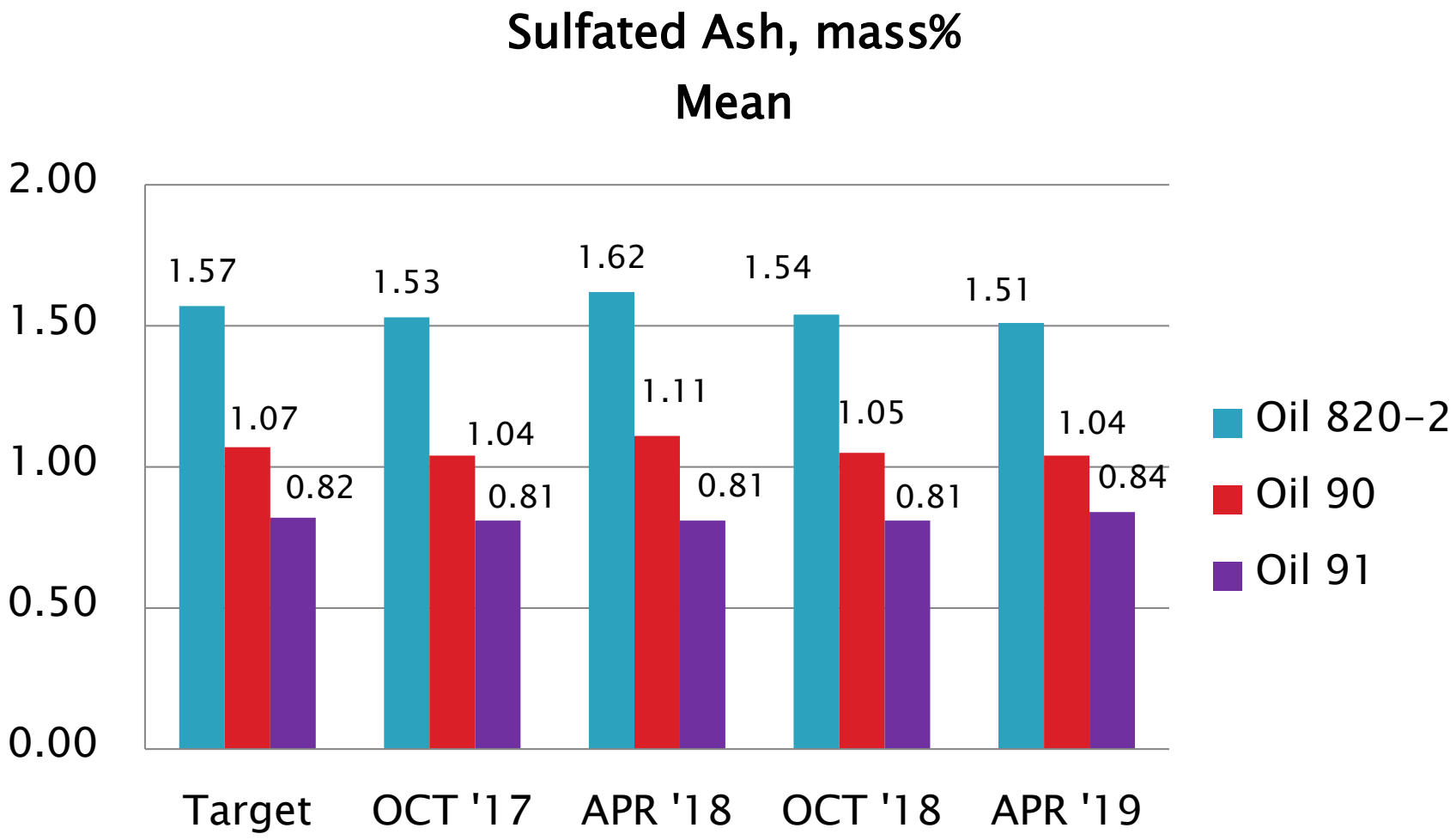


D874: Sulfated Ash

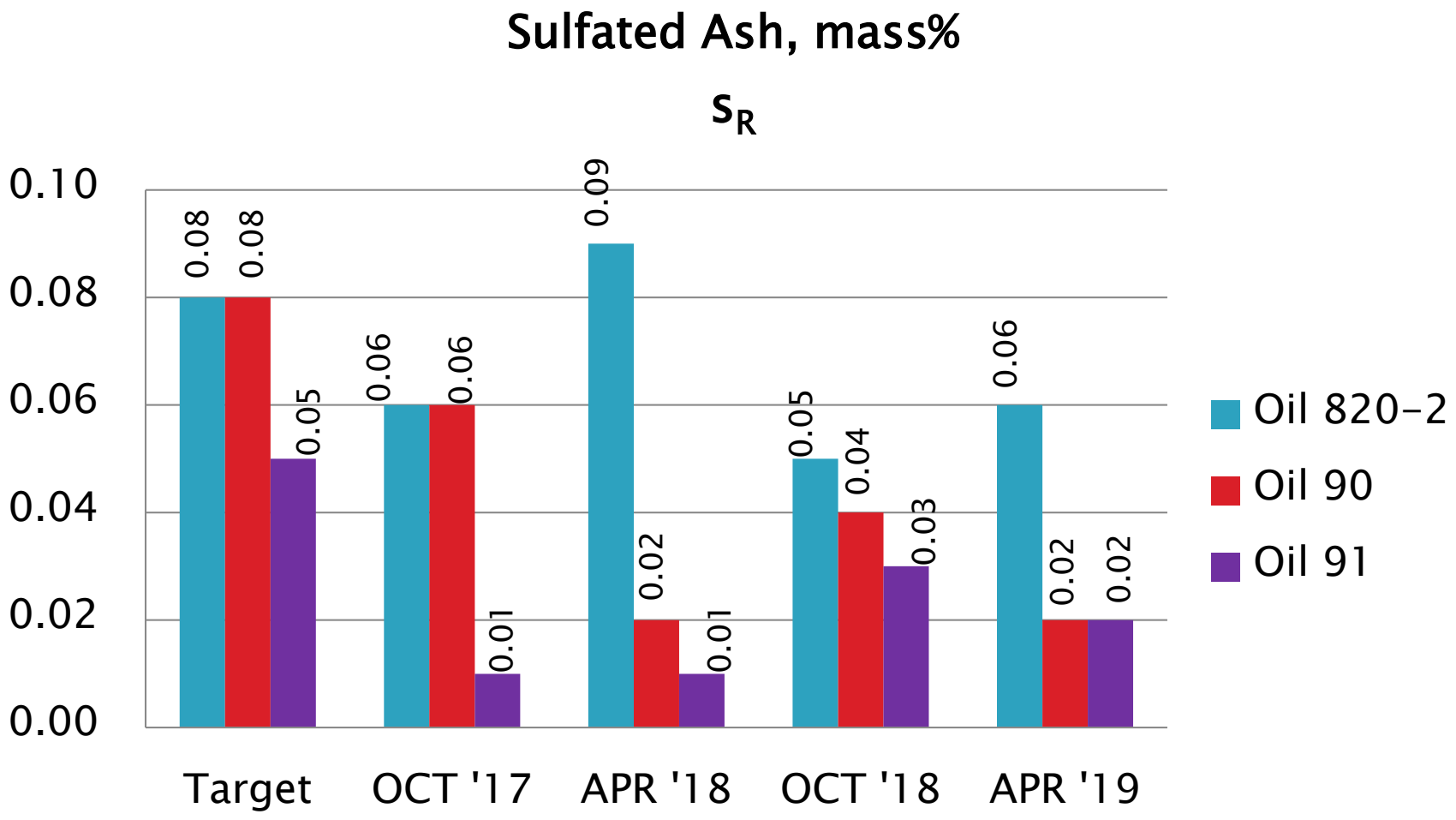
Performance by Oil
Sulfated Ash, mass%

	Targets			10/1/17 – 3/31/18				4/1/18 – 9/30/18				10/1/18 – 3/31/19			
Oil Code	n	Mean	s_R	n	Mean	s_R	Mean Δ/s	n	Mean	s_R	Mean Δ/s	n	Mean	s_R	Mean Δ/s
820-2	27	1.57	0.08	3	1.62	0.09	0.67	2	1.54	0.05	-0.31	3	1.51	0.06	-0.75
90	27	1.07	0.08	3	1.11	0.02	0.46	2	1.05	0.04	-0.25	3	1.04	0.02	-0.33
91	27	0.82	0.05	2	0.81	0.01	-0.20	4	0.81	0.03	-0.15	2	0.84	0.02	0.30

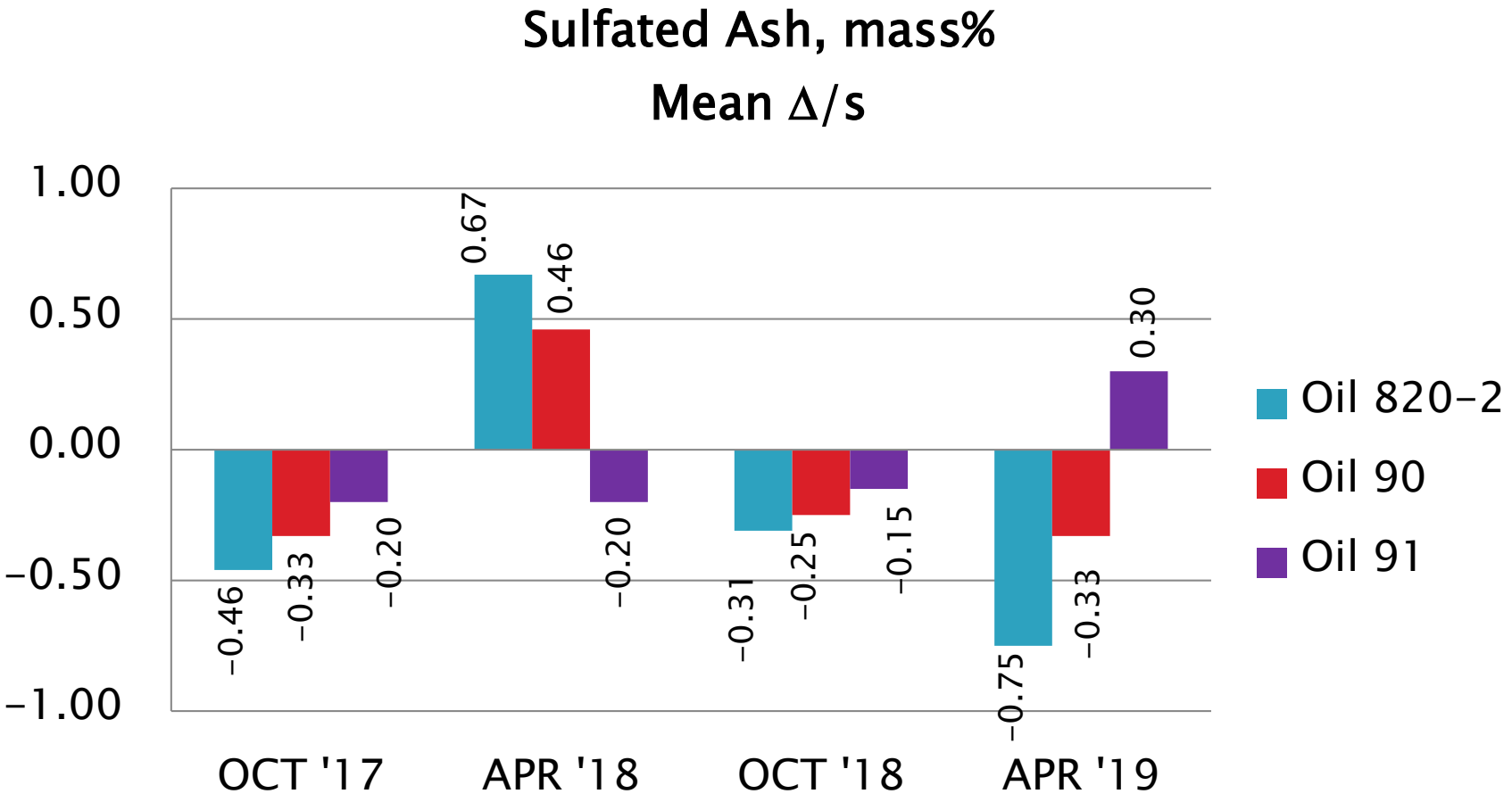
D874: Sulfated Ash



D874: Sulfated Ash



D874: Sulfated Ash



Return to Executive Summary

D7528: Oxidation by ROBO

Test Status	Validity Code	No. Tests
Acceptable Calibration Test	AC	85
Failed Calibration Test	OC	15
Operationally Invalidated by Lab	LC, XC	14
Operationally Invalidated After Initially Reported as Valid	RC	3
438-2 Replacement Oil RR	AG, LG	11
Dilute NO_2 Study	AG, OG, LG	9
Rig Shakedown Runs	NN	9
Total		**146**

Number of Labs Reporting Data: 6
Fail Rate of Operationally Valid Tests: 15%

D7528: Oxidation by ROBO

Operationally Invalid Calibration Tests

- 2 tests EOT MRV Yield Stress off-spec (RC)
- 1 test power failure (XC)
- 3 tests NO_2 flow off-spec (LC)
- 1 test vacuum failure (LC)
- 8 tests heater or heater control failure (RC, LC, XC)
- 1 test cracked condenser (XC)
- 1 test wrong reaction vessel selected (XC)

Other Tests

- 11 donated runs to establish initial performance targets on replacement oil 438-2 (AG, LG)
- 9 runs reported to study performance of modified rig setup using dilute NO2 (AG, OG, LG)
- Of the 9 shakedown runs reported, 3 were required pre-calibration runs on a new rig, and several more were to confirm operation of rigs before converting for dilute NO2 study runs.

D7528: Oxidation by ROBO

Statistically Unacceptable Tests (OC)	No. Of Tests
Natural Log (MRV Viscosity) Mild	7
Natural Log (MRV Viscosity) Severe	8

- 4 tests mild on 434-2
- 2 tests severe on 434-2
- 3 tests mild on oil 435-1
- 4 tests severe on 435-1
- 2 tests severe on 438

- Calibration requirement updates are now issued as LTMS document updates

D7528: Oxidation by ROBO

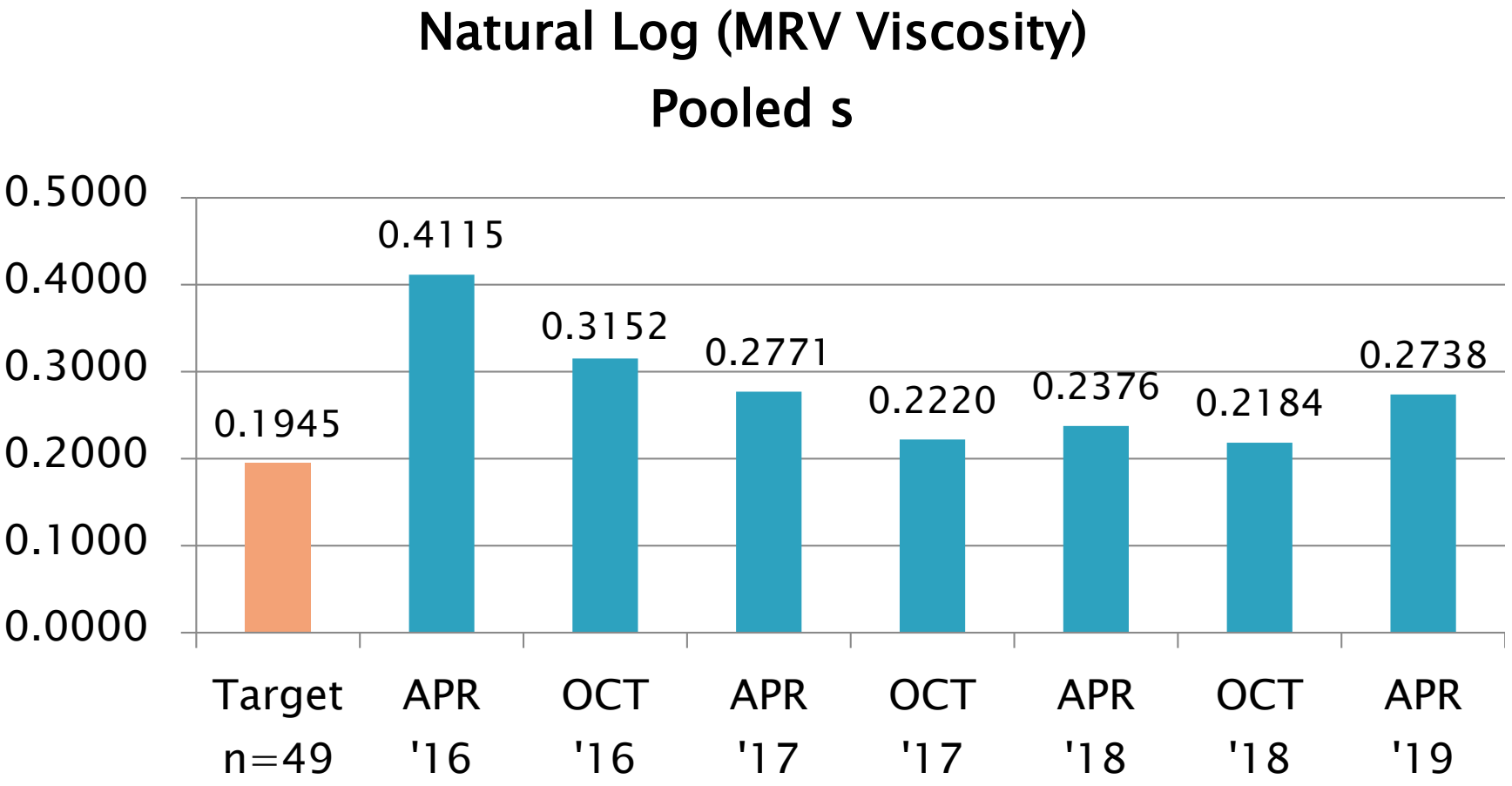
Period Precision and Severity Estimates

Natural Log (MRV Viscosity)	n	df	Pooled s	Mean Δ/s
Current Targets	49	46	0.1945	-----
10/1/15 through 3/31/16*	92	89	0.4115	-0.10
10/1/15 through 3/31/16*	91	88	0.3661	-0.20
4/1/16 through 9/30/16	74	71	0.3152	-0.53
10/1/16 through 3/31/17	78	75	0.2771	-0.91
4/1/17 through 9/30/17	99	95	0.2220	-0.76
10/1/17 through 3/31/18**	90	86	0.2376	-0.91
10/1/17 through 3/31/18**	83	79	0.2076	-0.74
4/1/18 through 9/30/18	126	122	0.2184	-0.49
10/1/18 through 3/31/19	100	96	0.2738	0.04

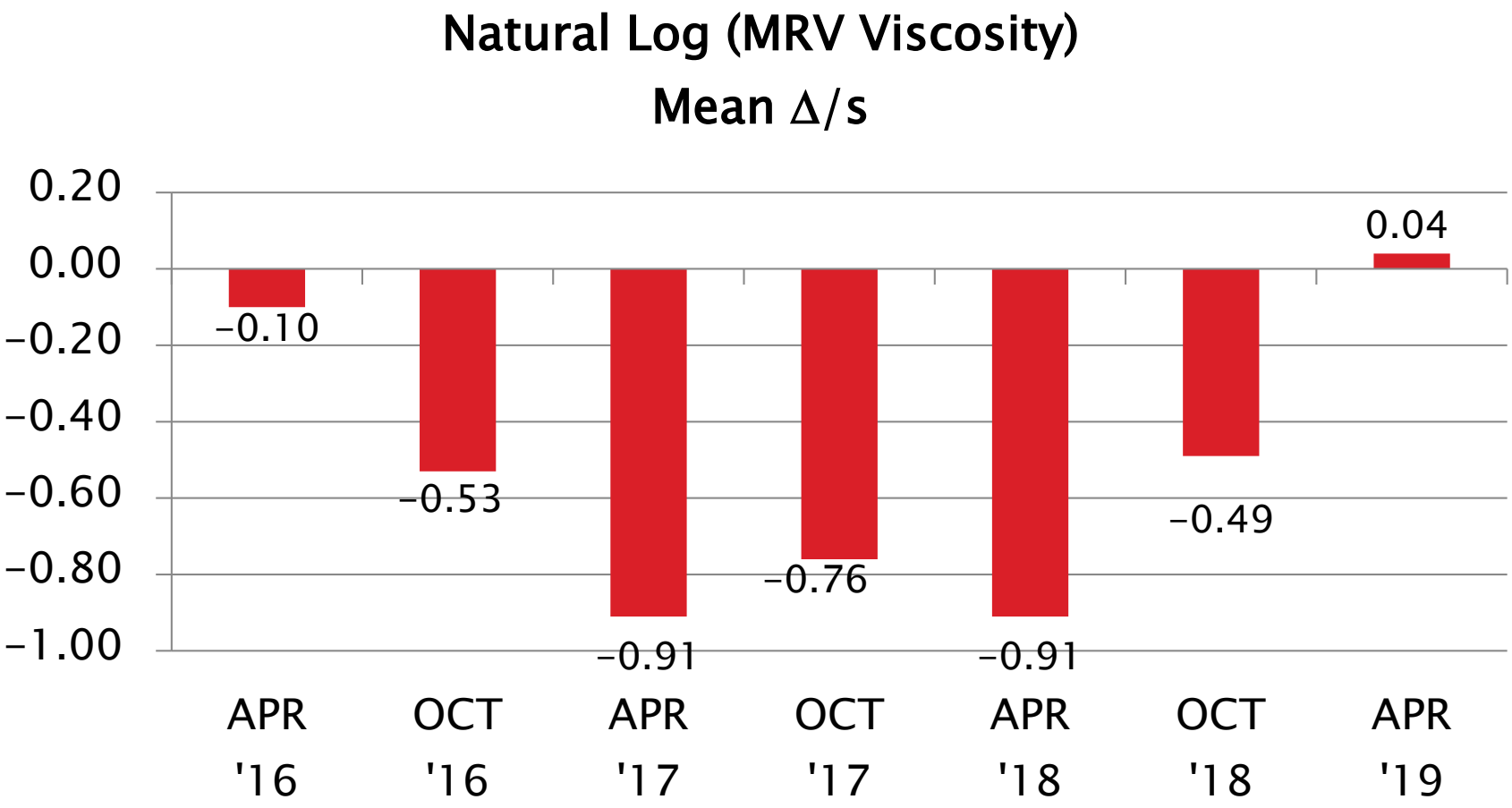
*Period statistics with one extreme result included and excluded

**Period statistics with seven suspect results from two rigs included and excluded

D7528: Oxidation by ROBO



D7528: Oxidation by ROBO

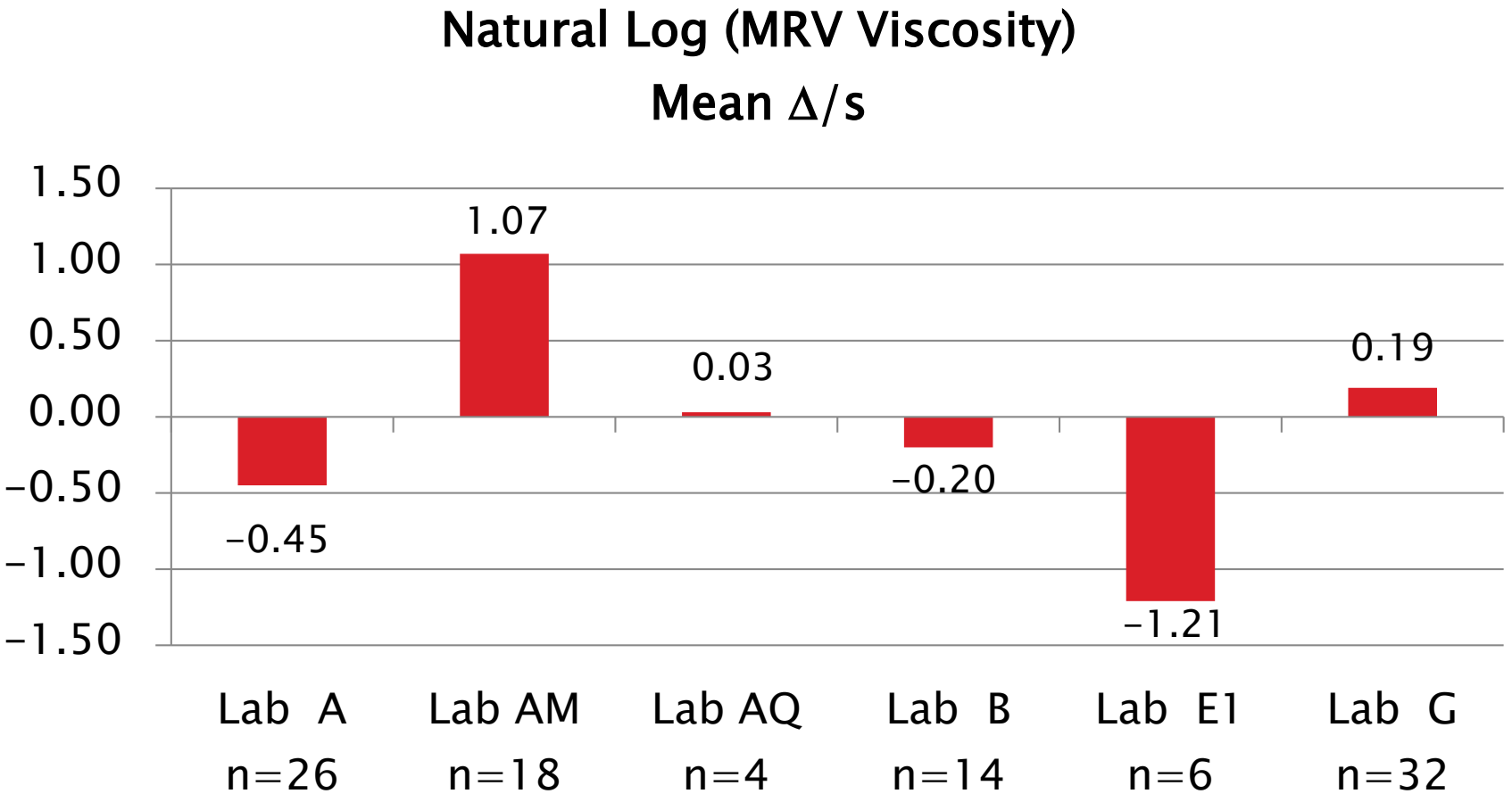


D7528: Oxidation by ROBO

Current Period Severity Estimates by Lab Natural Log (MRV Viscosity)

	n	Mean Δ/s
Lab A	26	-0.45
Lab AM	18	1.07
Lab AQ	4	0.03
Lab B	14	-0.20
LAB E1	6	-1.21
Lab G	32	0.19

D7528: Oxidation by ROBO



D7528: Oxidation by ROBO

- One test reported this period as operationally valid failed -5.0 s mild (Rig E1 1). As failing ROBO results of similar magnitude (mild or severe) now occur most every report period, these will no longer be singled out as extreme events in period statistics, but will be noted in summary.

D7528: Oxidation by ROBO

- Precision (Pooled s) is notably less precise than the last three periods
  - Continues to be less precise than target
  - Poorer precision this period is consistent across the three reference oils.
- Performance (Mean Δ/s) is on-target for this report period

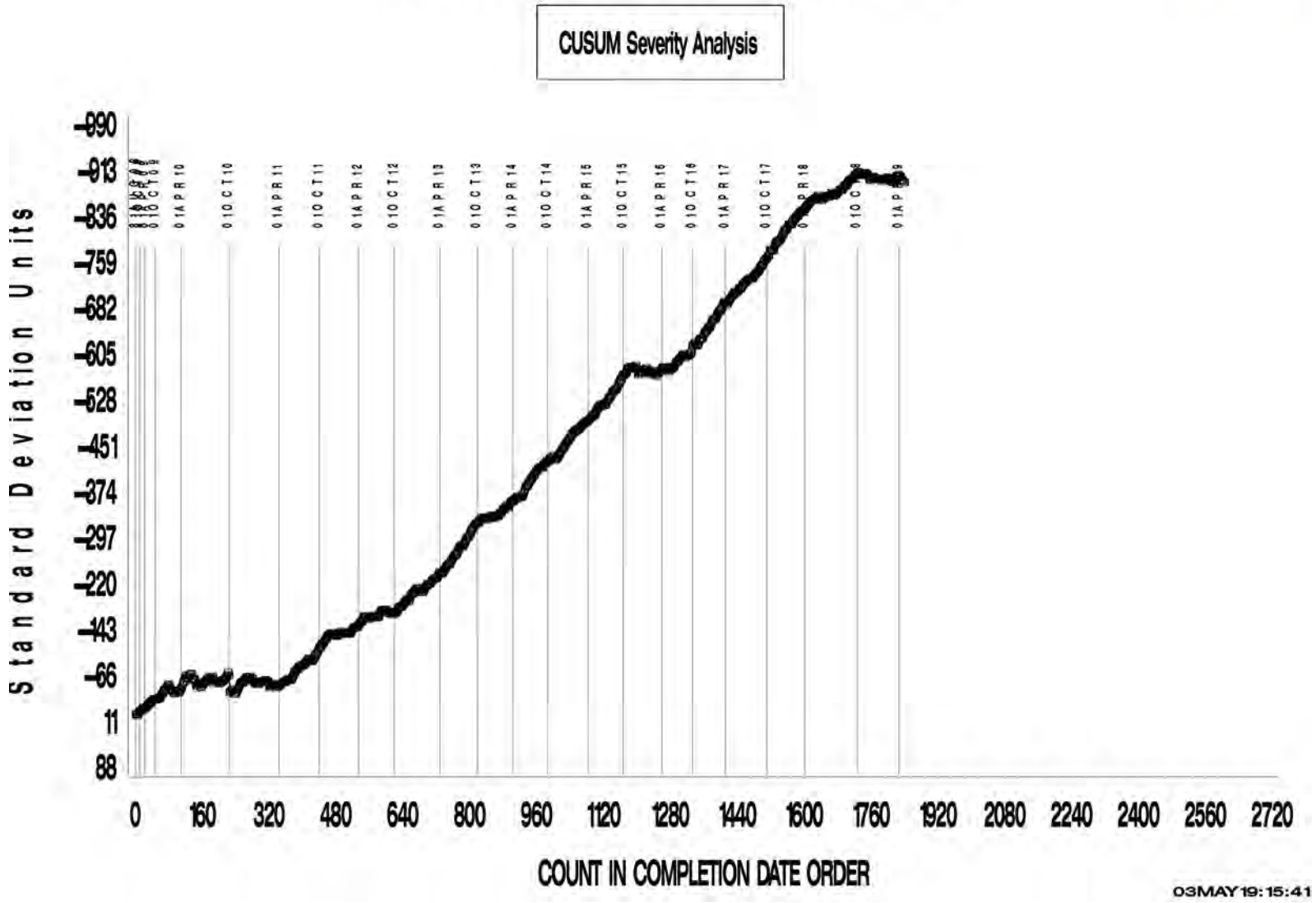
D7528: Oxidation by ROBO

- Only one test was reported this period on nearly depleted reference oil 434-1
  - 434-2 targets were set with consideration of preserving (or not canceling out) the mild trend observed on oil 434-1. However, 434-2 overall performance this period is only slightly mild of the target mean.
  - Any 434-1 in current lab inventories is still being assigned. Only Lab D has any 434-1 left in inventory; Lab D did not contribute any calibration test runs this period.

- CUSUM Severity Plot shows an overall leveling to on-target performance this period, following a long overall mild trend since the 01APR11 timeline (following a 2011 ROBO workshop). A similar, but brief, leveling is also noted in the CUSUM plot coincident with the October 2015 ROBO workshop held in San Antonio, TX, but the mild trend returned on subsequent periods, denoted by date timelines in the plot.

ROBO TEST INDUSTRY OPERATIONALLY VALID DATA

AGED OIL MRV APPARENT VISCOSITY



Test Monitoring Center

http://astmtmc.cmu.edu

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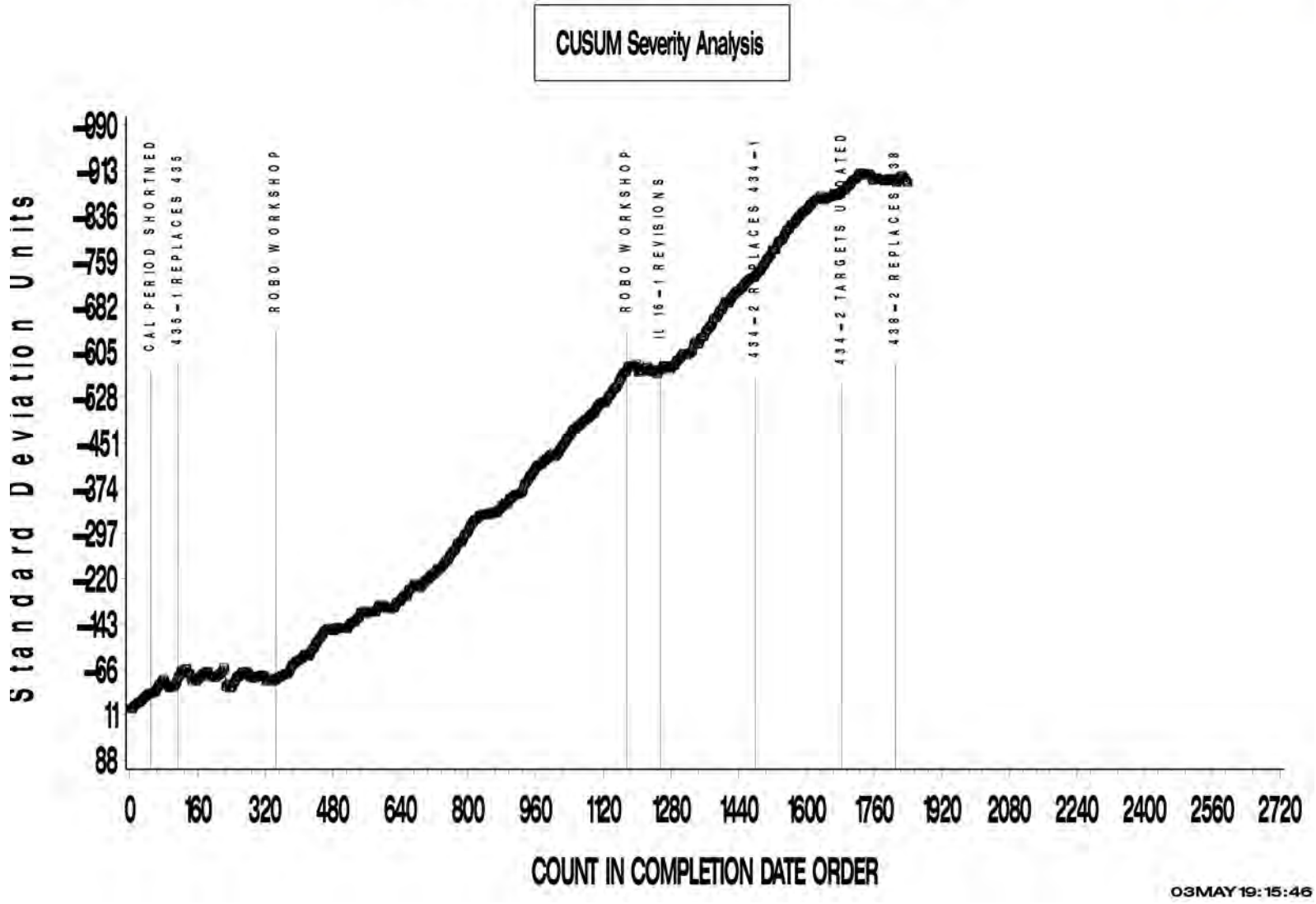
ROBO TEST INDUSTRY OPERATIONALLY VALID DATA

AGED OIL MRV APPARENT VISCOSITY

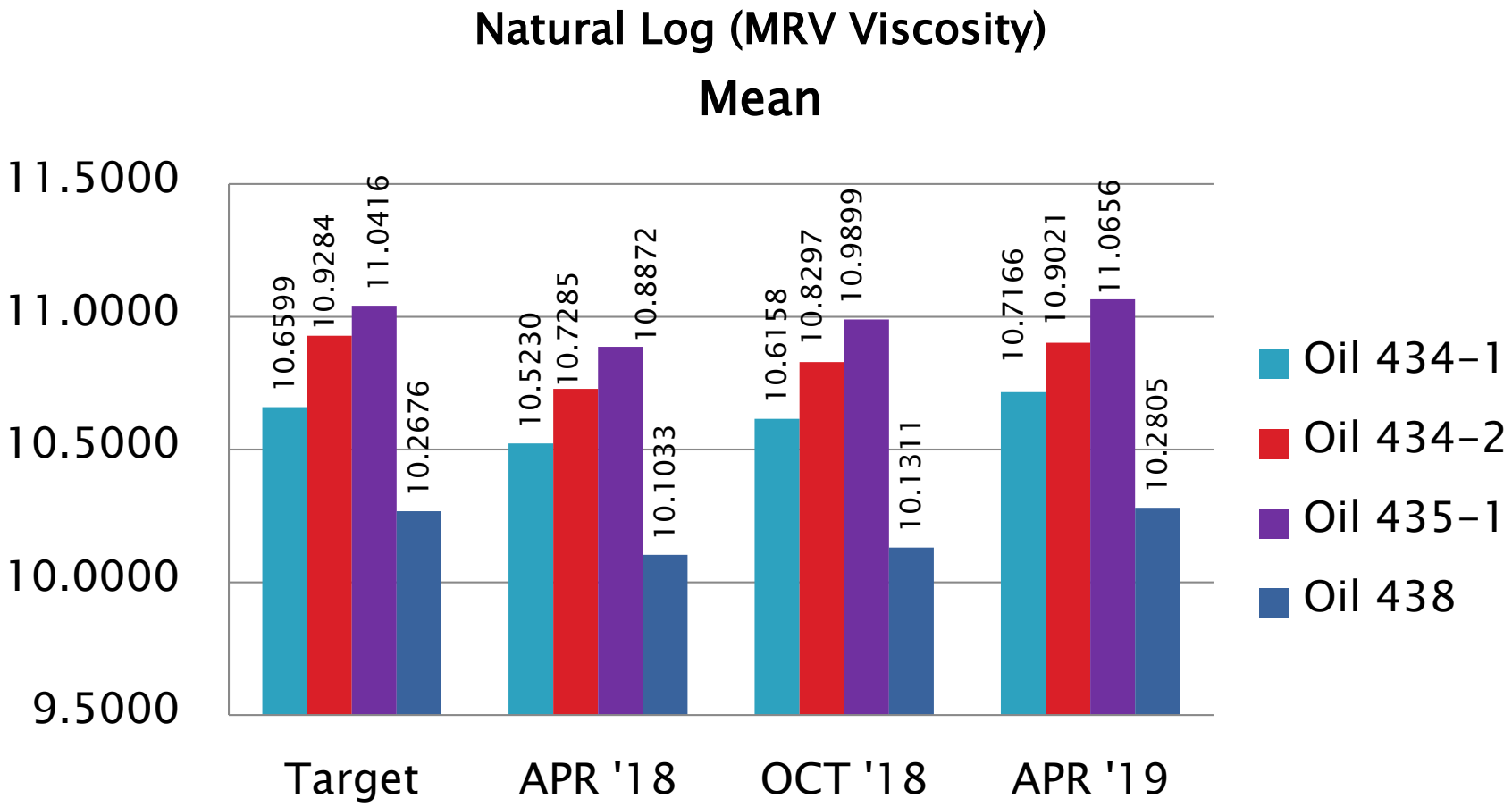


D7528: Oxidation by ROBO

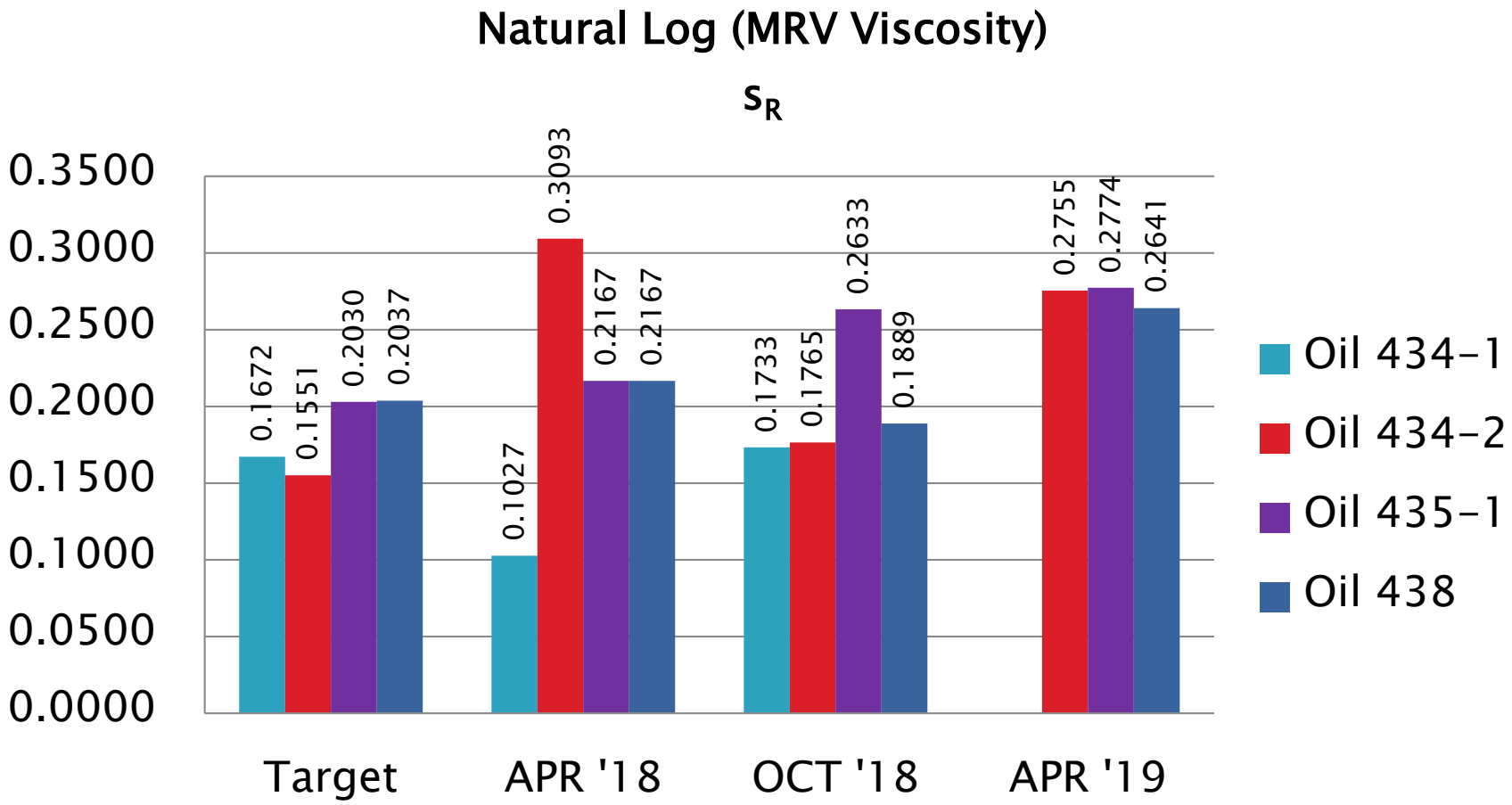
Performance by Oil
Natural Log (MRV Viscosity)

	Targets			10/1/17 - 3/31/18				4/1/18 - 9/30/18				10/1/18 - 3/31/19			
Oil Code	n	Mean	s_R	n	Mean	s_R	Mean Δ/s	n	Mean	s_R	Mean Δ/s	n	Mean	s_R	Mean Δ/s
434-1	13	10.6599	0.1672	8	10.5230	0.1027	-0.82	4	10.6158	0.1733	-0.26	1	10.7166	-----	0.34
434-2	36	10.9284	0.1551	23	10.7285	0.3093	-1.27	37	10.8297	0.1765	-0.66	25	10.9021	0.2755	-0.17
435-1	22	11.0416	0.2030	40	10.8872	0.2167	-0.76	50	10.9899	0.2633	-0.25	50	11.0656	0.2774	0.12
438	14	10.2676	0.2037	19	10.1033	0.2167	-0.81	35	10.1311	0.1889	-0.67	24	10.2805	0.2641	0.06

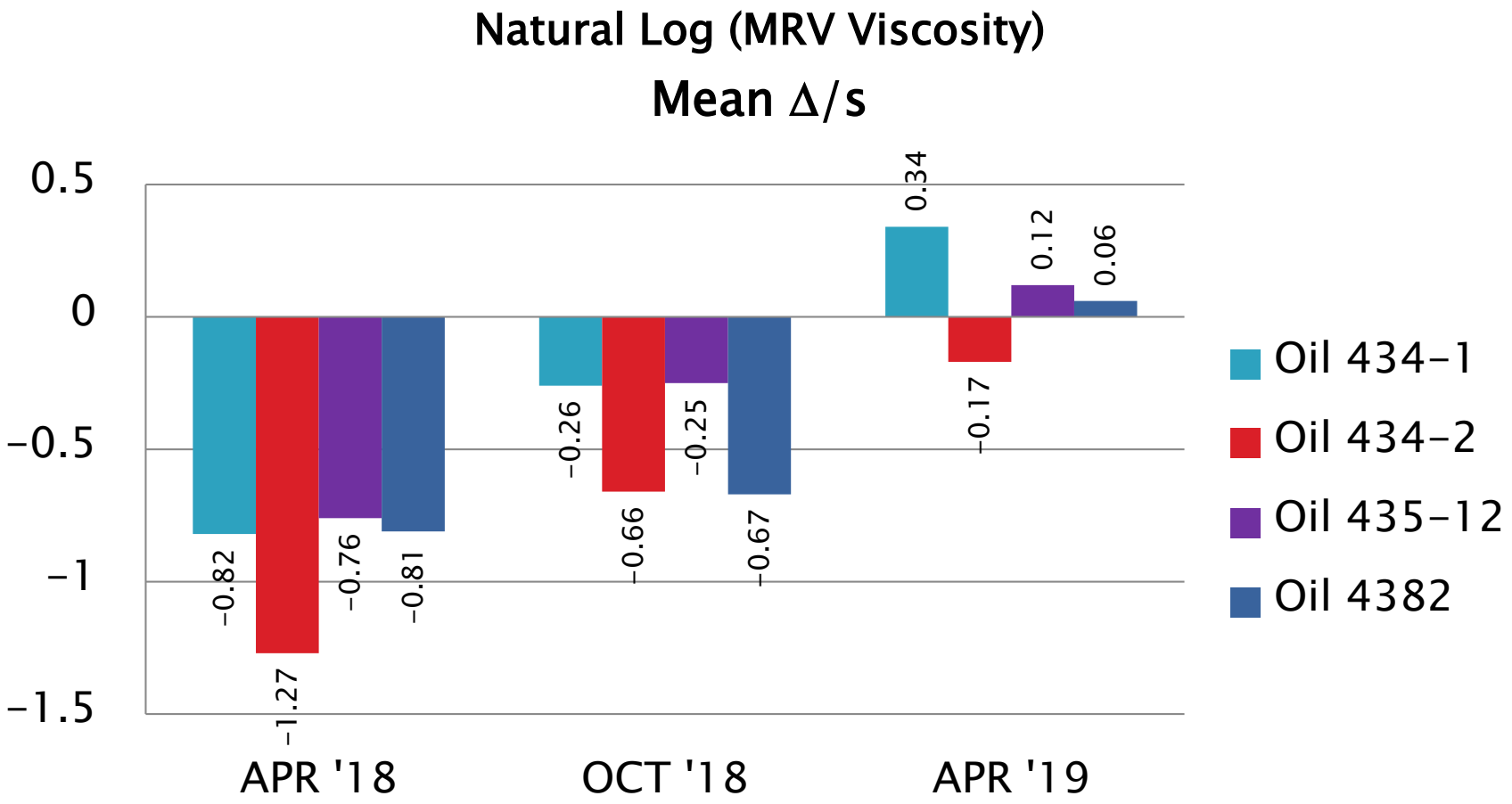
D7528: Oxidation by ROBO



D7528: Oxidation by ROBO



D7528: Oxidation by ROBO



Return to Executive Summary

Reference Oil Inventory

- As of 3/31/2019

Reference Oil Inventory

D5800

Oil	Year Rec'd By TMC	Tests	TMC Inventory, gallons	Gallons Shipped last 12 months
VOLC12	2013	D5800	33.9	3.8
VOLD12	2013	D5800	31.8	3.6
VOLE12	2013	D5800	30.4	4.1
VOLD14*	2014	D5800QC	3.9	78.3
VOLD18*	2018	D5800QC	1077	12.8

*VOLD18 is approved to replace oil VOLD14 as D5800 Daily QC Check Oil

Reference Oil Inventory

D6417, GI

Oil	Year Rec'd By TMC	Tests	TMC Inventory, gallons	Gallons Shipped last 12 months
52	1995	D6417	59.5	0.02
55	1995	D6417	66.0	0.02
58*	1998	D6417, GI	115.4	0.19
62**	1996	GI	0.3	0.1
GIA17**	2017	GI	9.8	0.1
1009	2002	GI	37.9	0.2

*58 is also used for D6417 QC Check Oil
**GIA17 is approved to replace oil 62

Reference Oil Inventory

TEOST, MTEOS & ROBO

Oil	Year Rec'd By TMC	Tests	TMC Inventory, gallons	Gallons Shipped last 12 months
432	1998	MTEOS	104.0	0.6
434*	2003	MTEOS	1.0	0.5
75**	2010	TEOST	0.9	0.9
75-1**	2016	TEOST	8.0	0.0
435-2***	2010	TEOST	42.3	0.3
434-2*	2014	ROBO	7.1	9.1
435-1	2008	ROBO	405	17.9
438-2***	2017	ROBO	48.3	5.7

*434-3 currently being evaluated as potential replacement in MTEOS and ROBO
**75-1 (reblend) is approved to replace oil 75
***Multi-test oil; estimated aliquot reserved for bench testing.

Reference Oil Inventory

D6082 & D874

Oil	Year Rec'd By TMC	Tests	TMC Inventory, gallons	Gallons Shipped last 12 months
FOAMB18*	2018	D6082	95.8	2.5
66	2002	D6082	77.6	3.2
820-2	2001	D874	8.9	0.0
90**	2005	D874/D874QC	19.0	1.1
91	2006	D874	3.9	0.0

*FOAMB18 is approved to replace depleted oil 1007
**Oil 90 is also used as a D874 QC Check Oil

Additional Information

Additional Information

- Available on the TMC's Website:
  - Lubricant Test Monitoring System (LTMS) Document
  - CUSUM Severity Plots
  - Reference Data, Period Statistics and Timelines
  - Information Letters and Technical Memos
  - Report Forms & Data Dictionaries
  - Online Store, and more…

- www.astmtmc.cmu.edu

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