

PC-12 Matrix Design Task Force Update to Cummins SP

June 8, 2023

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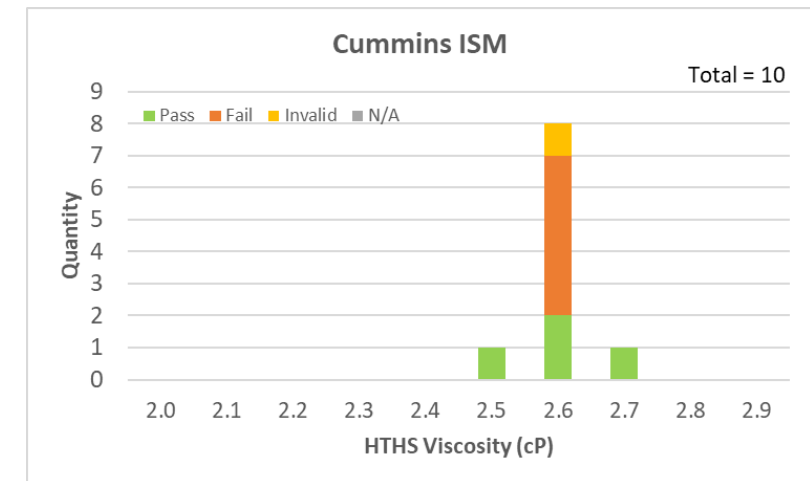
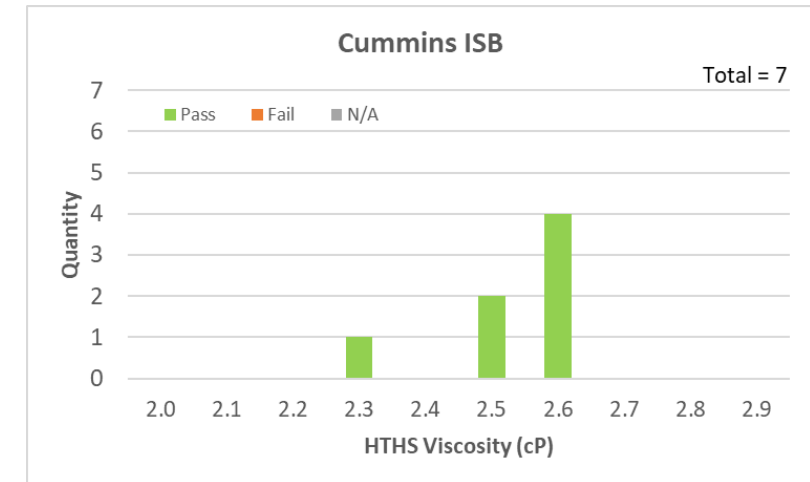
PC-12 NCDT Priority Survey Responses – Reference Oils

Current Reference Oils	Cummins ISB	Cummins ISM
	1 (15W-40)	1 (15W-40)
ACC 1	15W-40 / 5W-20	15W-40 / 5W-20
ACC 2	15W-40 / 5W-20	15W-40 / 5W-20
ACC 3	XW-20 / 15W-40	XW-20 / 15W-40
ACC 5	15W-40 / xW-20	15W-40 / xW-20
API 2	15W-40	15W-40
API 4	15W-40 / HTHS≤2.9	15W-40 / HTHS≤2.9
EMA 3	10W-30 FA-4	10W-30 FA-4
EMA 4		
Other 1	15W-40	15W-40
Other 2	5W-20 and/or 10W-30 FA-4	5W-20 and/or 10W-30 FA-4
	15W-40 / XW-20	15W-40 / XW-20
	New Needed	New Needed

- Respondents to the NCDT Priority Survey asked for the addition of an XW-20 reference oil to be added for both the Cummins ISB and ISM

Cummins Surveillance Panel

Is the test capable of running to completion on low viscosity oils?	Yes
Would low viscosity oils be expected to contribute to a higher than normal rate of invalid/uninterpretable tests?	No. The panel would not expect a significant increase to invalid or uninterpretable tests, but with the limited data set there is an indication that this needs to be monitored
Would low viscosity oils require any modification to the procedure with respect to either hardware or test cycle?	No. The panel does not believe any procedure or hardware changes would need to be made
Would low viscosity testing contribute to an increase in consumption of test parts compared to high viscosity testing?	The panel speculates there may be an increase in usage of ISB engine hardware because the lower end of the engine is not replaced from test to test (bearings, rods, etc.). There may be an over time effect of low HTHS that decreases engine life since these are not replaced. ISM does get engine rebuilds, so we do not believe the ISM will be as affected in this regard. Parts that are not replaced from test to test will have to be monitored by labs to determine if hardware life is affected.
What level of prove-out testing would the SP recommend to provide confidence in running the test at low viscosity?	The panel does not need to see additional prove-out testing to change our confidence in the test's ability to run at low viscosity, however we will monitor hardware usage as described in the above questions.
Does the test sponsor support the capability of the test running on low viscosity?	Cummins does not have the ability to answer the question about the capability of the engine to handle low viscosity fluids, however, are in support of using the engines to validate lower viscosity fluids.
Any additional comments or suggestions for proceeding with evaluating low viscosity capability:	There has been an inclination for the need of a low viscosity reference oil in addition to maintaining the current reference oil. The panel will continue to discuss how the addition of a new low viscosity reference oil will impact the LTMS, as 2 reference oils limit the data further.



Note: Invalid Test experienced a spun bearing on break-in
 Note: One failed test experienced high oil consumption

New Reference Oils Needed from NCDT

Current Reference Oils

Test	Reference Oil	Viscosity Grade	Phosphorous (%)	Sulfur (%)	SASH (%)	Performance
Cummins ISB	831-4	15W-40	0.076	0.24	0.85	Borderline
Cummins ISM	830-3	15W-40	0.115	0.40	1.37	Was Borderline (Now Fails Sludge)

- Matrix Design Task Force has been actively gathering submissions of new reference oils for the Cummins ISB and ISM

Test	Viscosity Grade	Performance	Supply Available
Cummins ISB	XW-20 (~2.6 cP HTHS)	Borderline	Interest Shown By Suppliers 1 & 3
Cummins ISM	XW-20 (~2.6 cP HTHS)	Borderline	Interest Shown By a Supplier 1

- EMA has asked for 0.10% max Phos, 0.35% max Sulf, 0.9% max SASH for PC-12
 - These limits were suggested to be used for reference oils and includes the tighter window of 0.08% max Phos, 0.3% max Sulf, 0.9% max SASH which was considered the tougher OEM target.
- A 5-year supply volume has been recommended for each of these reference oils

Low Viscosity Reference Oil Offerings

Supplier	Test	%P	%S	%SASH	Viscosity Grade	HTHS	Base Stock Group	Performance
1	ISB	0.076	0.246	0.8	5W-20		II	Borderline (below)
1	ISM	0.076	0.246	0.8	5W-20		II	Borderline (below)
3	ISB	0.08	0.31	0.89	5W-20	2.7	II	Borderline (TBD)

Cummins ISB

Cummins ISM

Cam (Similar Chemistries)	Tappet (Similar Chemistries)
31	74
39	39
112	76
48	90
32	78
Expected Value = 58	Expected Value = 90
CK-4 Limit = 55	CK-4 Limit = 100

Sludge (Similar Chemistries)	Crosshead (Similar Chemistries)	Injector Screw (Similar Chemistries)	Filter Plugging (Similar Chemistries)	Top Ring Mass Loss (Similar Chemistries)	Merits
9.1	4.5	39	8	40	1284
9.1	7.3	79.9	1	68.3	Failing
9.2	4.6	33.5	1	29.1	1422
Expected Value = 8.9	Expected Value = 6.4	Expected Value = 43	Expected Value = 7.1	Expected Value = 44	
Merit Max = 8.7	Merit Max = 7.1	Merit Max = 49	Merit Max = 19	CK-4 Limit = 100	CK-4 Limit = 1000

Is the Surveillance Panel comfortable with the offered reference oils for the Cummins ISB and ISM?

Low Viscosity Reference Oil Matrix Designs

Matrix Design Task Force has recommended the following matrices to be run in the Cummins ISB and ISM to introduce these new reference oils

- Cummins ISB – Targeting 8 Tests
- Cummins ISM – Targeting 8 Tests

4 Stand Design Option – ISB/ISM

Stand 1	Stand 2	Stand 3	Stand 4	Tentative Funding
Low Viscosity RO	Low Viscosity RO	Low Viscosity RO	Low Viscosity RO	Funded by Test Lab to Reference Stand
Low Viscosity RO	Low Viscosity RO	Low Viscosity RO	Low Viscosity RO	Funded Externally to help set targets

- To reference an active stand a lab will only need to run 1 test on a reference oil
- To gather enough data to set targets for the new reference oil the statisticians recommended running a minimum of 8 tests across 4 stands

Lab Participation

- **How many labs/stands will be participating in each of these matrices?**

Responses have been received from all labs about their participation.

Labs responded that they will participate in test areas they have stands in, assuming the activity is funded by the industry.

ISM: 5 of 5 Labs Confirmed

ISB: 4 of 4 Labs Confirmed

T11 replacement (Cummins ISB): 4 of 4 Labs Confirmed

- 3 Labs said that they will have a different stands for wear and viscosity growth tests
- 1 Lab suggested that they will use the same Cummins stand for both test types
 - This could impact the timeline to run the matrix for both the low viscosity reference oil and the T-11 replacement tests, if both planned for 4Q 2023 – 1Q 2024.

(Lab preference is T-11 Replacement test matrix if there is timing conflict)

Reference Cycle Details

Cummins ISB: (4 Labs / 7 Stands Active)

- Stands usually are referenced for 1 year before needing to be referenced again.
- Cummins ISB just ran testing to bring in new parts
 - These stands will next come off reference in ~June 2024.
- Labs G will gain an extension to their new reference period for the stand which ran the new parts further extending that end time.
- Labs A and G have stands that should be coming off reference in 3-4Q2023.
- Matrix Design TF is hoping the Surveillance Panel will work to align references for bringing in new reference oil when available. Target is 4Q2023 when some stands come off reference.

Test (ref period)	Lab A	Lab B	Lab D	Lab G
Cummins ISB (12 months)	Referenced Stand 4 (expires 9/1/23)			Stand 3 - New Parts (Run 3/29/23) (Calibration expires 11/12/23)
	Referenced Stand 3 (expires 10/31/23)			Referenced Stand 1 (expires 12/08/23)
	Stand 2 - New Parts (Run 4/7/23)	Stand 4 - New Parts (Run 4/29/23)	Stand 1 - New Parts (Run 3/28/23 & 5/3/23)	

Reference Cycle Details

Cummins ISM: (4 Labs / 5 Stands Active)

- 3 labs are sitting with stands that have expired references currently.
- A 5th lab has shown interest in taking part in a reference oil matrix and would like to bring a stand on stream.
- This would be a good opportunity in time to bring in a new reference oil to reference all of these stands. (If labs reference their stands on current reference oil it will be another year before we reach the next reference cycle for those stands.)
- Matrix Design TF is hoping the Surveillance Panel will work to align references for bringing in new reference oil when available

Test (ref period)	Lab A	Lab B	Lab C	Lab D	Lab G
Cummins ISM (12 months)	Referenced Stand 5 (expires 4/2/24)			Referenced Stand 1 (expires 7/16/23)	
	Stand 2 (expired 10/1/22)	Stand 1 (expired 9/17/22)	Stand 1 (expired 2/19/23)		Interested in taking part in matrix. Looking to activate stand on current reference oil before participating.

- **We have 5 labs that are willing to participate in Matrix. How do we determine which 4 labs will be included?**

Low Viscosity Reference Oil Timeline

Item #	TASK	DATE YearMon	2023												2024											
			J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
18	Establish New Reference Oils		[Green bar]																							
18a	Confirm Reference Oil Status in Each Current Test	Complete	[Empty]																							
18b	Review MOA		[Red bar from Feb 2023 to Jun 2023]																							
18c	ISB: New Ref Oil (CL/Low Vis)		[Grey bar from May 2023 to Jun 2024]																							
18d	ISM: New Ref Oil (CL/Low Vis)		[Grey bar from May 2023 to Jun 2024]																							
19	Extend BOI/VGRA		[Green bar]																							
19a	Design Matrices		[Grey bar from Feb 2023 to Jun 2023]																							
19b	Additive Technologies Chosen/Sent to Labs		[Grey bar from Jun 2023 to Dec 2023]																							
19c	Review MOA for BOI/VGRA		[Grey bar from Oct 2023 to Dec 2023]																							
19g	ISB BOI/VGRA		[Grey bar from Jan 2024 to Dec 2024]																							
19h	ISM BOI/VGRA		[Grey bar from Jan 2024 to Dec 2024]																							

- Reference oil testing (**Best Suggested Timing to meet reference periods – Lab involvement is critical for timing**)
 - Cummins ISB should start around Oct - Nov 2023:** This will align to when the stands finish their reference cycle at Lab A & Lab G.
 - Cummins ISM should start ASAP or may miss the reference window:** Reference oil supply is critical to help with timing

Appendix

Answers from Supplier 1

1. For the Cummins ISB and Cummins ISM can the supplier specify how far from the offered RO the similar tested technologies are? (i.e. within minor mod)

Answer: These are similar as in no different than 1% formulation variability, however they don't always satisfy minor modification guidelines.

- a. Are these "similar" technologies, multiple runs on the same oil or all different "similar" technologies to the candidate offered.

Answer: these are all DIFFERENT "similar" technologies, not the same technologies run multiple times. Different changes from tested to final exist with each formulation.

2. Can the supplier speak to the variability seen in the results shared for the Cummins ISB and Cummins ISM. Is there a specific reason why the 3rd ISB result and 2nd ISM result are very different from the others provided?

Answer: We supplied all data we had on similar chemistry, the changes in formulation are not linear. The combination of slightly different chemistry and test variability equate to test variability.

3. How were the estimated values determined for the RO offered?

Answer: estimated values are predictions based on modeling results from chemistry we have run in the test. Similar formulation results were shared to show that our estimated values are often times more severe than tested, and/or not overly optimistic. After taking into account test variability and changes, we do expect the expected values to be a good indicator of performance.

4. Would the supplier be willing to run the ISB and ISM on the oil being proposed?

Answer: it is something we can discuss internally but would not guarantee or want the committee to expect this would be done. Additionally, due to test variability we are concerned about making an assessment based upon 1 test result, especially since test parts have changed recently.