Engine Tests for B20 Effects on Lube Performance

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for

ASTM HDEOCP

Review

June 2008

Engine Lube Tests with B-20

- **Objective: To determine if there are any effects on lubricant performance from the use of B-20 fuel**
- **Plan: Run standard engine tests with B-20 using reference oils to compare lube performance with # 2 diesel**
  - **Does NOT cover high fuel dilution conditions**
- **Fuel: B-20 blended from PC-10 fuel and B-100 meeting D 6751**

Engine Tests for B-20 Evaluation

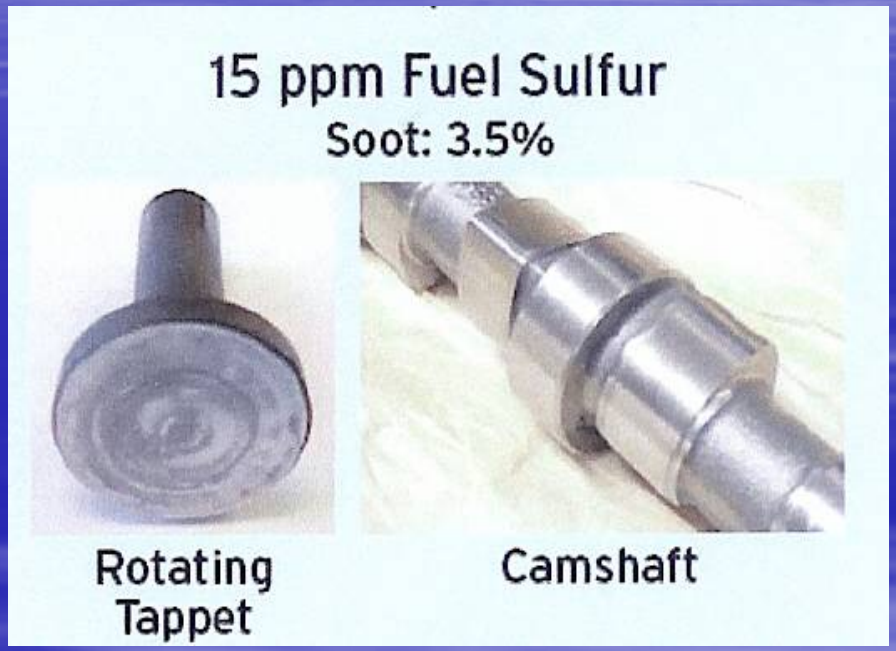
- ISB, C13, T-12 cover critical lube performance measures
- None of the standard tests cover high fuel dilution conditions

API CJ-4 Engine Test and Performance Criteria									
Performance	Cummins ISM	Cummins ISB	GM 6.5L	Cat C13	Cat 1N	Mack T-12	Mack T-11(A)	Gasoline IIIG / IIIF	Navistar 7.3L
Valve Train Wear	X	X	X						
Liner Wear						X			
Ring Wear	X					X			
Bearing Corrosion						X			
Oxidation						X		X	
Oil Consumption				X	X	X			
Iron Piston Deposits				X					
Aluminum Piston Deposits					X				
Soot Viscosity Increase							X		
Sludge	X								
Filter Plugging	X								
Aeration									X
Low Temp Pump @ 5.2% Soot							X		
Performance areas covered in B-20 testing									

"API CJ-4: Diesel Oil Category for Both Legacy Engines and Low Emission Engines Using Diesel Particulate Filters" James A McGeehan, et.al. **SAE 2006-01-3439** SAE 2006 Transactions Journal of Fuels and Lubricants.

Engine Tests for B20 Effects Cummins ISB

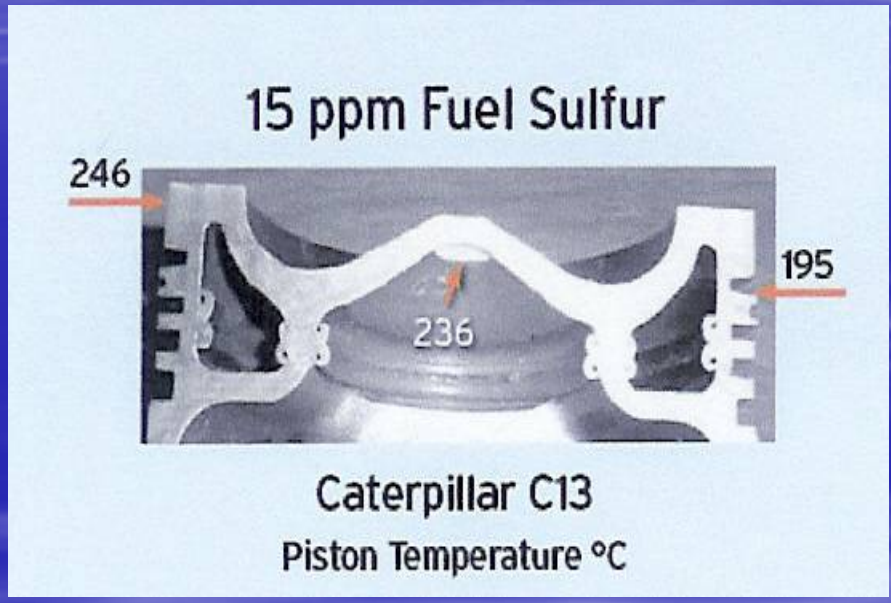
- **Engine**
  - Cummins '04 ISB 5.9L, EGR with VG Turbo, 300 bhp @ 2600 rpm
- **Test Cycle**
  - 100 hr retarded timing
  - 3.0 – 3.5% soot window
  - 250 hr cycle from low idle to rated to peak torque
- **Wear Parameters**
  - Rotating Tappet Wt Loss, mg
  - Cam Nose Wear, um



"API CJ-4: The Most Robust Diesel Engine Oil Category for All Engines" J. A. McGeehan, Lubrication Magazine, http://www.lubricantsuniversity.com/images/stories/LubricationMagazine_March2008_LoRes.pdf

Engine Tests for B20 Effects
Cat C13

- Engine
  - Cat C-13, 12.5L ACERT, Twin Turbo '04, 430 bhp @ 1800 rpm
- Test Cycle
  - Constant 1800 rpm@ 430 bhp for 500 hr
  - Fuel rate: 159 lb/hr
  - Oil temp: 98 °C
  - Low Soot: ~ 2%
- Control Parameters
  - Oil Consumption Increase
  - Top Land Carbon
  - Top Grove Carbon
  - 2nd Ring Top Face Carbon



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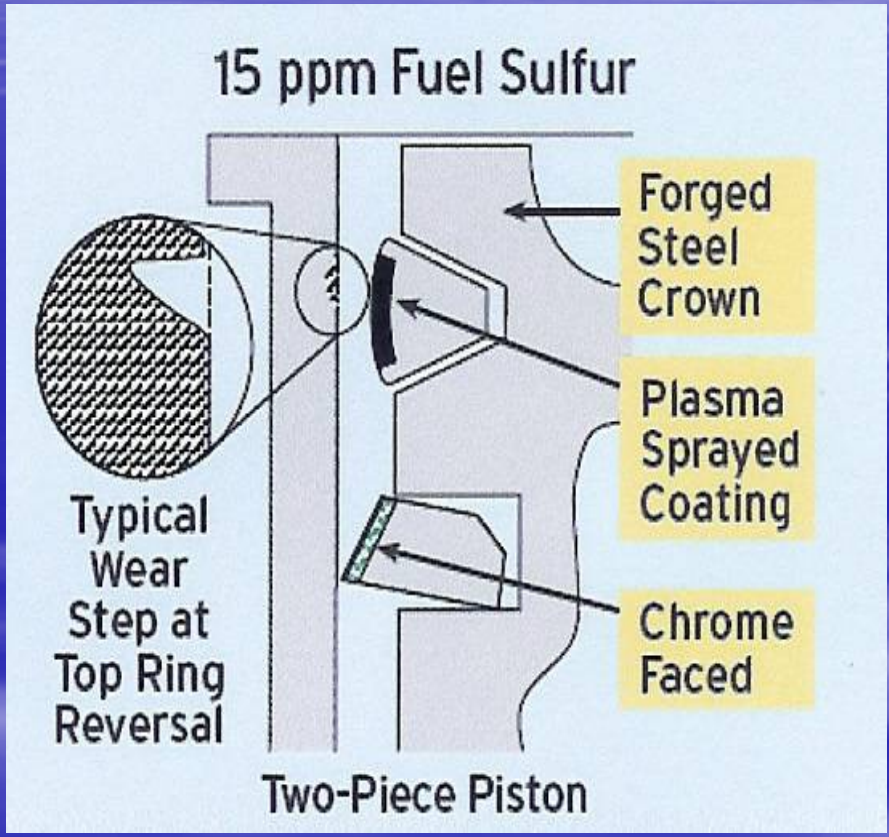
Engine Tests for B20 Effects
Mack T-12

- Engine
  - E-Tech V, 12L, Cooled EGR, VG Turbo
- Test Cycle
  - 100 hr retarded timing
  - 35% cooled EGR@ 1800 rpm
  - Soot target 4.3%
  - 200 hr @ peak torque, 1200rpm
  - 15% EGR
  - Oil temp: 116 ^{o}C gallery 127 ^{o}C sump
  - EOT Soot 6%
- Control Parameters
  - Ring wt loss, mg
  - Liner step wear, um
  - EOT Lead and Delta Lead



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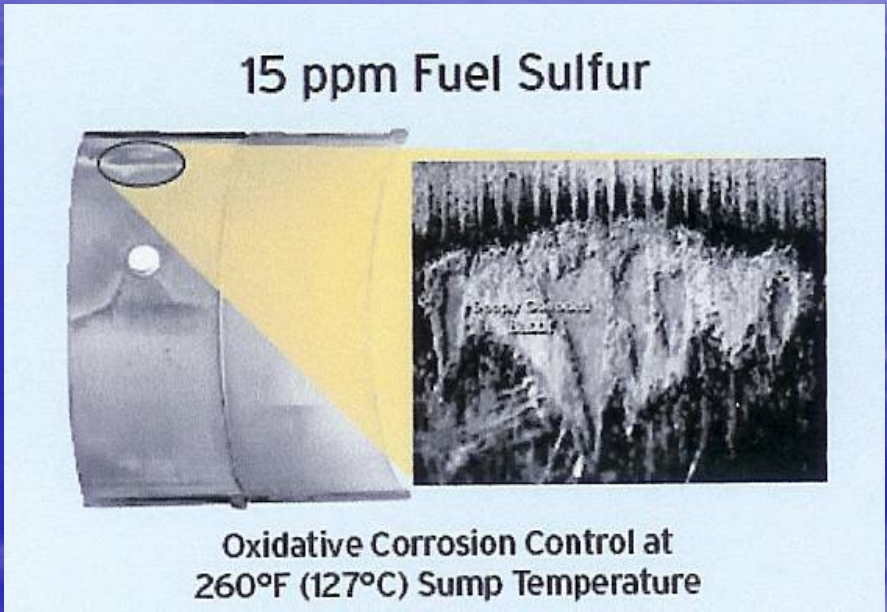
Engine Tests for B20 Effects
Mack T-12

- Mack T-12 Parts (Cont'd)
- Control Parameters
  - Ring wt loss, mg
  - Liner step wear, um
  - EOT Lead and Delta Lead
- Bearing Corrosion
  - Bearings not rated
  - Oxidative corrosion
  - Measured by used oil lead
  - Sensitive to acids, oil temperature and oxidation



Oxidative Corrosion Control at 260°F (127°C) Sump Temperature

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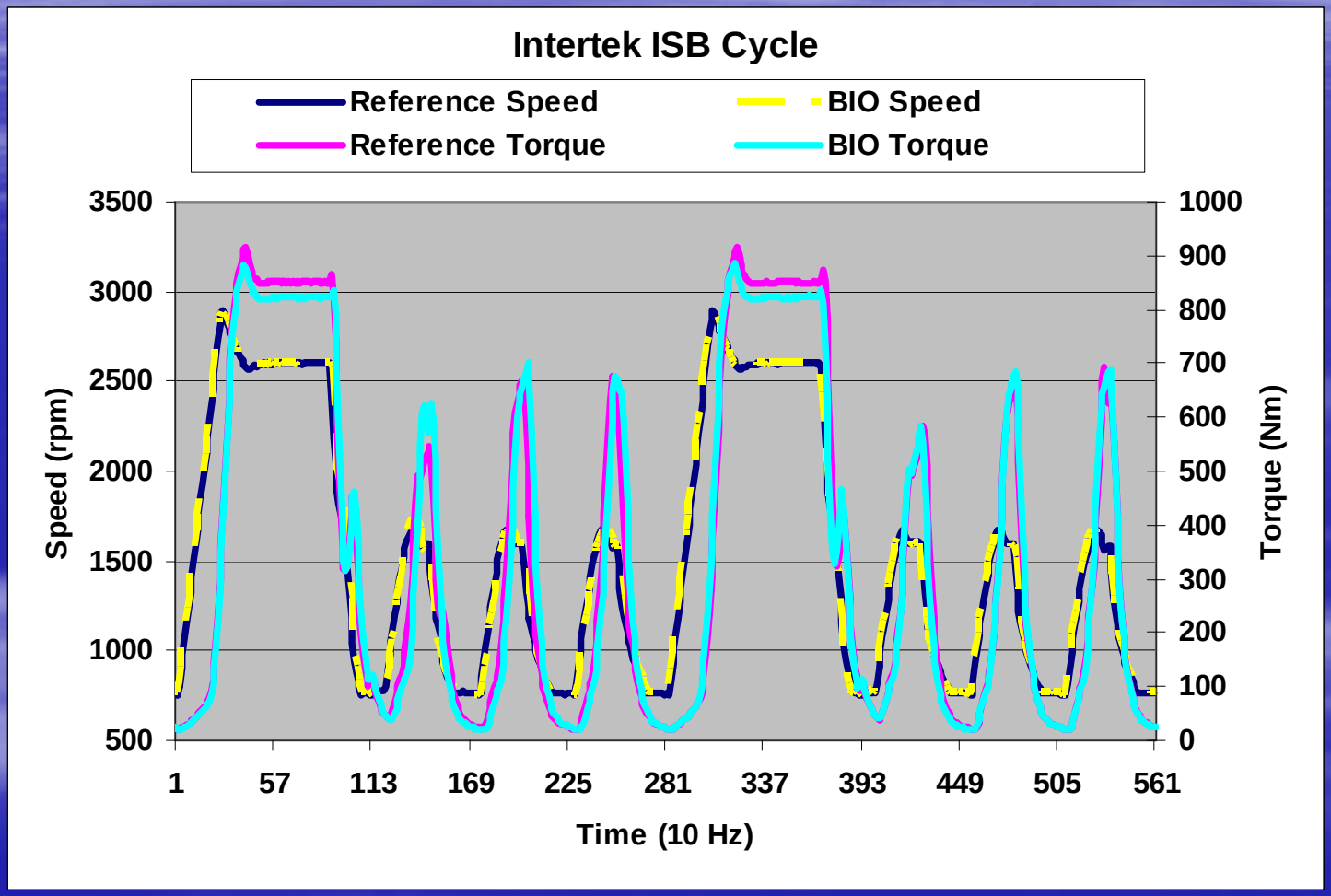
B-20 Blend Meets EMA Fuel Spec.

Item	Performance Characteristics	Requirements		B-20
		D1 Blends	D2 Blends	Blend
1	Flash Point, °C, min.	38	52	**69**
2	Water and sediment, vol %, max.	0.05	0.05	**0**
3	Physical Distillation, T90, °C, max.	343	343	**333**
4	Kinematic Viscosity, cSt@40C	1.3~ 4.1	1.9~4.1	**2.56**
5	Ash, mass%, max.	0.01	0.01	**0**
6	Sulfur, wt%, max.	Per regulation	Per regulation	**9**
7	Copper strip corrosion rating, max.	No. 3	No. 3	**1A**
8	Cetane Number, min.	43	43	**47**
9	Cloud point [1]	Per footnote	Per footnote	**-14**
10	Ramsbottom carbon residue on 10% distillation residue, wt%, max.	0.15	0.35	**0.09**
11	Lubricity, HFRR@60C, micron, max.	460	460	**190**
12	Acid number, mg KOH/g, max.	0.3	0.3	**0.17**
13	Phosphorus, wt%, max.	0.001	0.001	**0.0001**
14	Total Glycerin	------	-----	
15	Alkali metals (Na+K),ppm, max.	Nd	Nd	**0**
16	Alkaline metals (Mg+Ca), ppm max.	Nd	Nd	**0**
17	Blend fraction, vol. % [2]	+/- 2%	+/- 2%	**19**
18	Thermo-oxidative Stability, insolubles, mg/100 mL, max.	10	10	
19	Oxidation Stability, Induction time, hours, minimum	6	6	**10.3**
	Specfic Gravity		**0.842**	**0.857**

ISB Operational Data

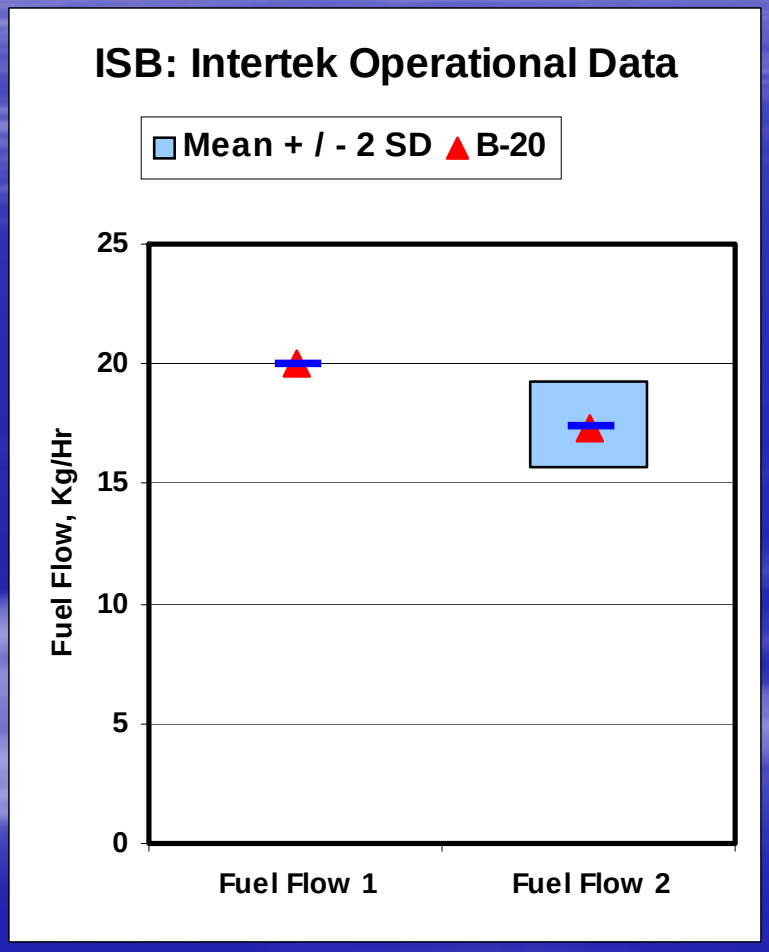
- Stage 1: Control to hit soot window
  - "More retard in timing than PC-10 fuel"
    - Statistically insignificant anecdotal comment
- Stage 2: Control to throttle position to match cycle
  - Load is within observed band

ISB Test Cycle

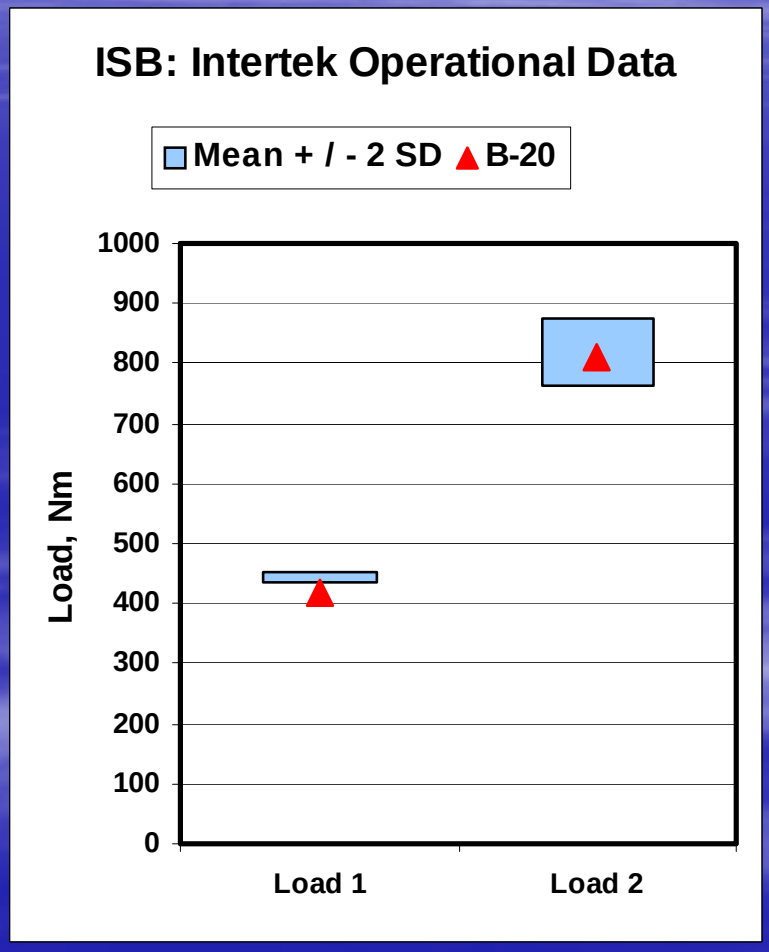


ISB Operational Data

Fuel Flow



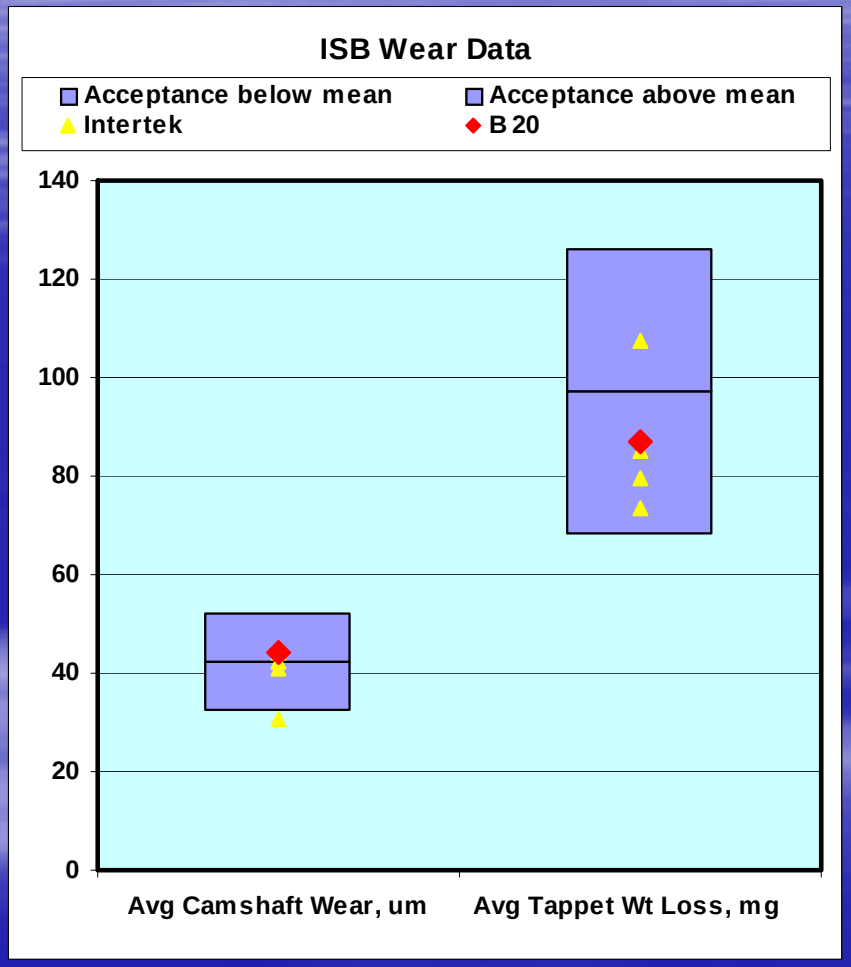
Load

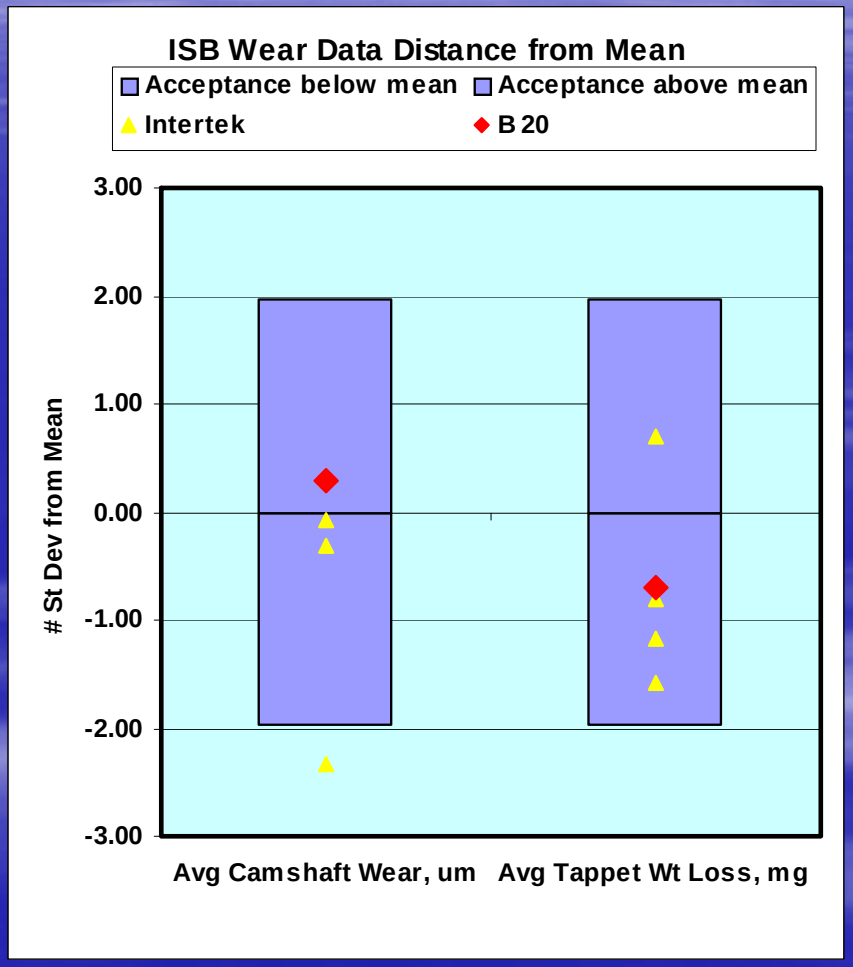


Test Results Presentation

- For each test there are two plots
- Actual test results of control parameters
  - Blue bars show TMC Acceptance Levels
  - Yellow triangles show Intertek reference runs
  - Red diamond is the B20 run
- Normalized data shown as a range expressed as # of Standard Deviations from the mean
  - Blue bars show TMC Acceptance Levels
  - Yellow triangles show Intertek reference runs
  - Red diamond is the B20 run

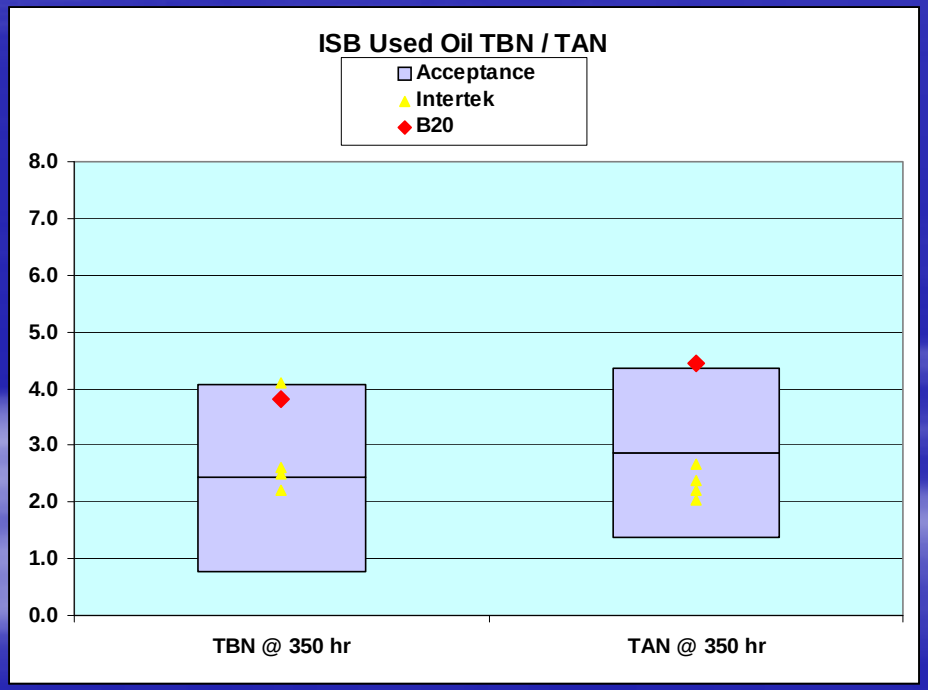
ISB Engine Data with B 20

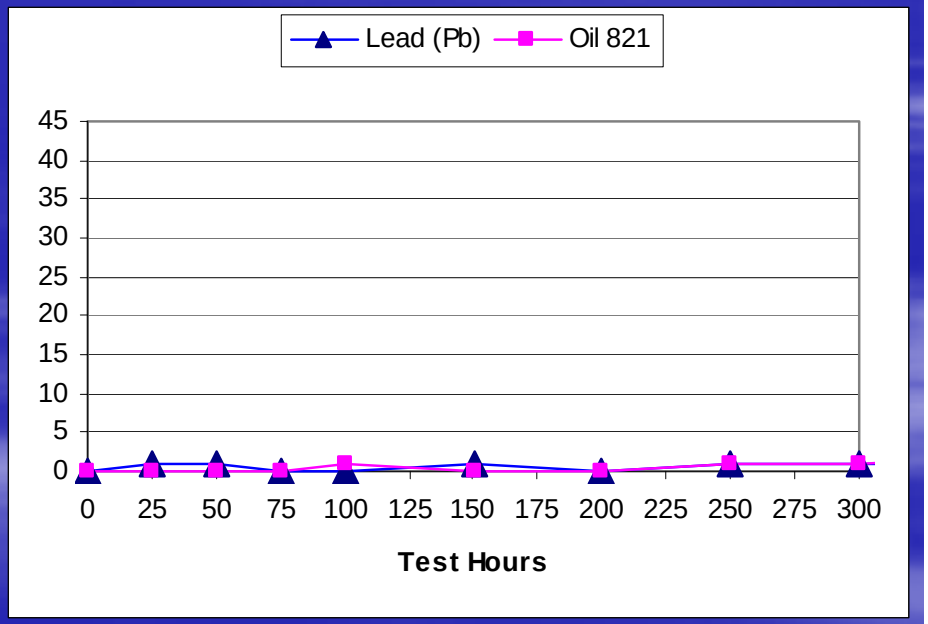




ISB Used Oil Analysis

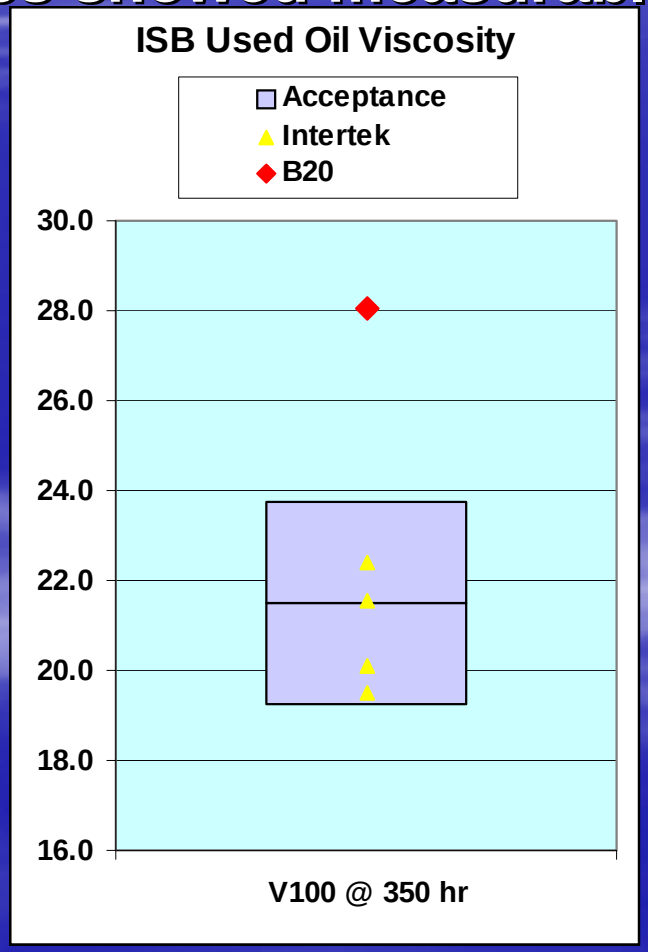
- B-20 test vs. recent 831 reference data
  - TBN Loss within range
  - TAN Increase just above range
  - PB Corrosion is not an issue in this test





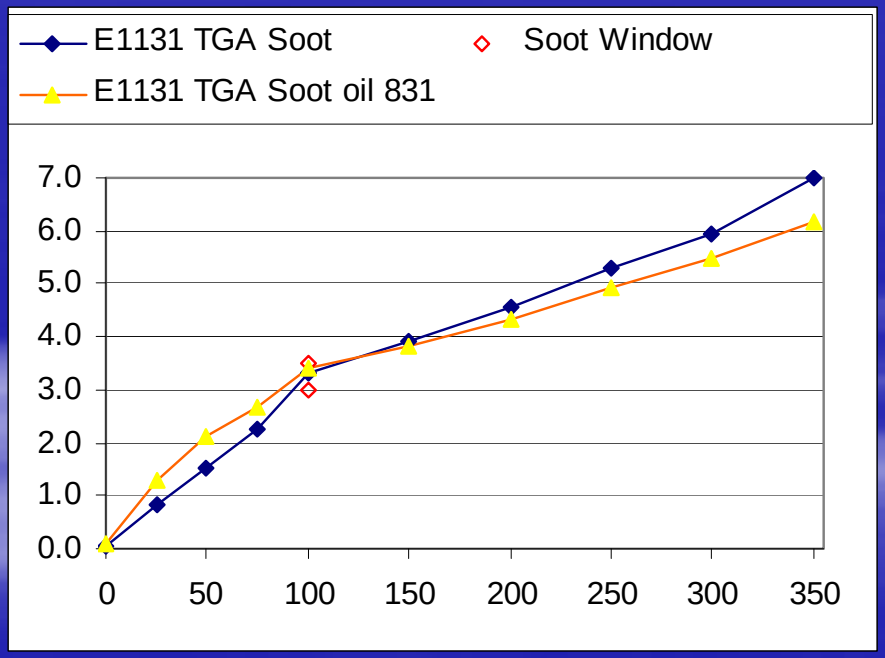
ISB Used Oil Analysis

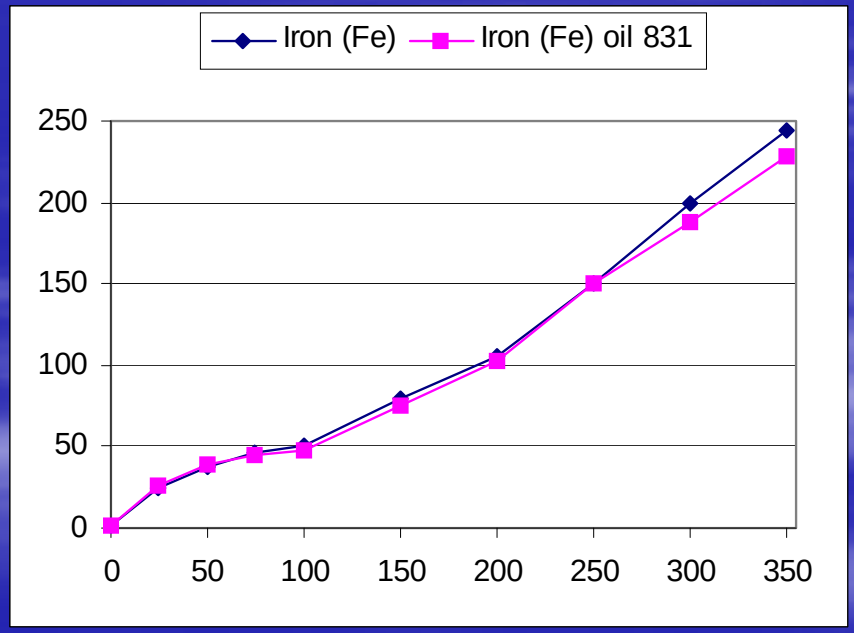
- B-20 test vs. recent 831 reference
  - Viscosity @ 100 C higher @ EOT
  - No samples showed measurable fuel dilution by GC



ISB Used Oil Analysis

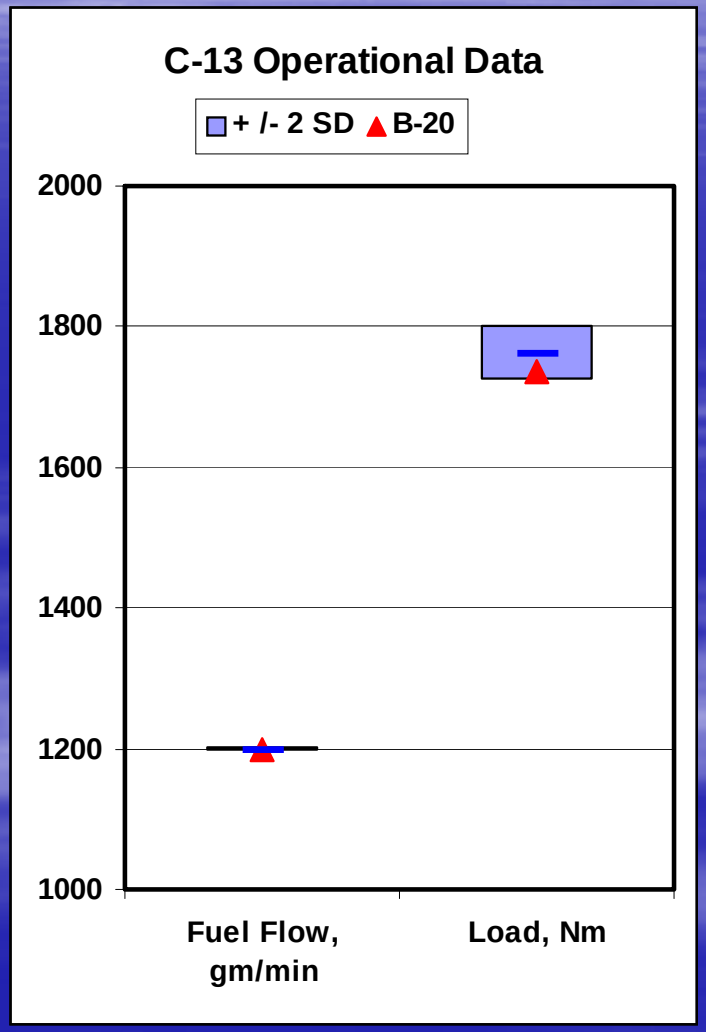
- **B-20 test vs recent 831 reference**
  - **Timing adjusted to hit soot window**
  - **Fe wear is comparable**



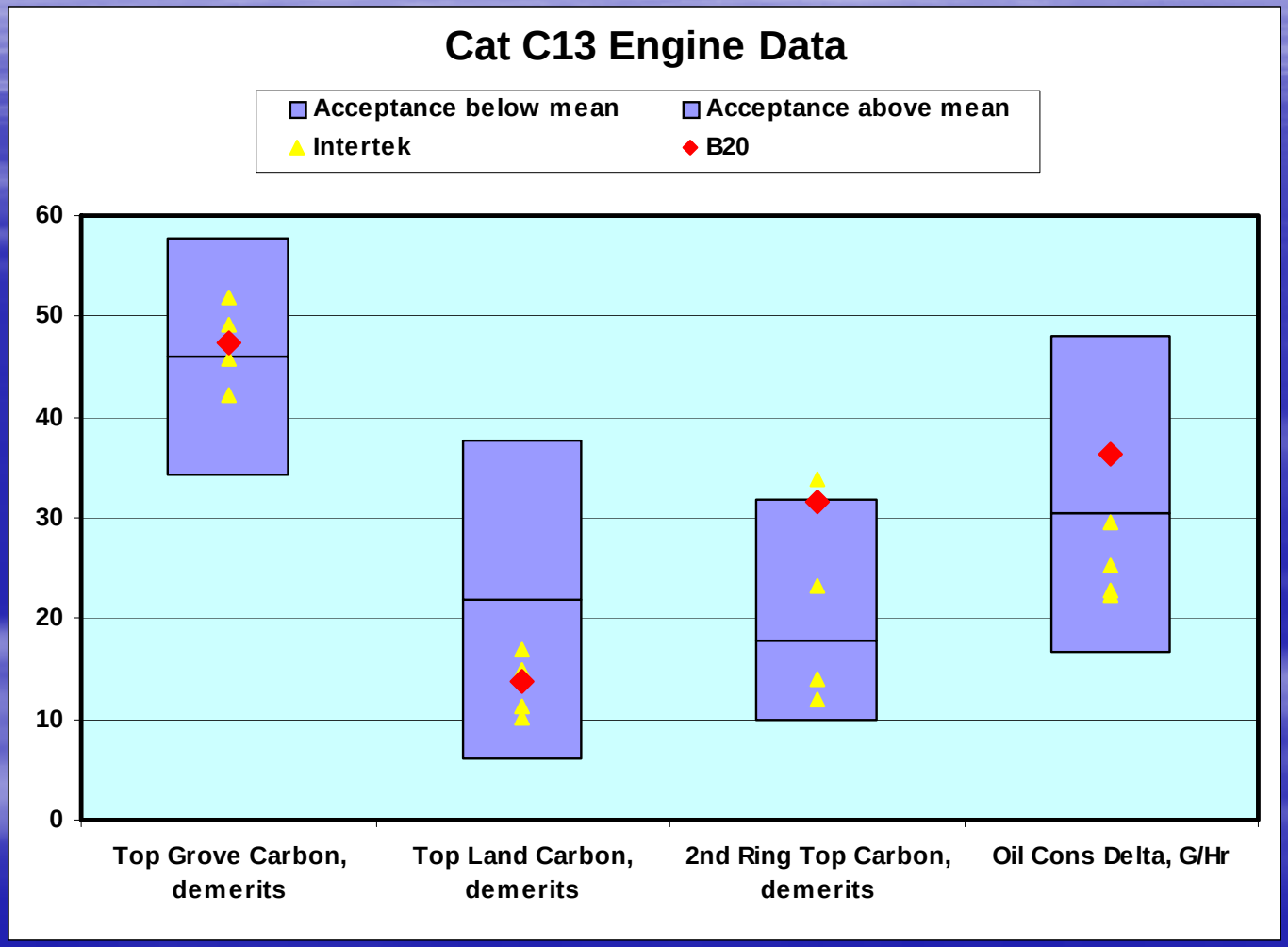


C-13 Operational Data

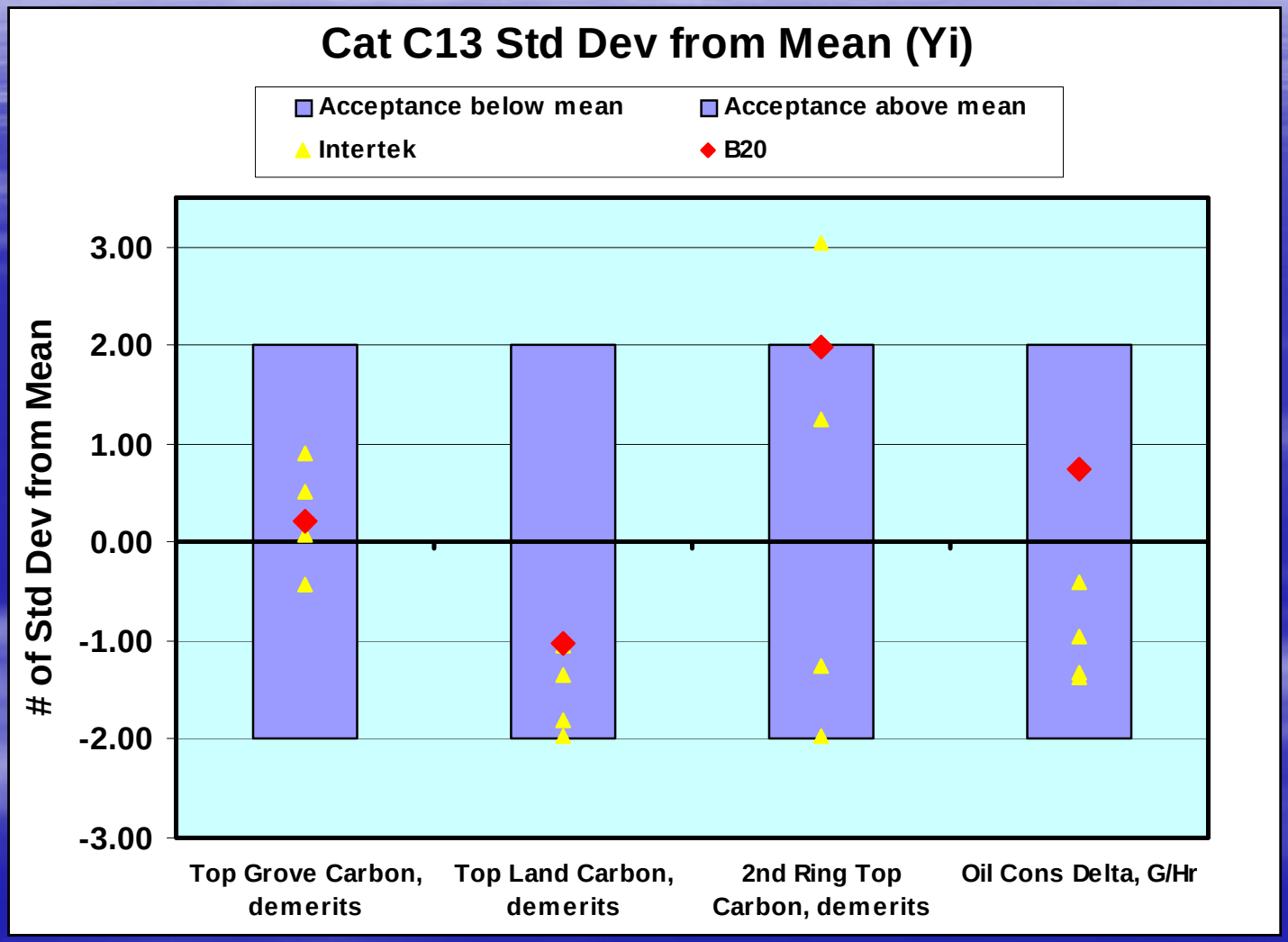
- **Fuel flow set @ 1200 gm / min**
- **Load falls within the band for all tests**



C13 Engine Data with B-20



C13 Statistical Data with B-20

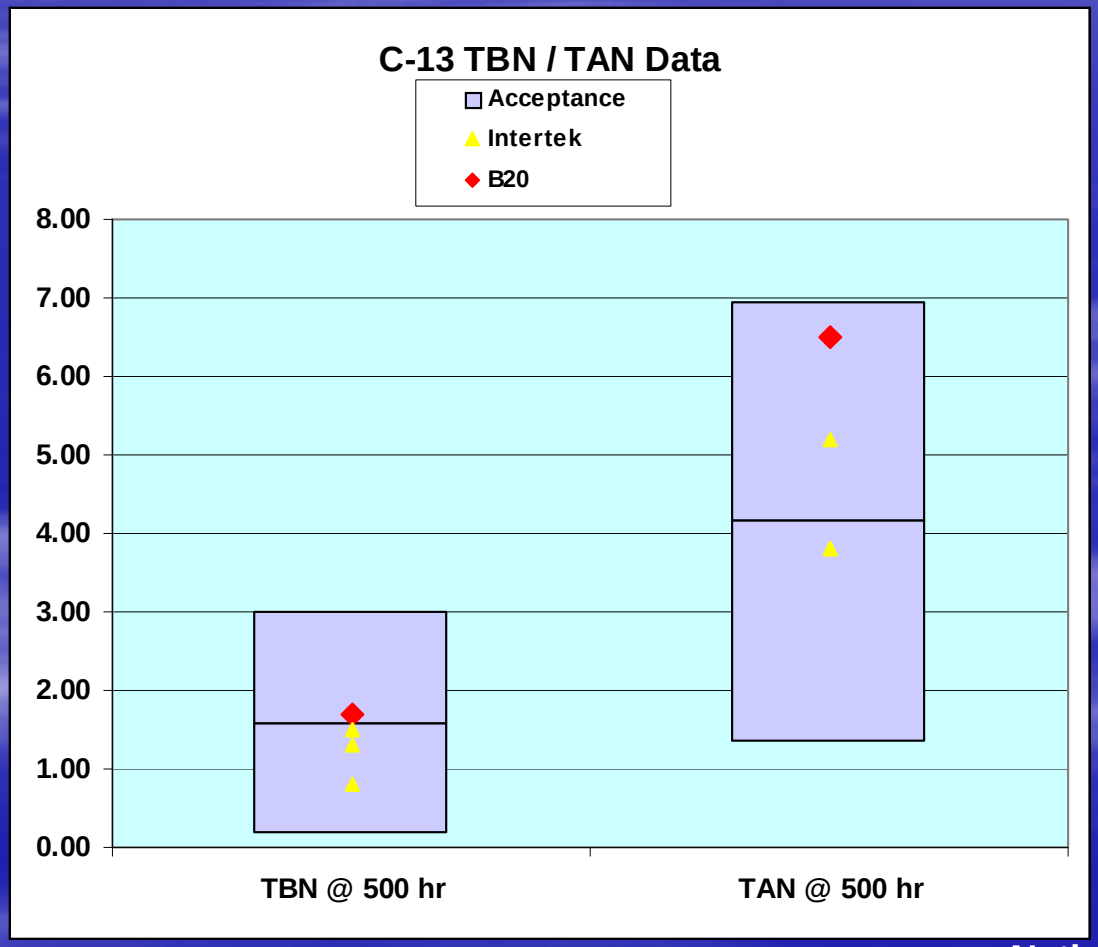


C-13 Rate & Report Factors

- 2 “Cold Stuck” rings were observed
- Lab reported a “cold stuck” ring on 2 other occasions with TMC 831
  - Tendency is there with high 2RTC
  - But the highest carbon ring was not the one stuck.
- This is an item to watch but it is not associated with high oil consumption in this test.

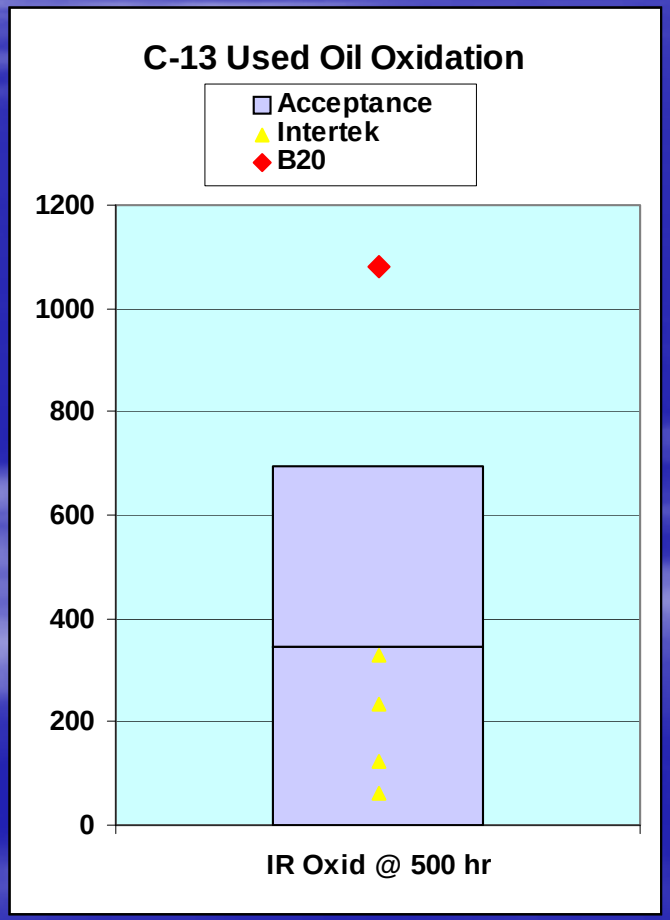
Cat C-13 Used Oil Analysis

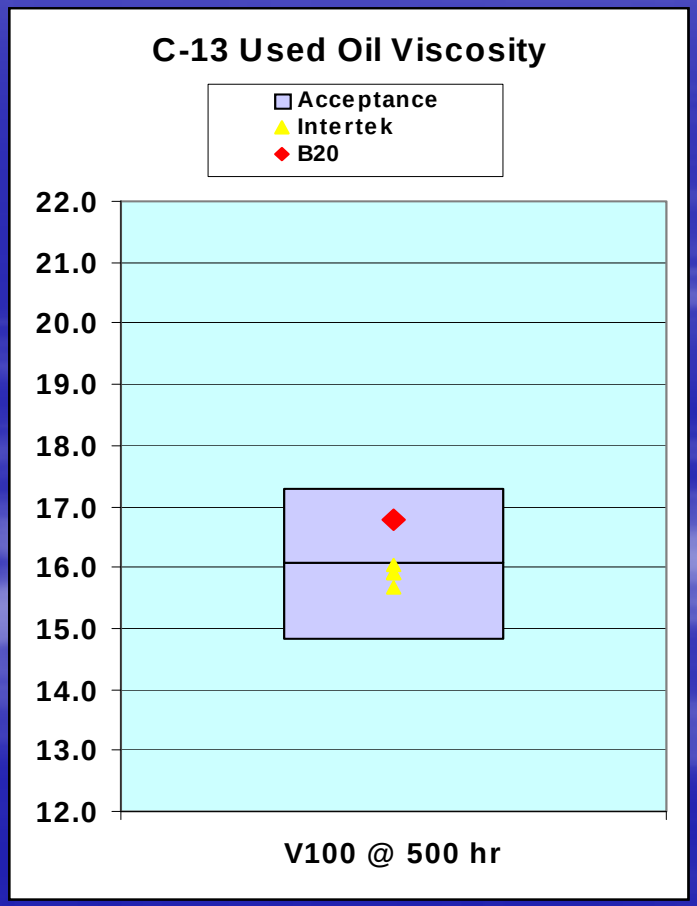
- B-20 test vs. 831 reference data
- 500 Hr TAN is near top of range of reference data
- 500 Hr TBN loss is at mean of reference data



Cat C-13 Used Oil Analysis

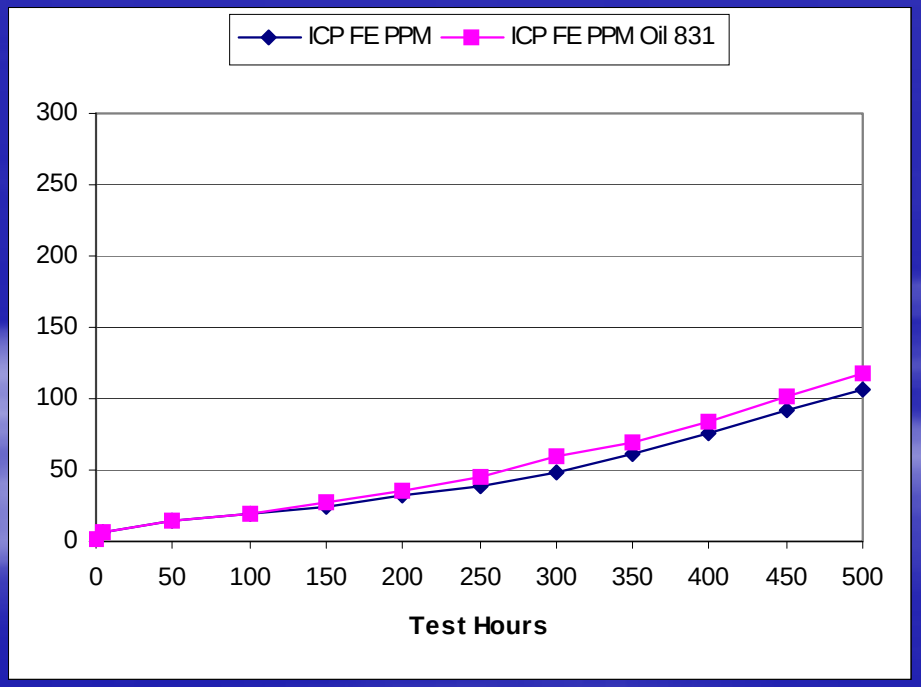
- Oxidation (DIR) appears higher; IR shows some ester
  - No samples showed fuel dilution by GC
- Viscosity increase is within range

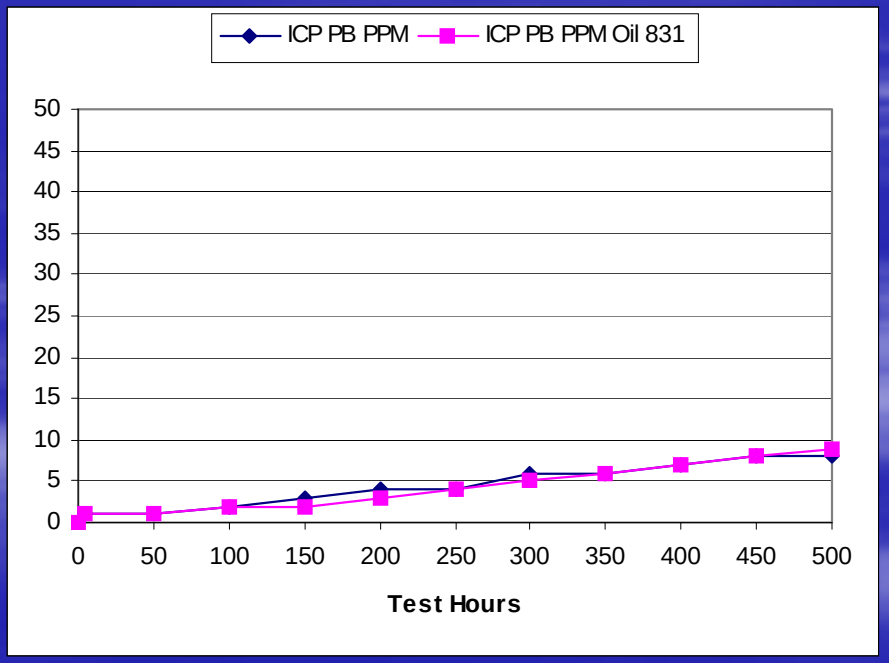




Cat C-13 Used Oil Analysis

- **B-20 test vs recent 831 reference**
  - **No issues with Fe, Pb or other wear metals**





Cat C-13 Parts Cleanliness

C13 / SME B20 / MCD5-029
ROCKER COVER

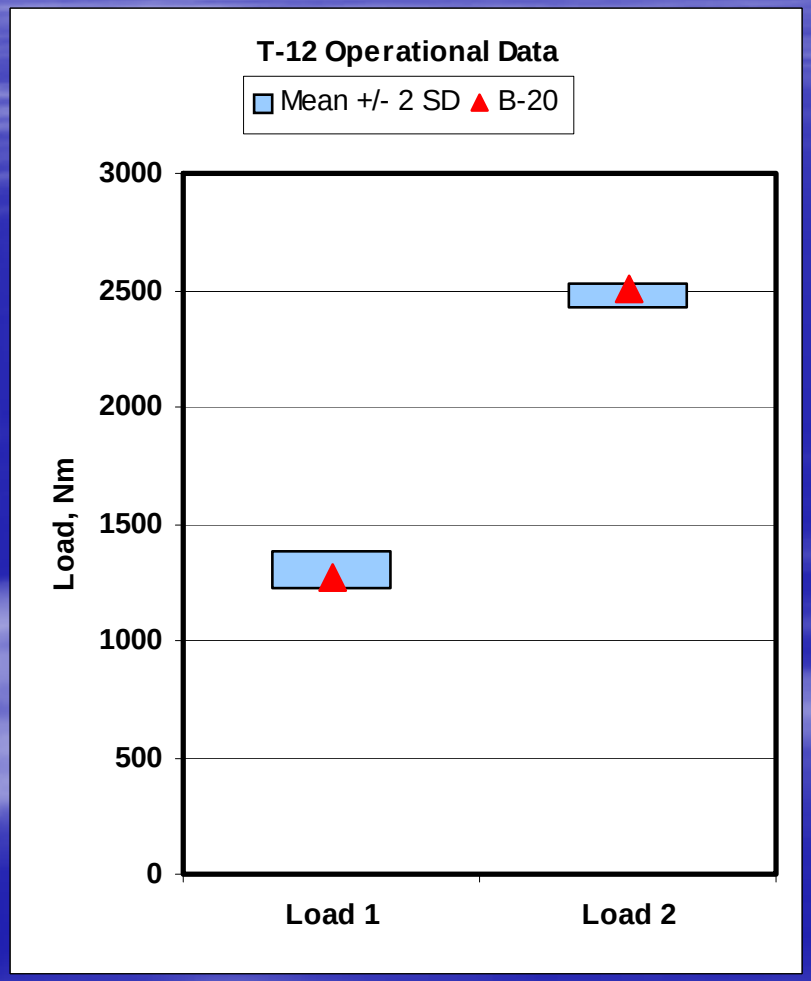
C13 / SME B20 / MCD5-029
OIL PAN

T12 Operational Data

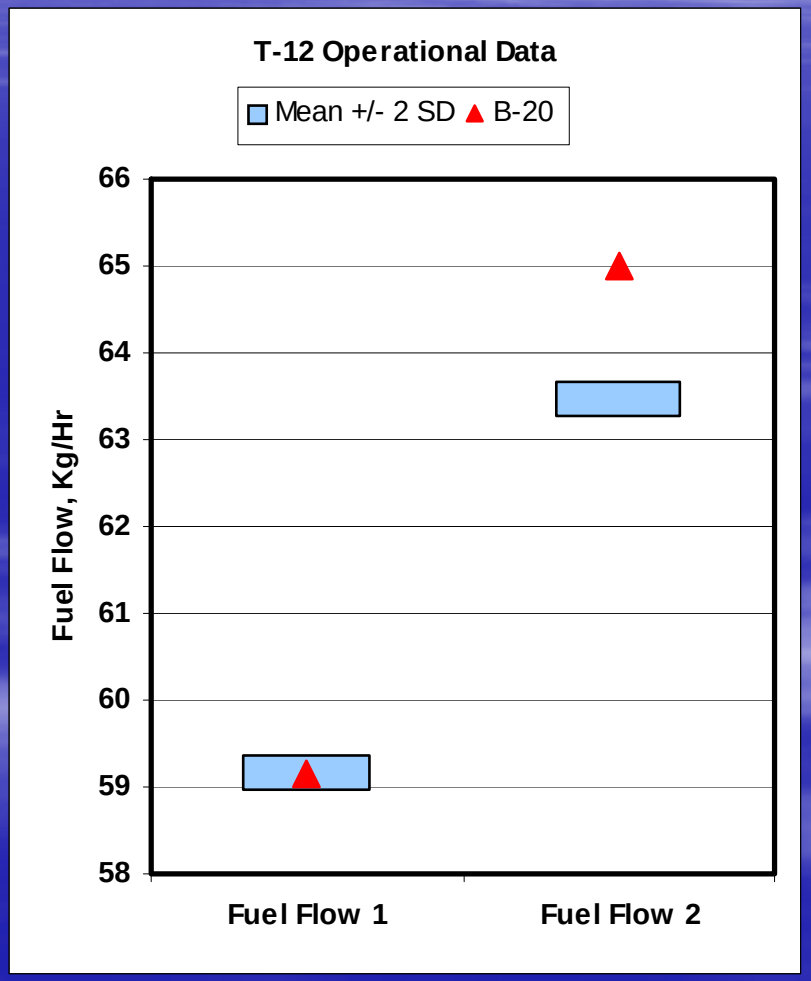
- **Stage 1: Ran to meet Soot Window**
  - **"More retard in timing than PC-10 fuel"**
    - **Statistically insignificant anecdotal comment**
- **Stage 2: Load critical**
  - **Adjust fuel flow to meet "typical load"**
  - **Set point raised from 63.5 to 65.0 Kg / Hr.**

T12 Operational Data

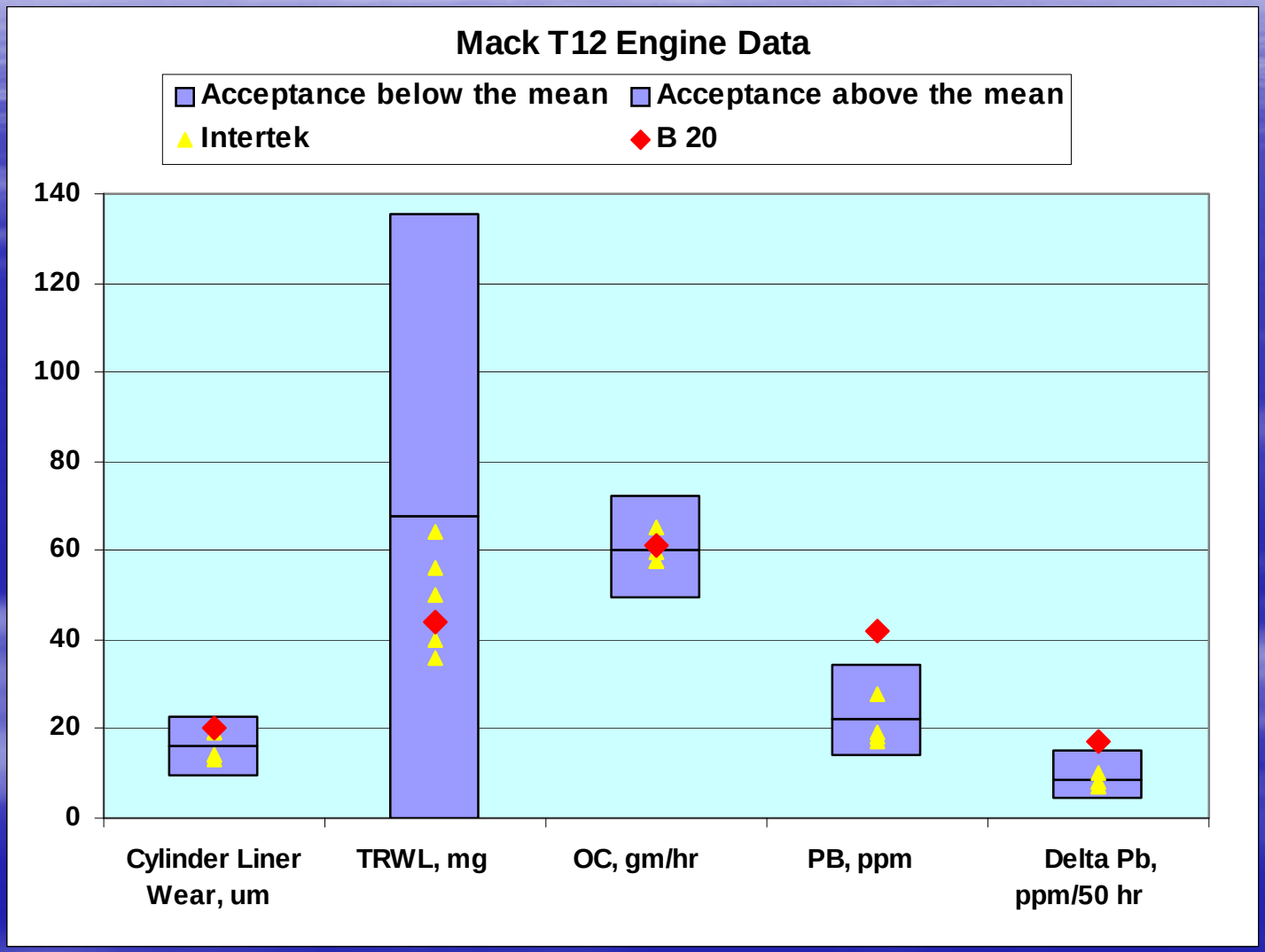
Load



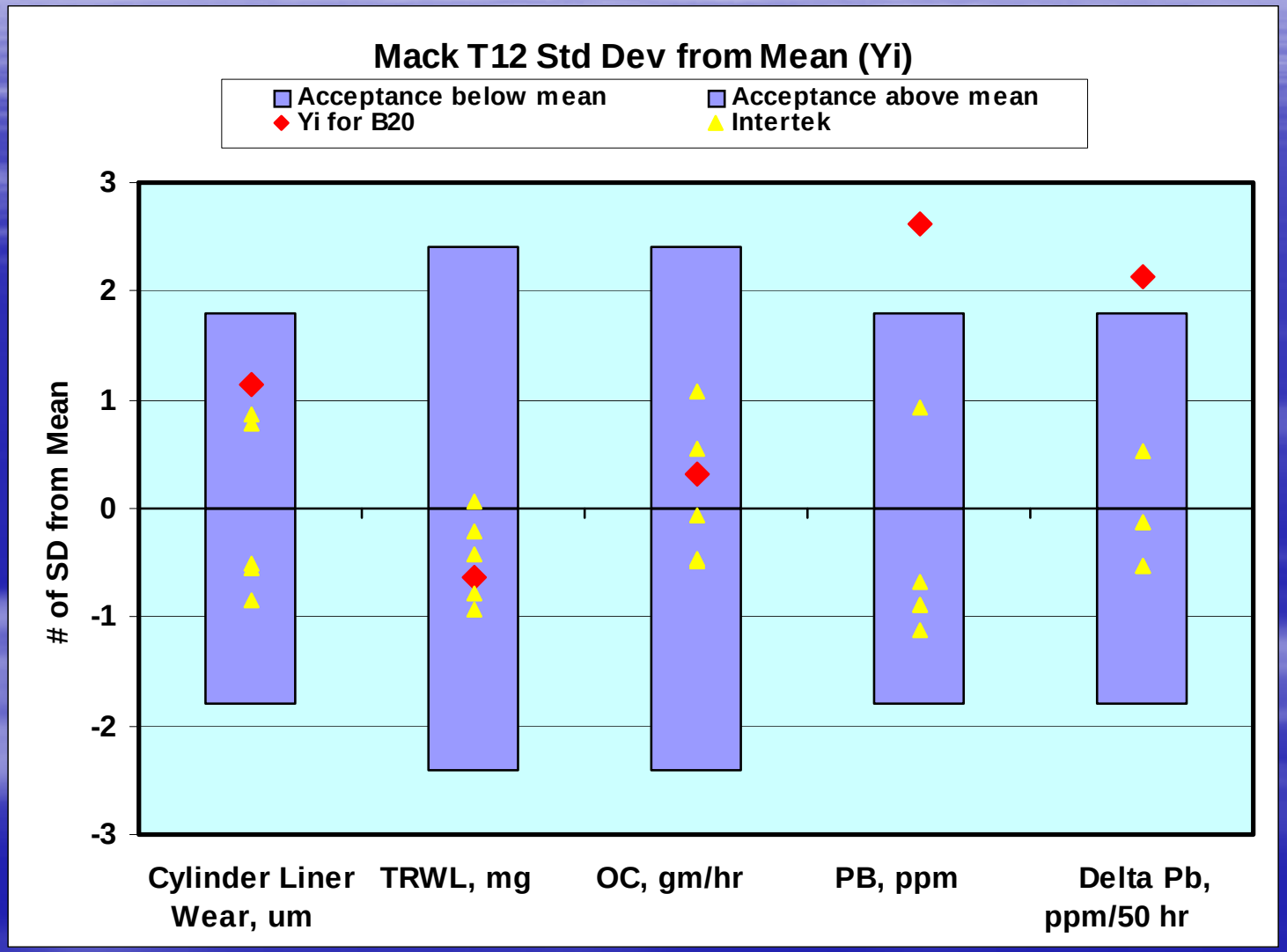
Fuel Flow



T12 Engine Data with B-20

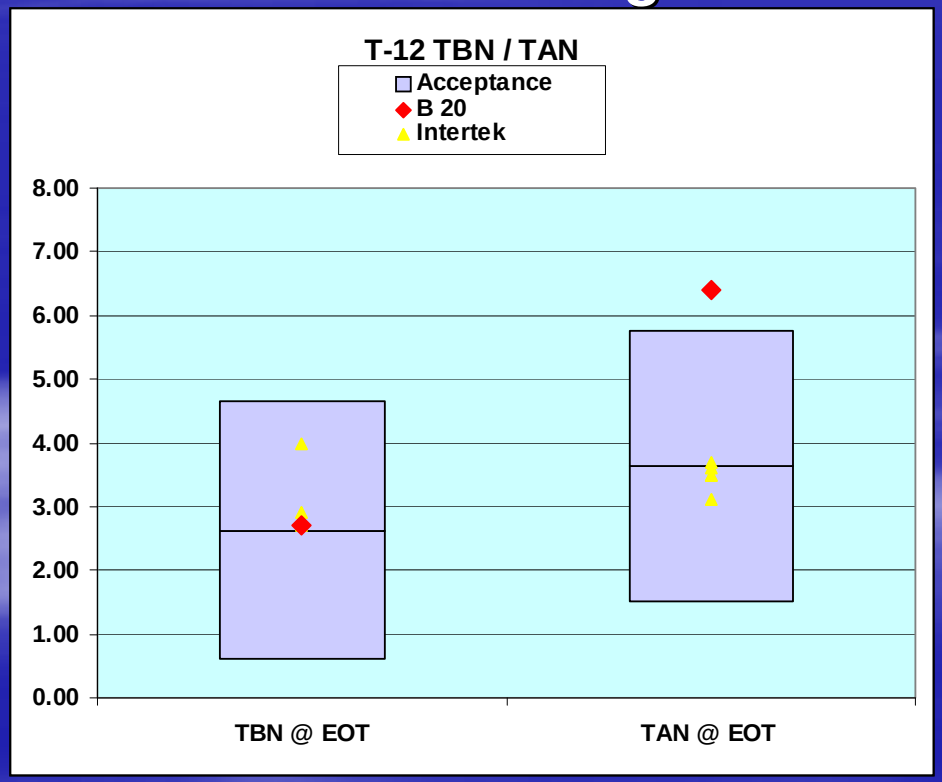


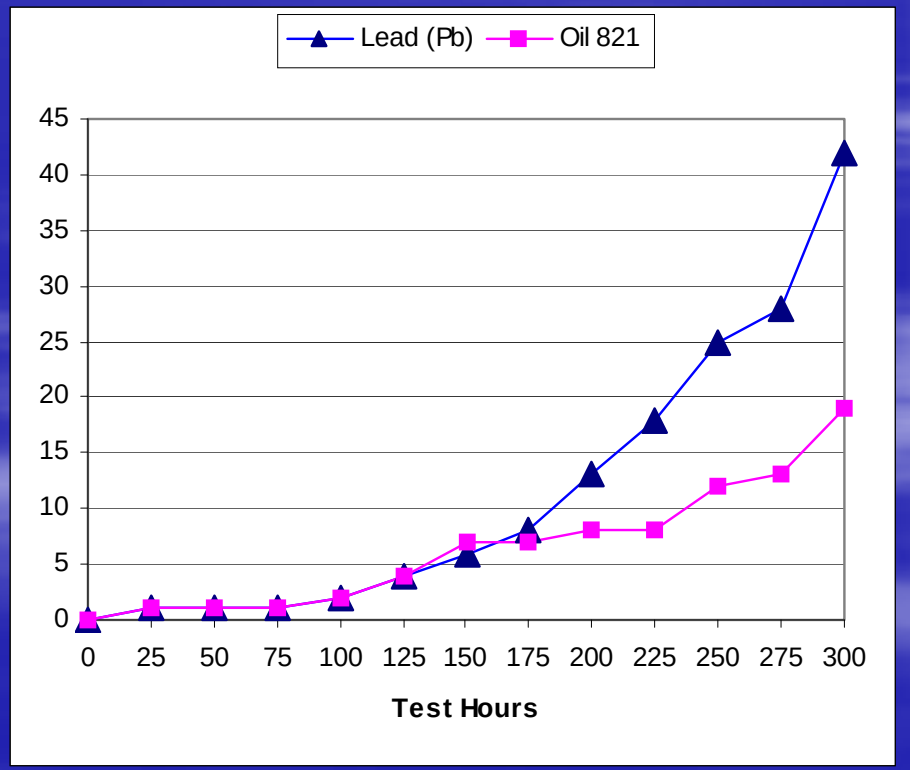
T12 Statistical Data with B-20



Mack T-12 Used Oil Analysis

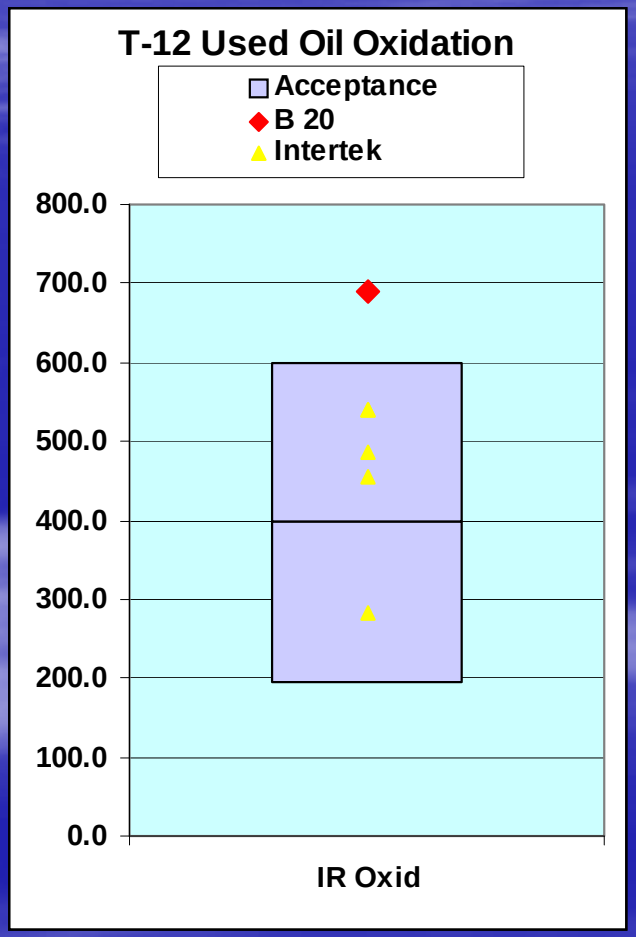
- B-20 test vs 821 reference data
  - TAN higher at EOT
  - TBN loss similar to mean reference data
  - Pb increase significant for last 100 hrs

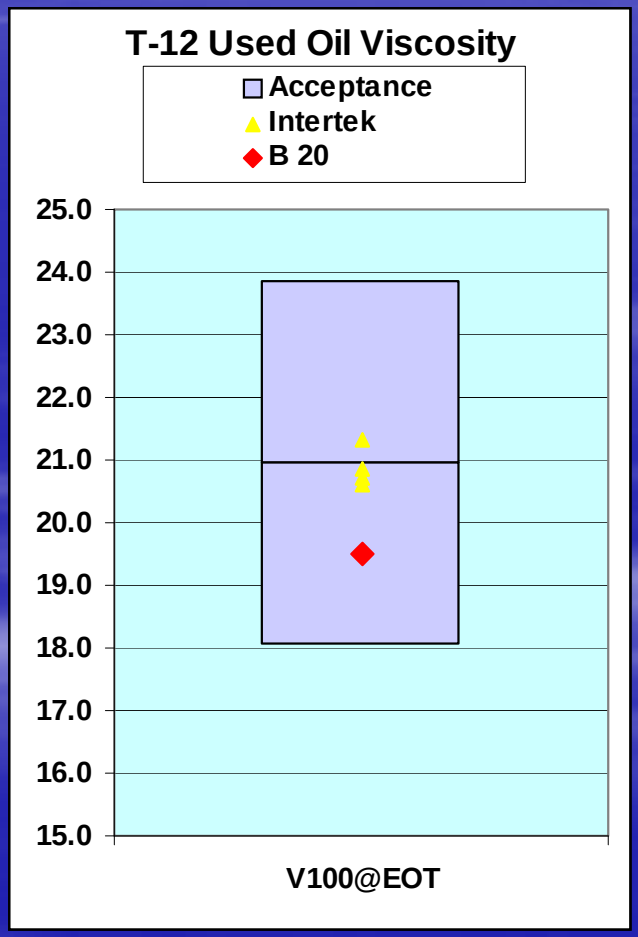




Mack T-12 Used Oil Data

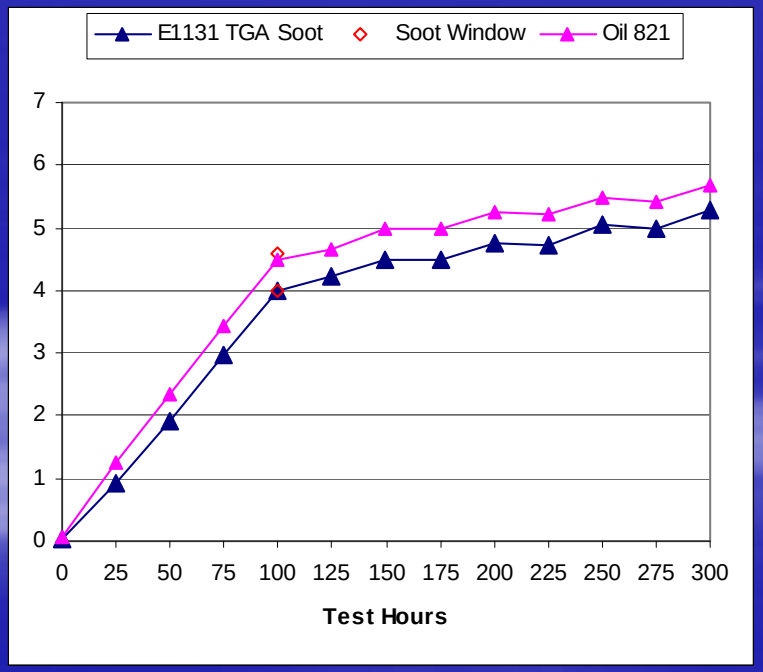
- Oxidation is significantly higher, but Viscosity is not affected
- No samples showed fuel dilution by GC but IR showed some ester

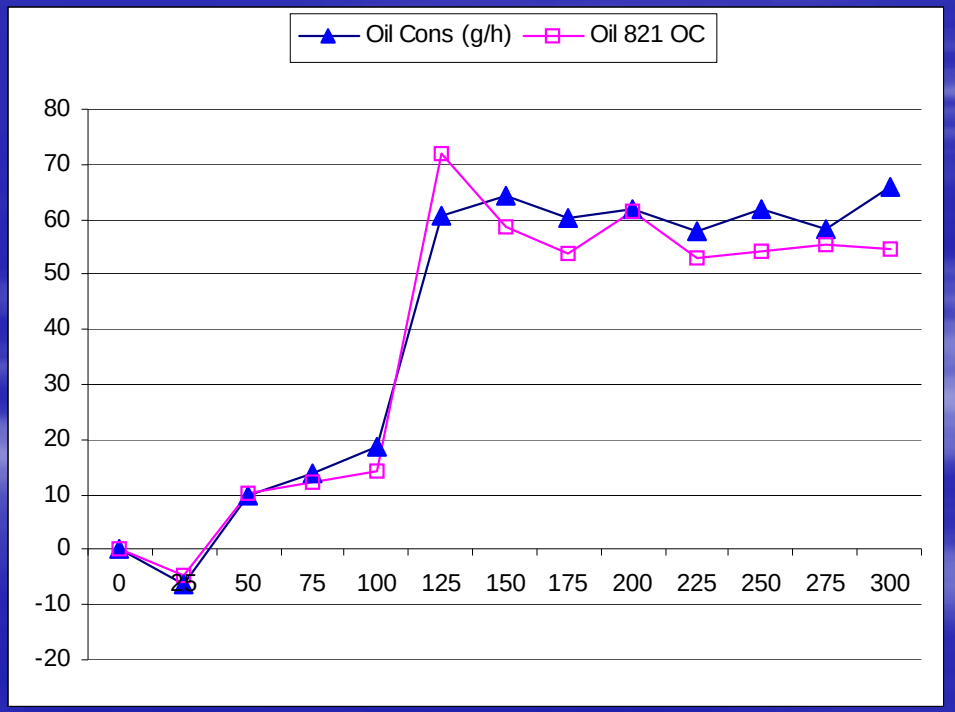




Mack T-12 Used Oil Analysis

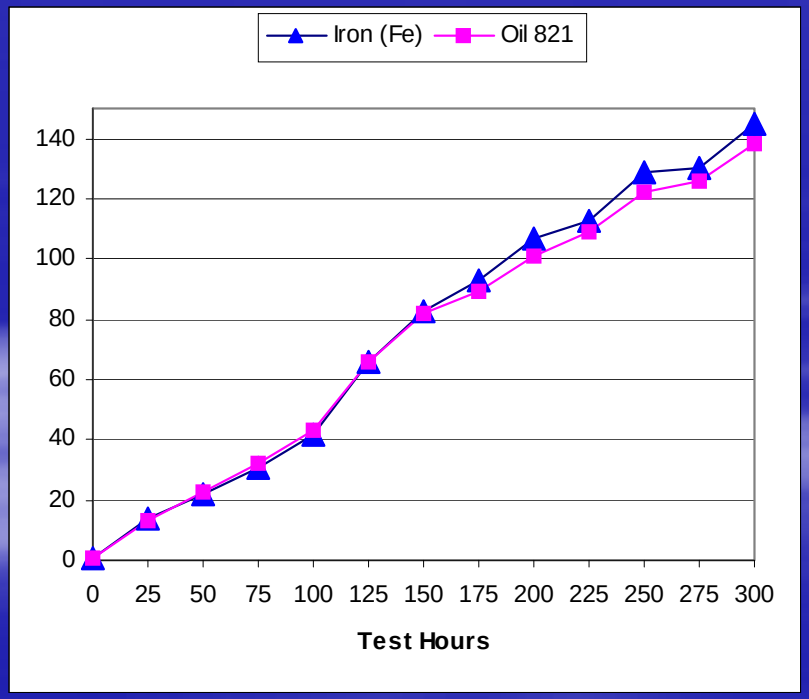
- **B-20 test vs recent 821 reference**
  - **No issues with Soot or Oil Cons**

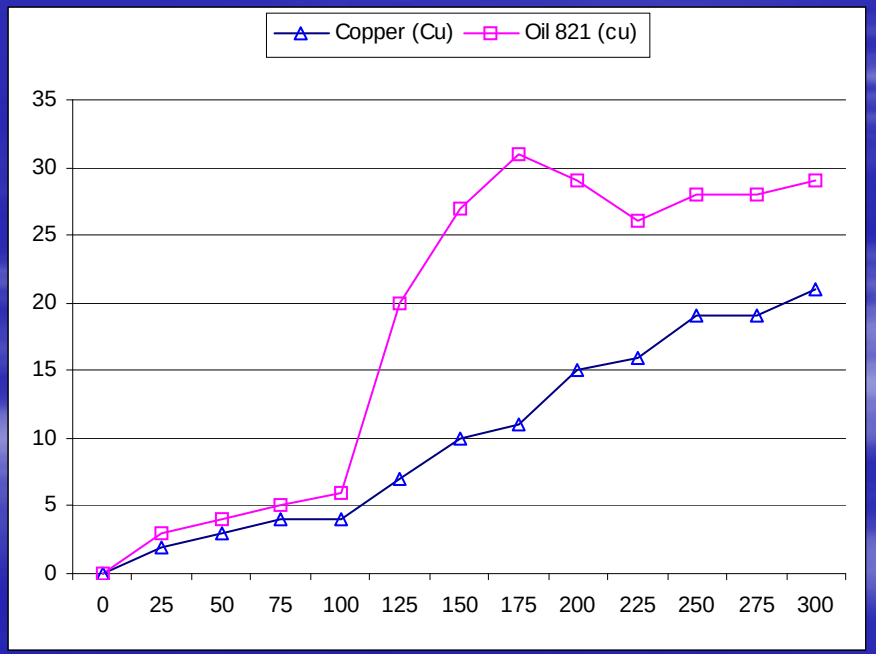




Mack T-12 Used Oil Analysis

- **B-20 test vs recent 821 reference**
  - **Fe and Cu: no issues**





Mack T-12 Used Oil Analysis

- Low temperature viscosity @ 100 hr
  - Previous stand reference MRV @ -20 C 11,500 cP
  - B-20 used oil MRV @ -20 C 11,100 cP
- No evidence that a unique soot was formed from the B-20 fuel
  - Low temp viscometrics
  - Wear data from T12, ISB

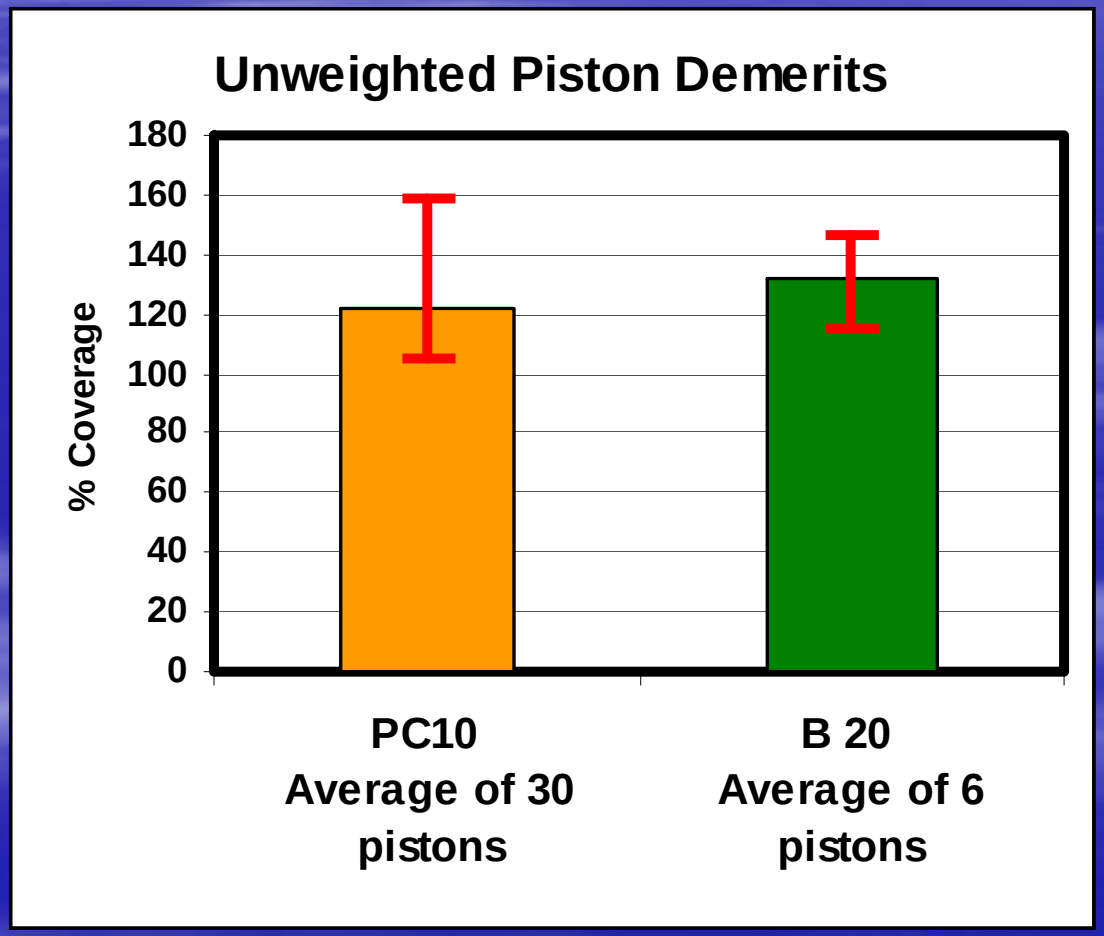
Used Oil Low Temp Viscosity

- Data from Rhomax
- Very good vis properties for sooted oils

Oil ID	Oil ID	YS	MRV TP-1 @ -15°C	YS	MRV TP-1 @ -20°C	YS	MRV TP-1 @ -25°C
65293	Cummins ISB 350	0	11,470	0	20,239	0	45,360
66302	Caterpillar C13 500	0	7910	0	15,270	0	30,720
62996	Can -1 Mack T12 300	0	9490	0	20,407	0	38,700
62996	Can - 2 T12 300	0	9500	0	18,750	0	38,200

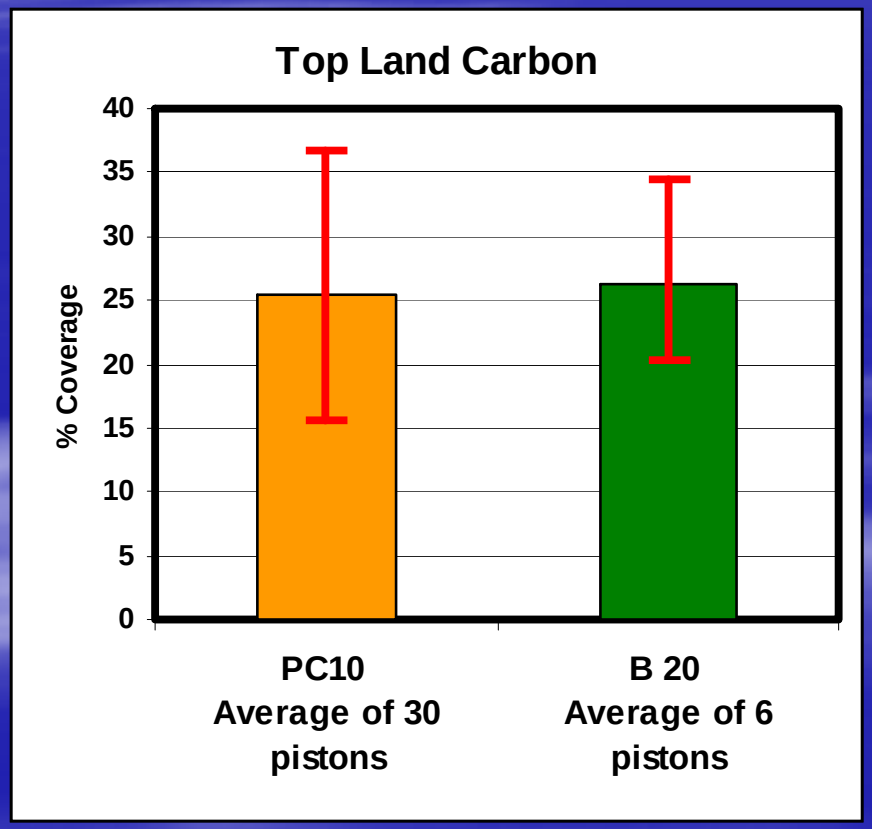
Mack T-12 Piston Deposits

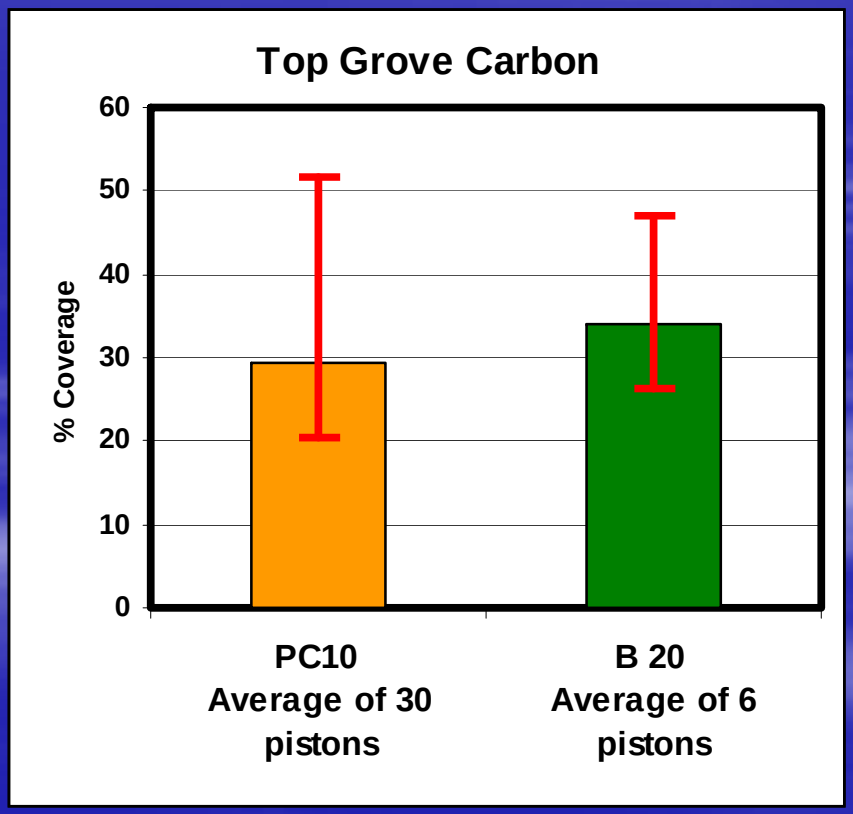
- **Un-weighted Piston Demerits**



Mack T-12 Piston Deposits

- Top Land Carbon
- Top Grove Carbon

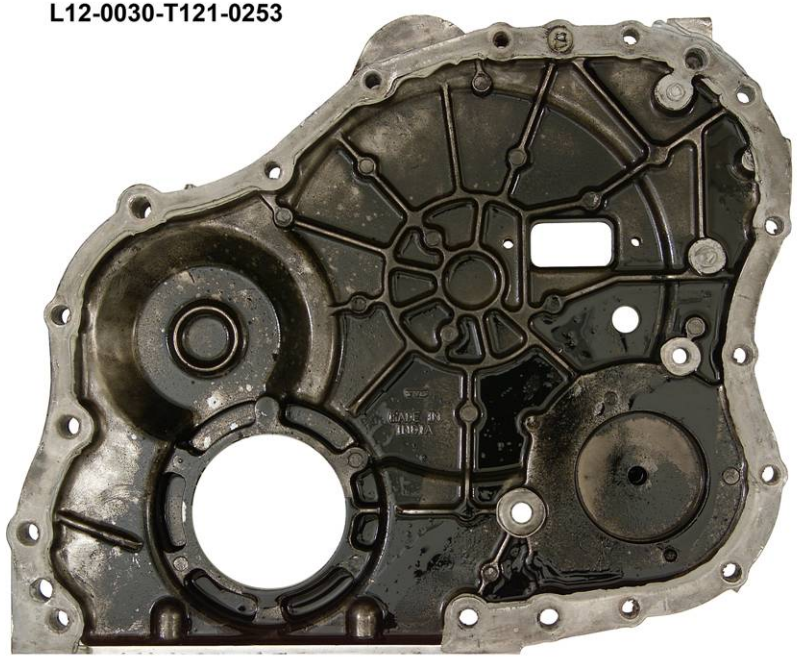




Mack T-12 Parts Cleanliness

T12
SME B20
L12-0030-T121-0253

FRONT COVER



T12 / SME B20 / L12-0030-T121-0253
OIL PAN

Mack T-12 Parts Cleanliness

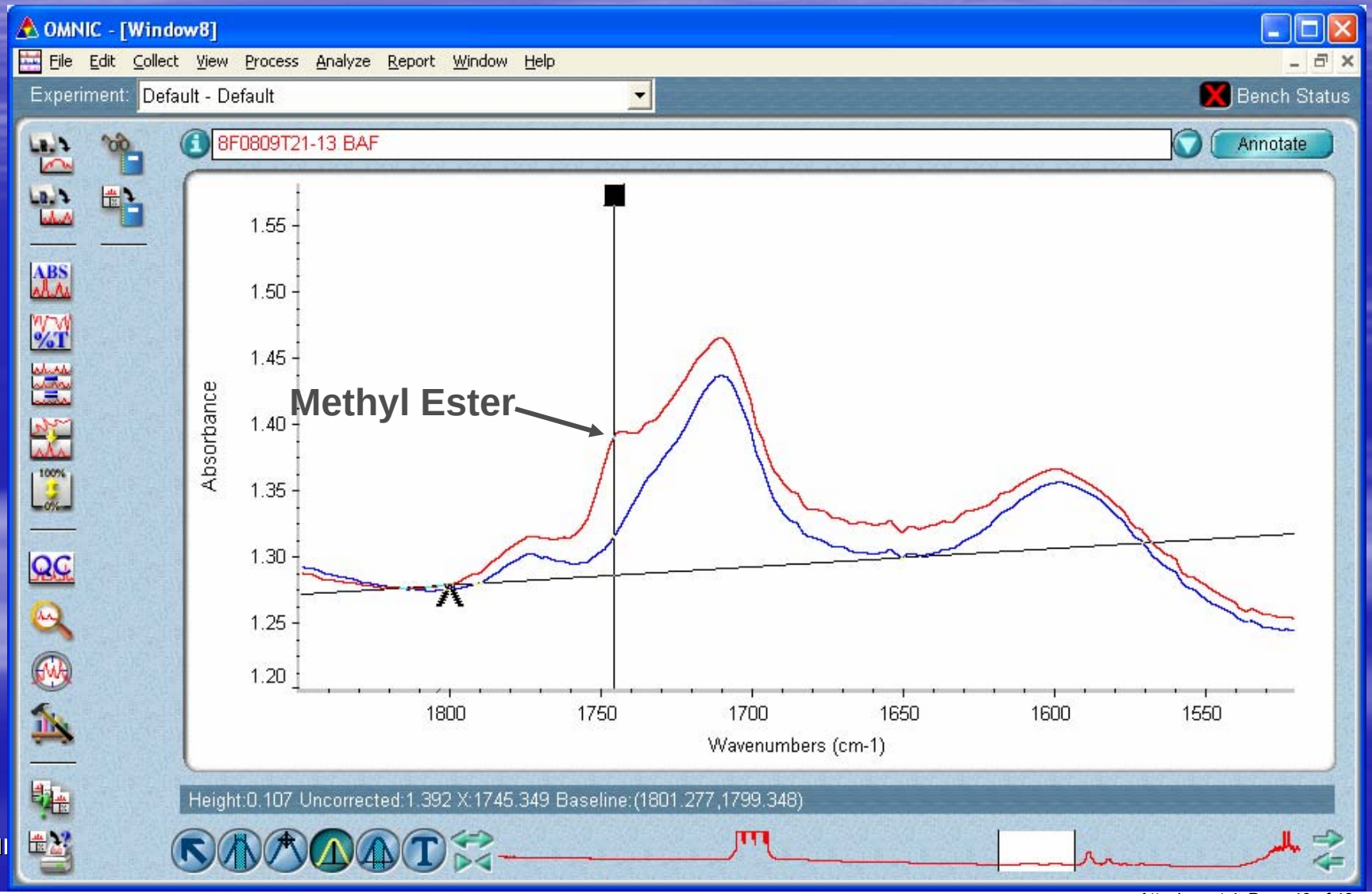
T12 / SME B20
Test No. L12-0030-T121-0253
ROCKER COVERS

Used Oil Data Summary

- **ISB**
  - TBN Loss: Upper Range (More TBN) ^
  - TAN Increase: Higher than Range ^^
  - Viscosity: Significantly Higher ^^^
  - Oxidation: No comparison
- **C-13**
  - TBN Loss: Near Mean -
  - TAN Increase: Upper part of Range ^
  - Viscosity: Upper part of Range ^
  - Oxidation: Significantly Higher ^^^
- **T-12**
  - TBN Loss: Near Mean -
  - TAN Increase: Significantly Higher ^^^
  - Viscosity: Lower part of range ↓
  - Oxidation: Significantly Higher ^^^

T-12 Used Oil

FTIR of B20 vs. PC10 EOT Oil



Summary

- Examination of the control parameters for these engine tests:
  - All wear data within acceptance limits
    - No evidence of unique, higher wear type of soot
  - All controlled piston / ring deposits within acceptance limits
  - Low temperature viscometrics not an issue
  - Only Pb Corrosion and T 12 oxidation are worse than acceptance limits

Summary (cont'd)

- Non rated engine parts appeared clean and free of sludge
- General trend toward higher TAN
  - Without corresponding loss of TBN
- IR shows more oxidation and esters
  - "Oxidation" not clearly associated with viscosity increase

Summary (cont'd)

- Mack T-12 issues
  - Sensitive to oxidation and TAN / TBN
  - Oxidation and Pb corrosion are an issue
    - Also reported by Infineum & Oronite papers
  - Piston deposits (not normally rated) show similar range of TLC, Demerits for B20 vs. PC-10 fuel
- May indicate that an oil could demonstrate some level of "Biodiesel Performance" by passing a Mack T-12 using B-20 blended with PC-10 fuel.
- High fuel dilution not represented in this testing