

PC-10 Update

James Mc Geehan

Chairman

ASTM Heavy-Duty Engine Oil Classification Panel

November 2004



PC-10 Performance Requirement

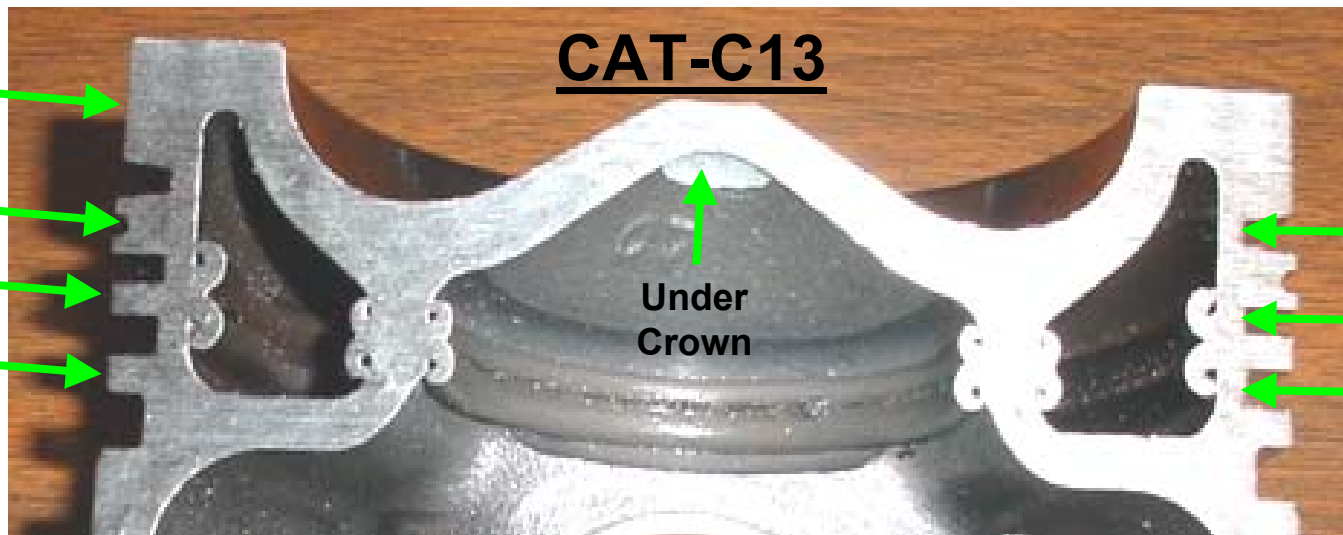
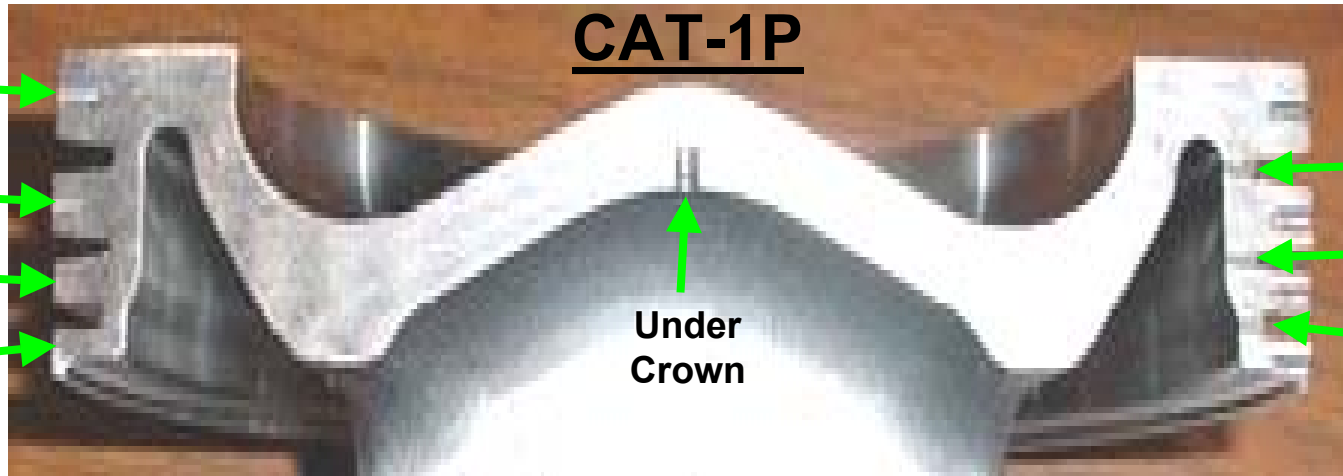
Performance Criteria	Fuel Sulfur, Wt %	Test	PC-10 2006
Aluminum Piston Deposits, Oil Consumption	0.05	Caterpillar 1N	X
Viscosity Increase Due to Soot at 6.0%	0.05	Mack T-11	X
Roller-Follower Valve Train Wear	0.05	GM 6.5-Liter PC – Diesel	X
Aeration	0.05	Navistar HEUI 7.3-Liter EOAT	X
Foam	–	Bench Test Sequence I, II, III	X
Volatility	–	Noack D 5800 or Distillation D 2887	X
Used Oil Viscometrics at Low Temperature	–	J300 Bench Tests MRV TP-1 Soot	X
Elastomer Compatibility		D-471, Ref. Oils	X
High Temperature/High Shear		Bosch Injector	X
Valve Train Wear, Filter Δ P and Sludge	.05	Cummins ISM	X
Valve Train Wear	15 ppm	Cummins ISB	X
Oil Consumption and Piston Deposit	15 ppm	Caterpillar C-13	X
Ring, Liner Bearing Wear & Oil Consumption	15 ppm	MackT-12	X
Oil Oxidation	0.10	See III G (or III F)	X
Shear Stability – 90 Cycles	–	Bosch Injector ASTM D 3945	X
<i>Total Number of Engine and Bench Tests</i>			15

Yet to Be Decided

Engine Test Decisions Yet to Be Made

- **Alternatives:**
 - **Caterpillar in Aluminum Piston (Cat IN) and Caterpillar IP Forged Steel Piston (Single-Cylinder Tests)**
 - **Gasoline Tests IIF (API CI-4) or IIG (ILSAC GF-4) or Neither**
 - **Mack T-12 and Caterpillar C13 for Oil Oxidation Only**

Cat IP Temperatures Higher Than Cat 13

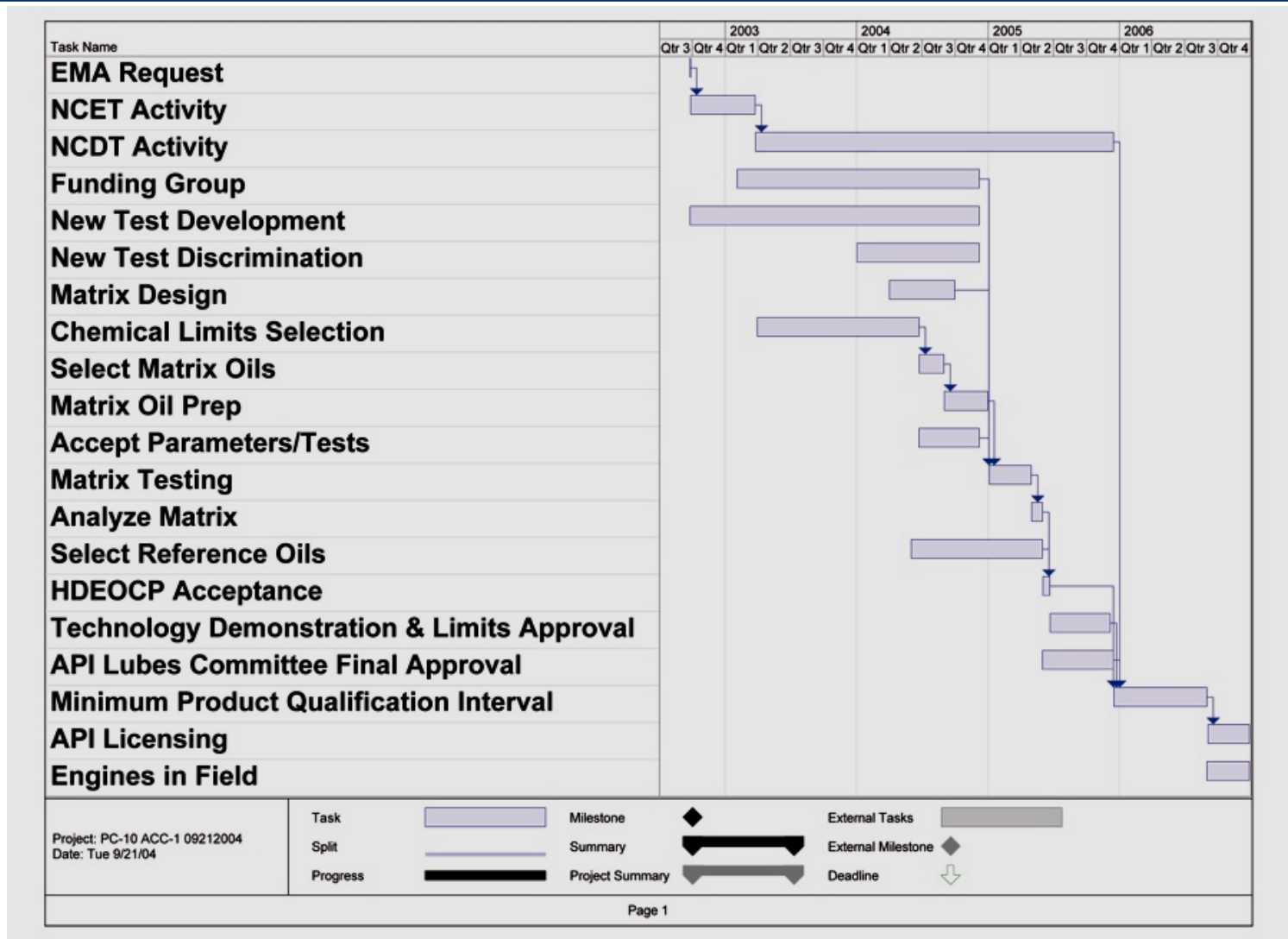


ATTACHMENT 15, 4 OF 30

Engine Oil Matrix for PC-10 Test

- **Precision Only for Cummins ISB and Mack T-12**
- **Precision and Base Oil Interchange (BOI) for Cat C-13 Only**
- **Total Matrix Cost = \$ 4.2 Million**
- **Base Oils Selected: API Group I, II and III**

PC-10 Program Timing



Timing

- **Plan Was to Select Engines for Matrix by December 7, 2004**
- **Due to Status of Cummins ISB, Mack T-12 and Caterpillar C13 Test Selection Moved to February 2005**
- **Licensing Potentially Moved to September 2006 Instead of June 2006**

Mack T12



Mack T-12

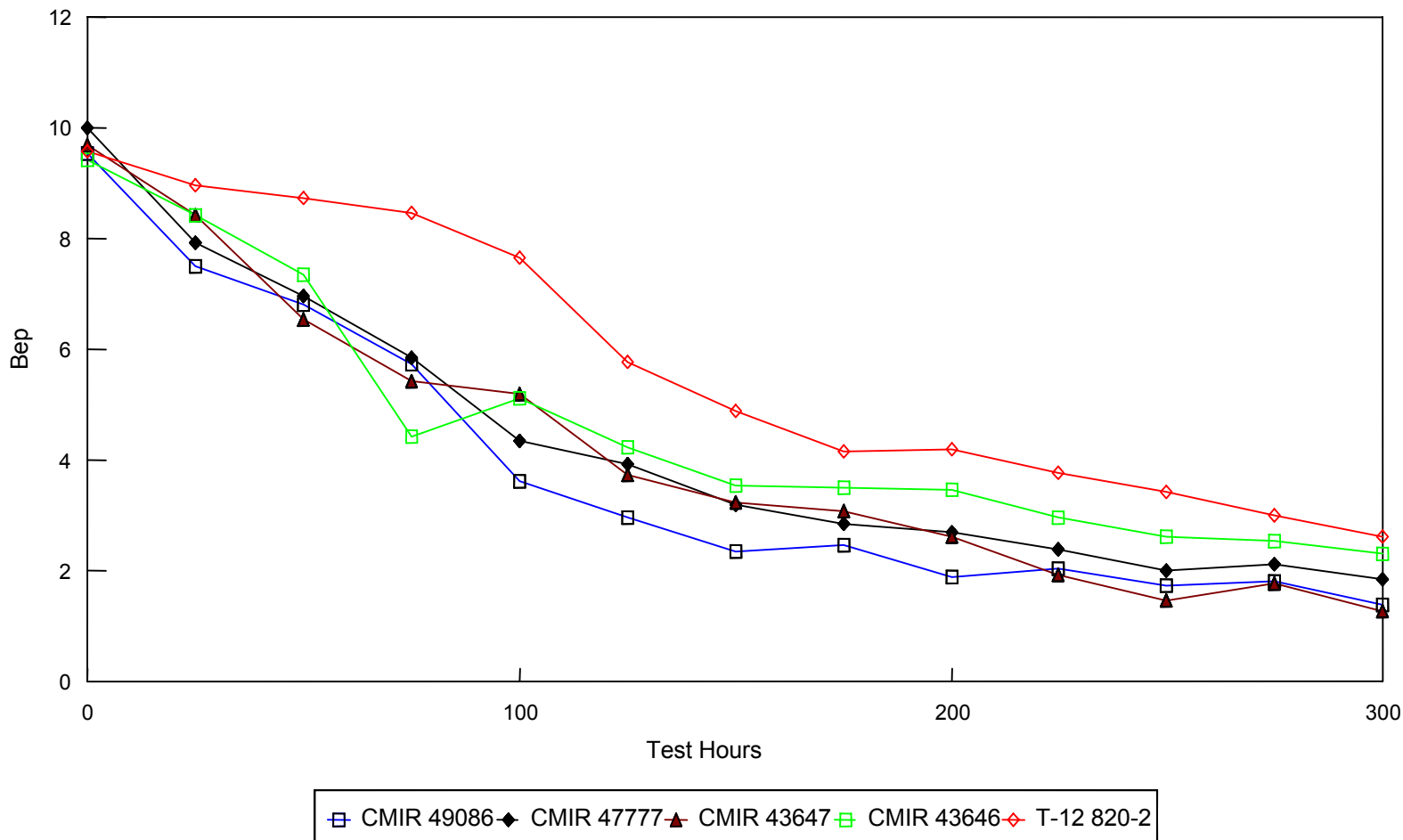
- **Parameters to Control**
 - Ring Wear
 - Liner Wear
 - Rod Bearing Wear (Load Increase)
 - Oil Consumption
- **Cyclic Based on Mack T-10 in API CI-4 With Mack T-10 Low Swirl Heads**
- **Test Length: 300 Hours**
 - 100 Hours Rated Load and Speed
 - 200 Hours Peak Torque

Mack T-12 Test Condition Targets

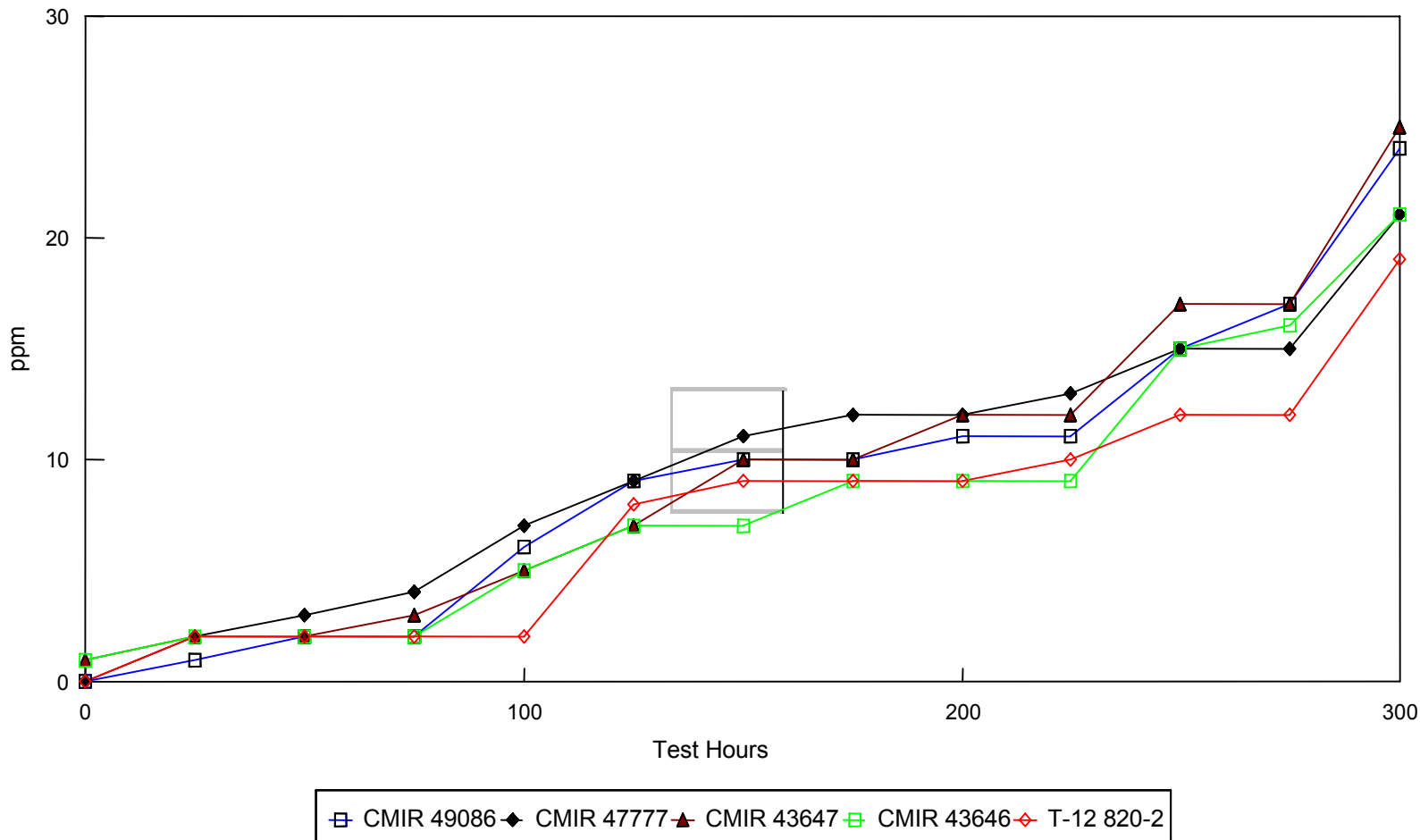
Parameter	Stage 1	Stage 2
Speed	1800	1200
Power, kW (bhp)	243 (325)	314 (420)
EGR Rate	35%	15-20%
AFR	22-23	21-22
Oil Sump Temperature , °C (°F)	99 (210)	127 (260)
Coolant Temperature, °C (°F)	66 (150)	88 (190)
Soot	4% at 100 Hours	6% at 300 Hours
Engine Hours	100	200

Mac T-10 Versus T-12

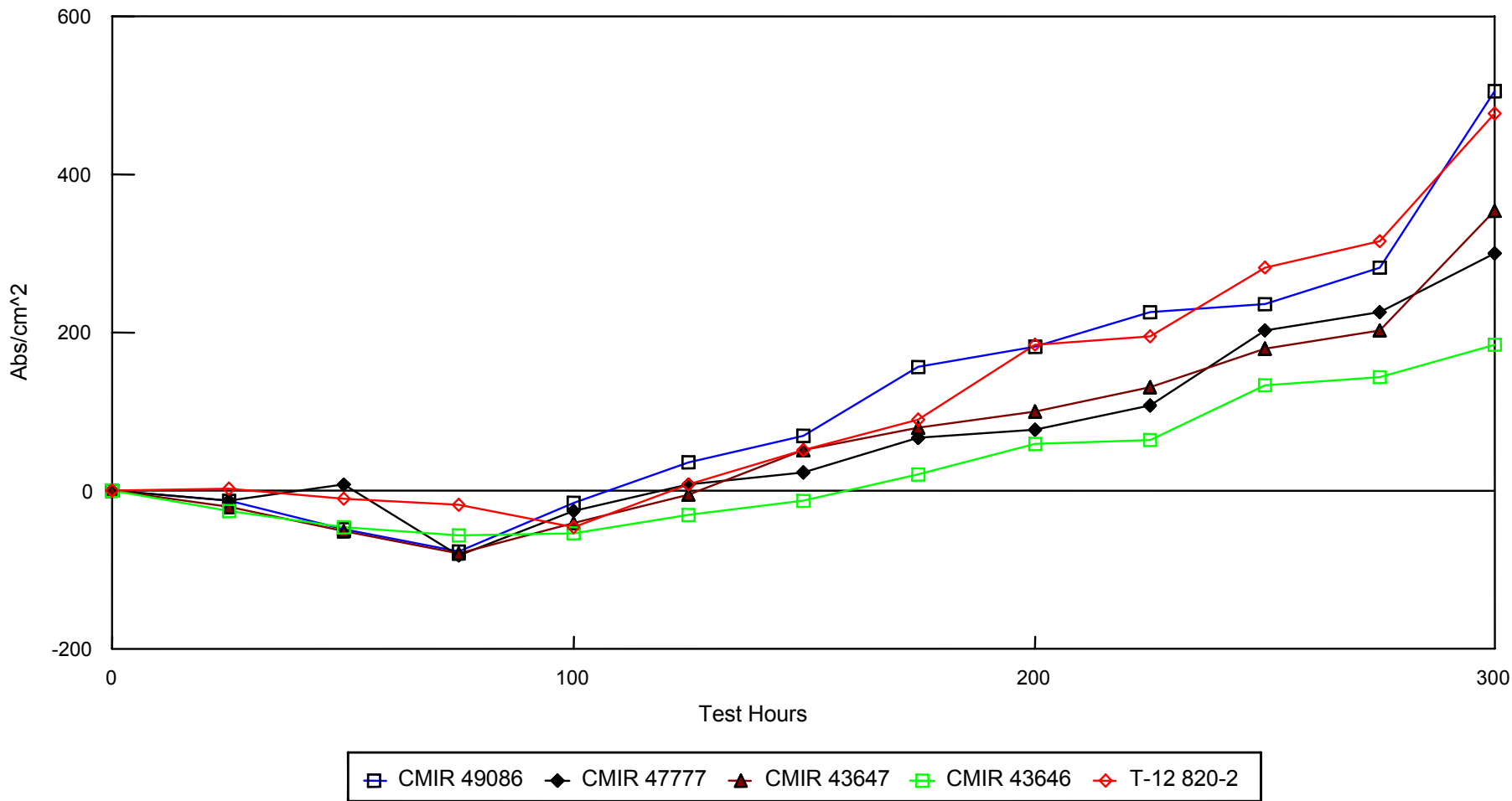
TBN – D 4739



Mac T-10 Versus T-12 Used Oil Lead

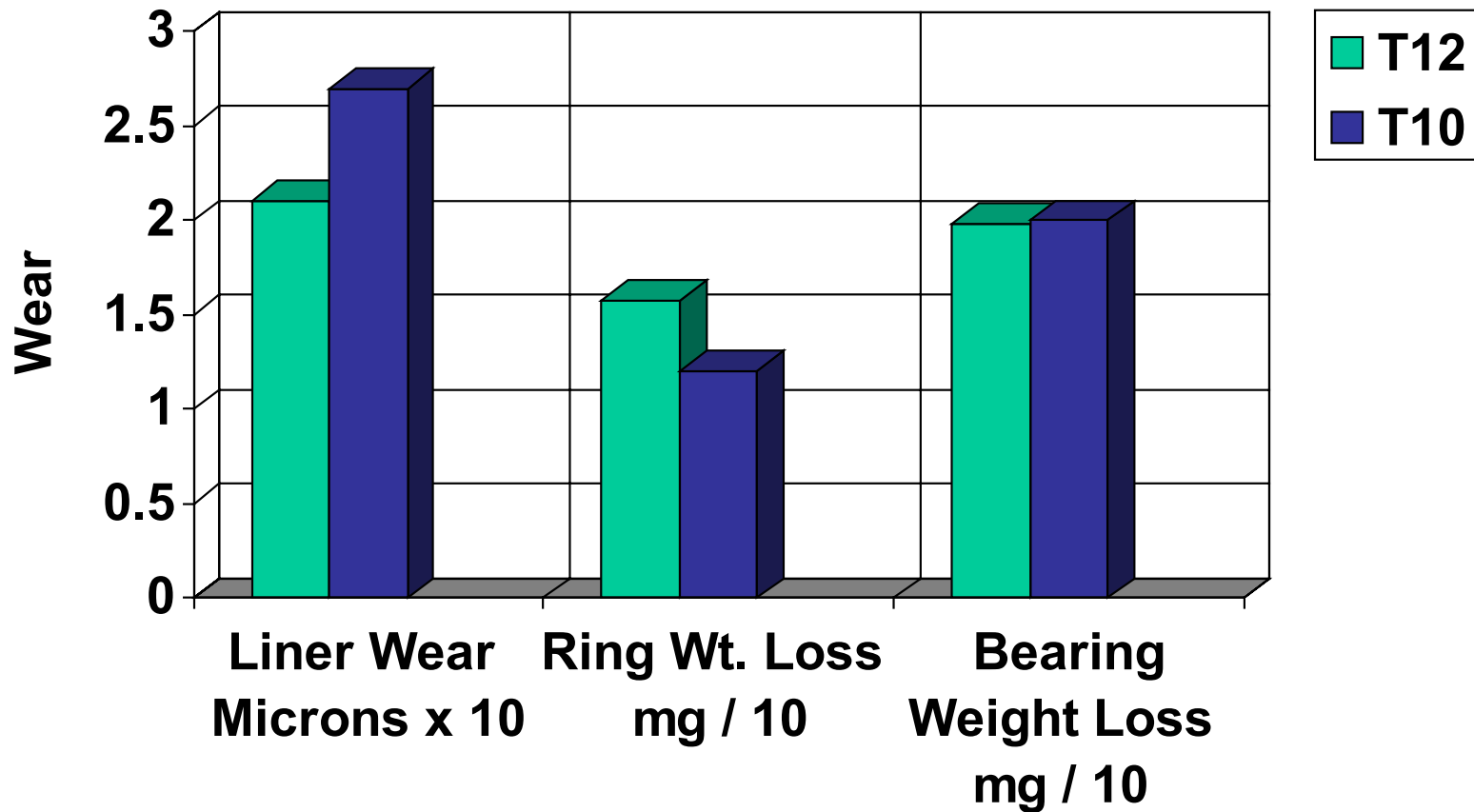


Mac T-10 Versus T-12 Oxidation FTIR Area



Wear T12 Versus T10

820-2 Ref Oil



GLS Nov 11th 2004

Jim Mc Geehan • ChevronTexaco

T12 and PC10 Engine Oil Test Development Schedule



	July	August	September	October	November	December
EGR Mapping	■	■				
Soot Mapping		■				
TBN Depletion Mapping			■			
Run Demonstration Test				■	■	
Run Discrimination Test	■					■
Deliver Draft Procedure				■	■	
Deliver Procedure for Matrix Testing						■

Cummins ISM (EGR)



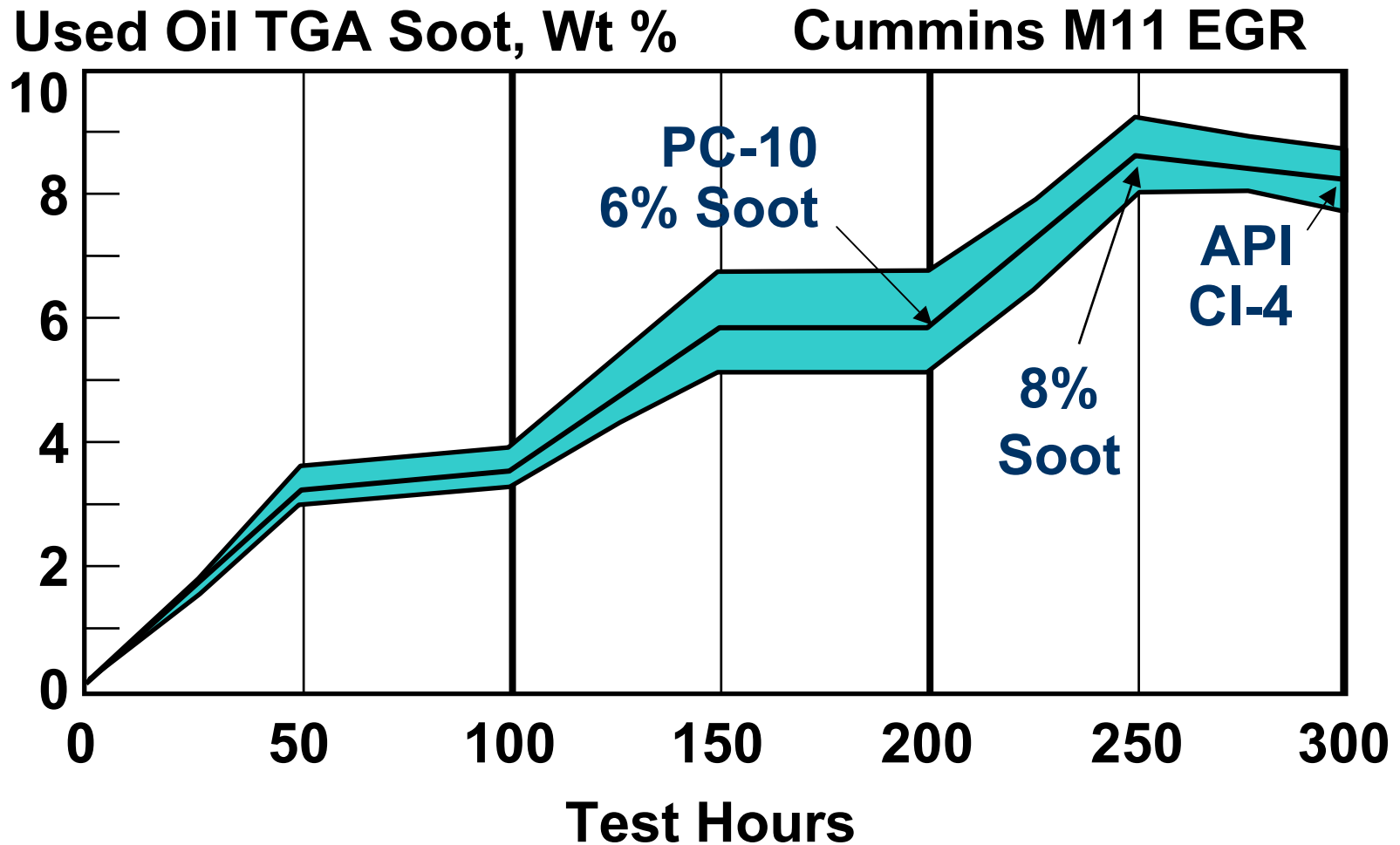
Cummins ISM (EGR)

- **Replace Cummins M11 EGR**
- **Parameters:**
 - **Cross-Head Weight Loss**
 - **Filter Plugging**
 - **Sludge**
- **Fuel Sulfur: 500 ppm**
- **Test Length: 200 Hours at 6% Soot**

ISM Test Conditions

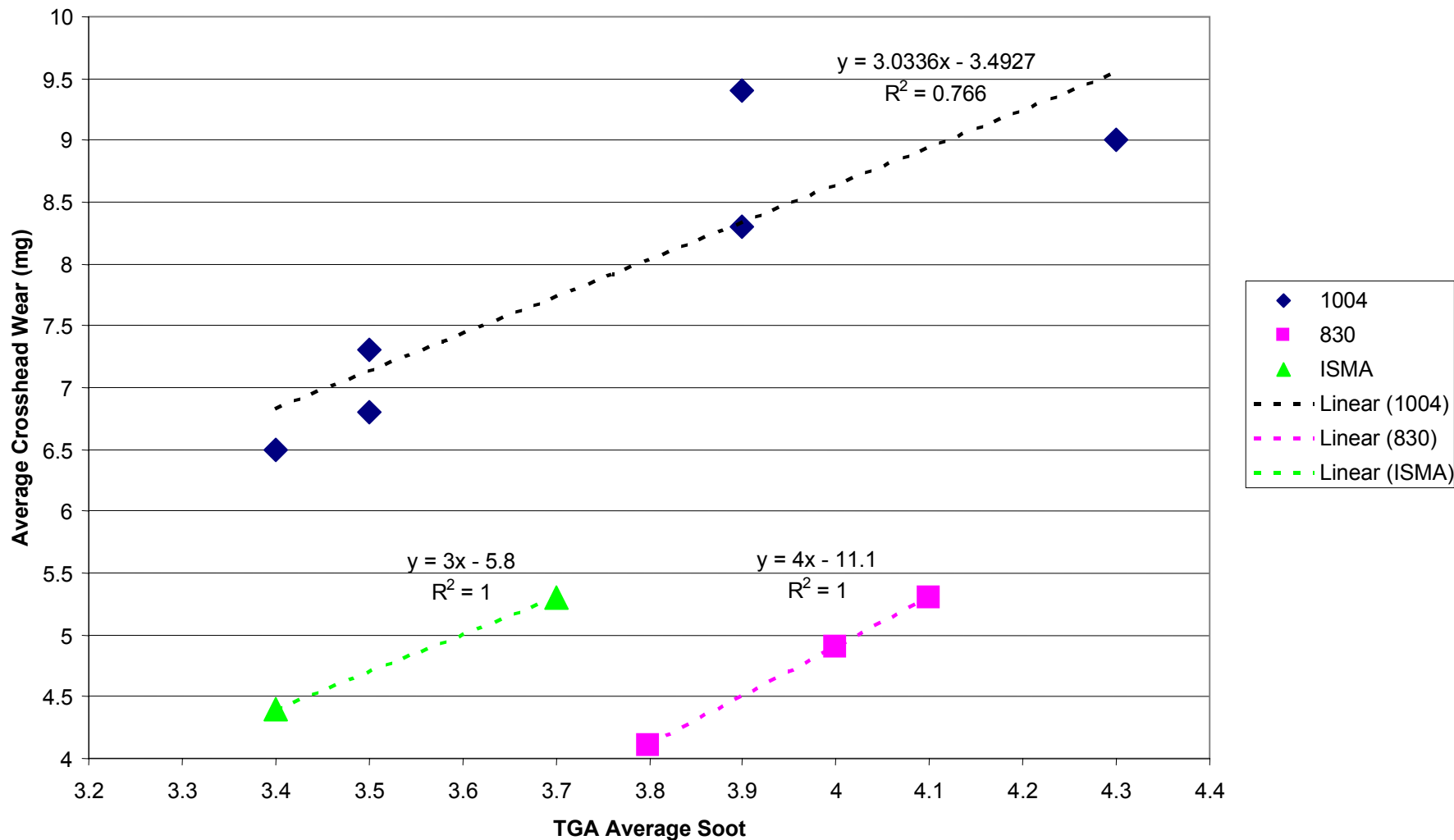
Parameter	Stage A	Stage B
Time, Hours	50	50
Speed, rpm	1800	1600
Power, kW (bhp)	236 (317)	302 (405)
Cooled EGR, %	9.5	15
Oil Gallery Temperature, °C	115	115
Fuel Flow, kg/Hour	58.0	64.4
Inlet Manifold Temperature, °C	80	65.5
Coolant Out Temperature, °C	65.5	65.5

Cummins M11-EGR and ISM-EGR Cycle



ISM Matrix Average Cross-Head Wear as a Function of Soot

Outlier Lab Removed



Cross-Head Weight Loss

- **Model Fit: $CWL=f(\text{Lab, Oil, Average Soot})$**
 - **No Lab Differences**
 - **Lab G 0.84 Mild if Fit Procedure Change Instead of Soot**
 - **All 3 Oils Statistically Significantly Different**
 - **CWL Increases 3.0332 per 1% Average Soot**

Crosshead Weight Loss	Oil 1004	Oil 830	Oil ISMA
LS Mean at 4% Soot	8.6385	4.8680	6.3605
Mean at 4% Soot	8.6416	4.8678	6.2149
StdDev at 4% Soot	0.5784	0.1477	0.0070
Mean at New Soot	8.9000	4.7667	6.8767
StdDev at New Soot	0.5568	0.6110	NA
M11 EGR Target	99.8000	12.2000	5.1000

Caterpillar C13



Caterpillar C13

Caterpillar ACERT Engine



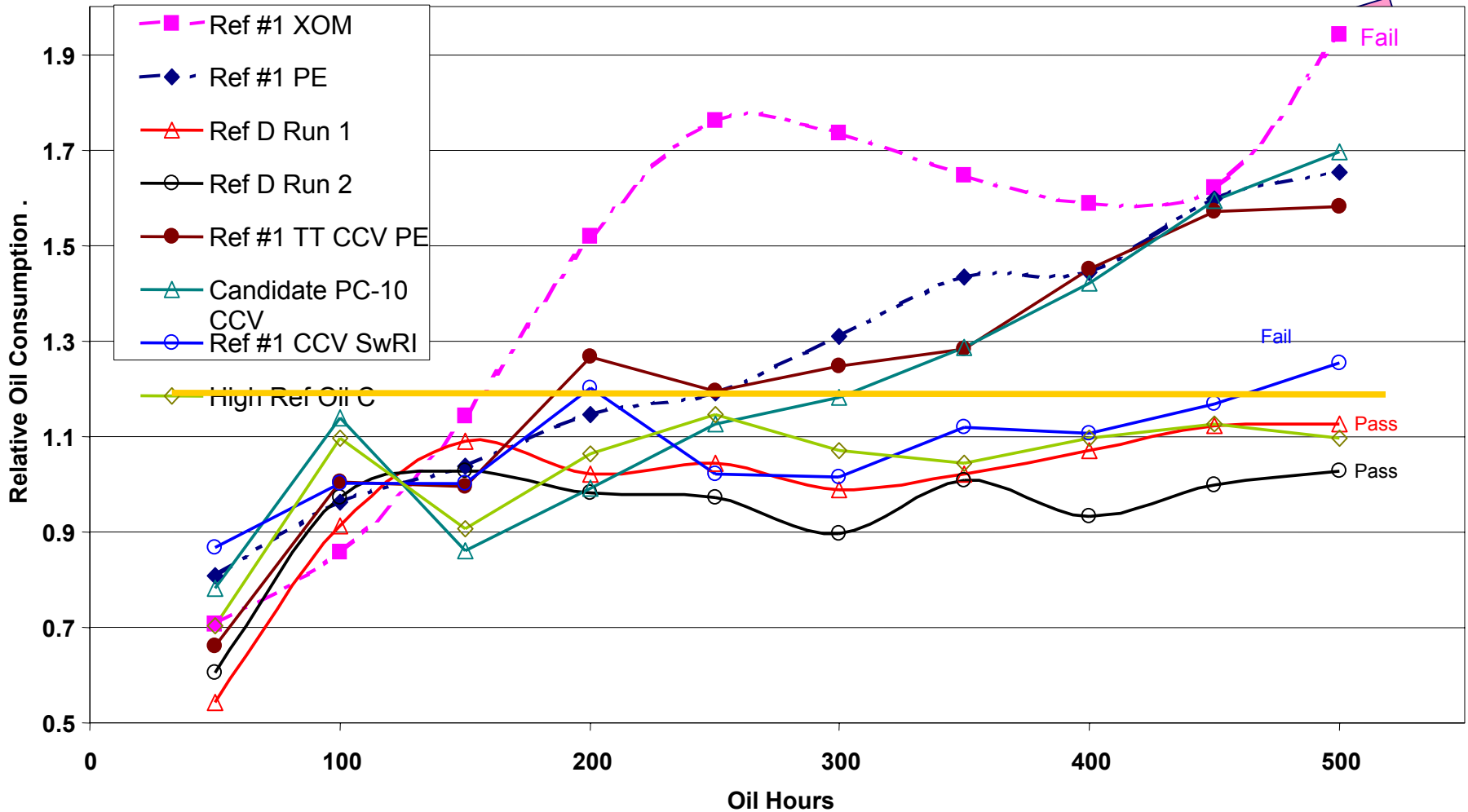
- **Caterpillar C13**
- **Parameter to Control**
 - **Oil Consumption**
 - **Piston Deposits**
 - **No ring sticking of second ring.**

Cat C13 Operation Conditions

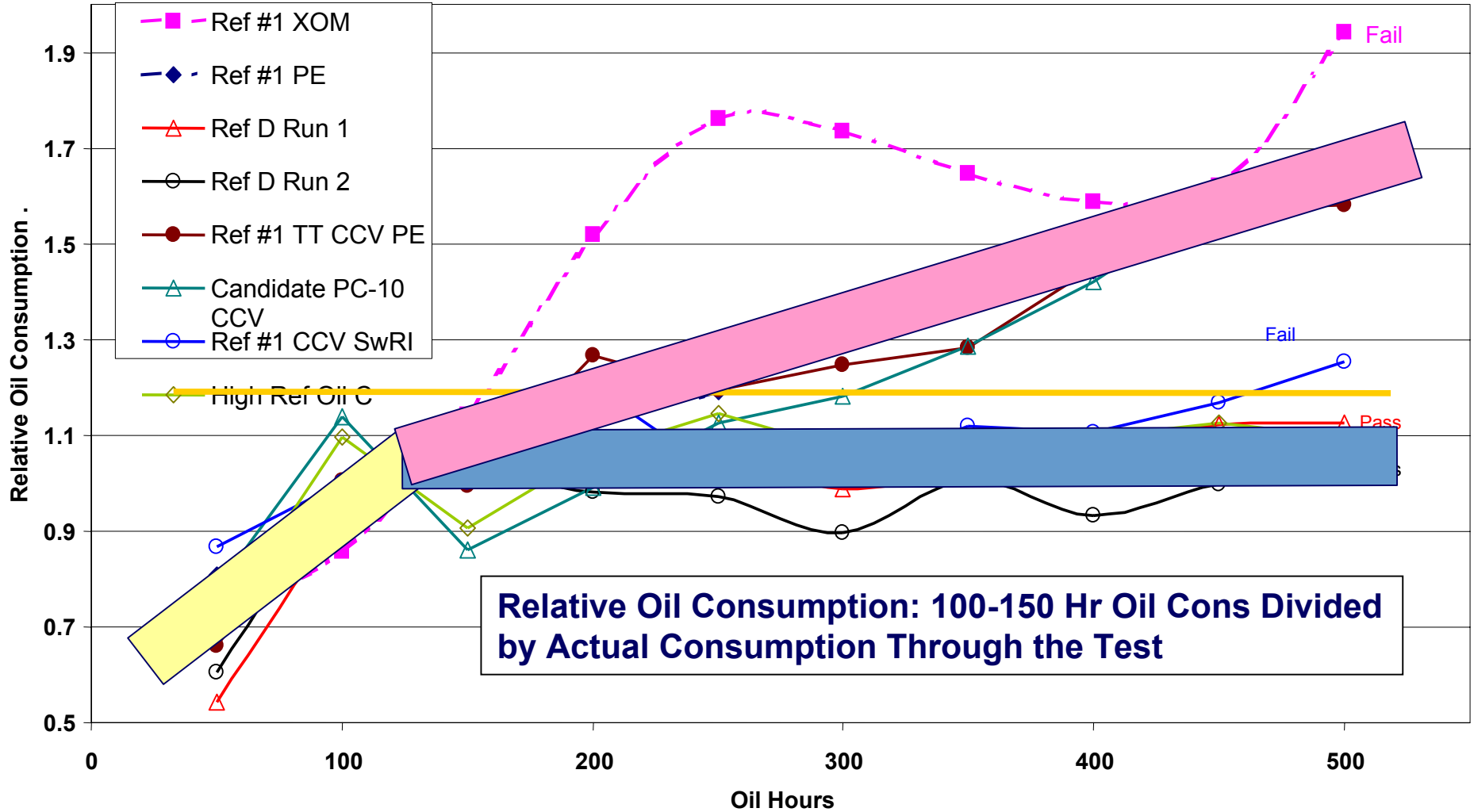
Operational Parameters	“Cool” Operating Condition
Power, kW (bhp)	338 (456)
Test Duration, Hours	500
Engine Speed, rpm	1800
Coolant Out Temperature, °C	88
Intake Manifold Temperature, °C	40
Exhaust Manifold Temperature, °C	641
Oil Gallery Temperature, °C	111

Caterpillar C13 Test Update

C13 Normalized Oil Consumption

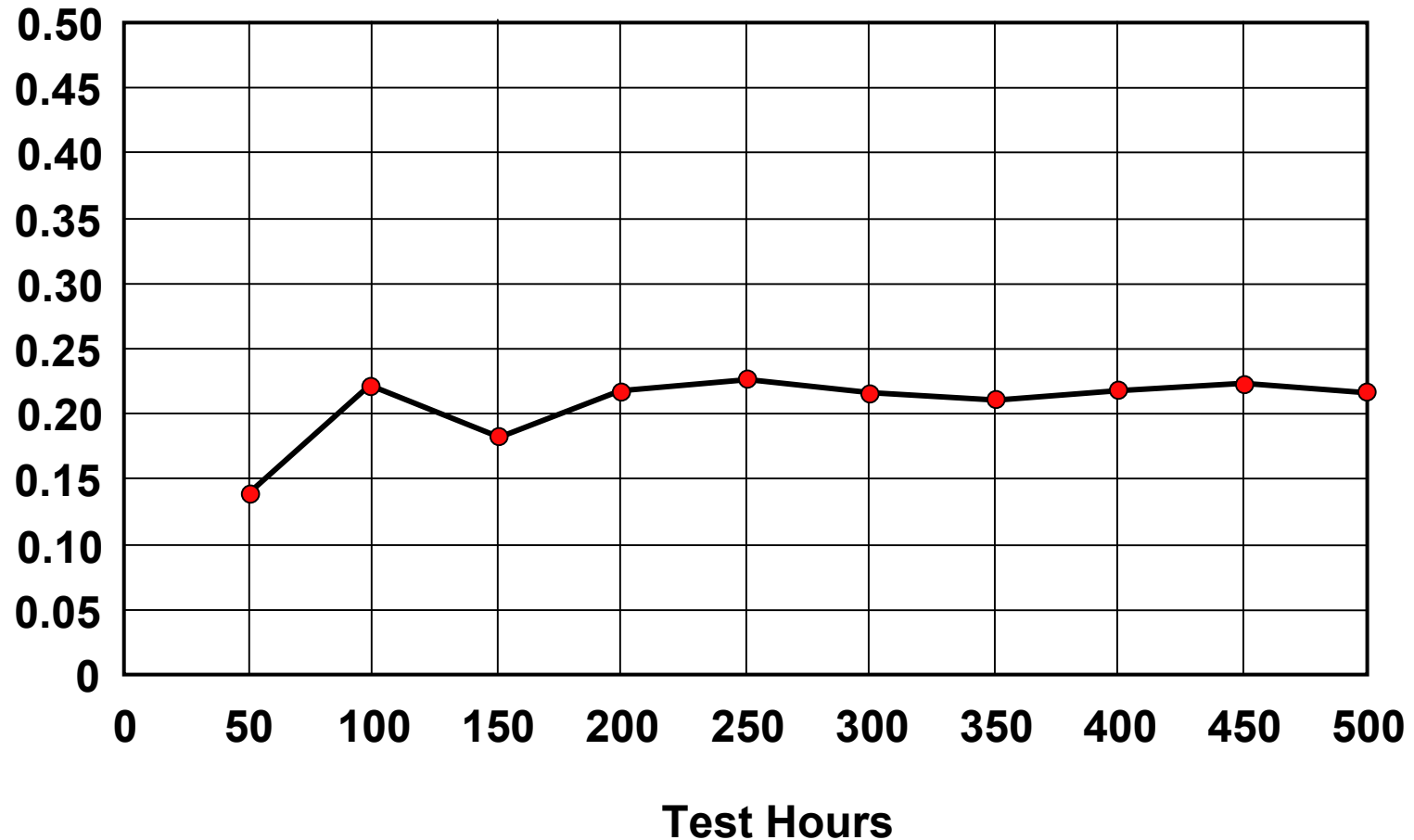


Caterpillar C13 Test Update



Cat C13 – Acceptable Oil Consumption

g/kW-Hr Initial Average: 0.17g/kW-Hr EOT Average: 0.20g/kW-Hr



Caterpillar C13

- **New High and Low Reference Under Evaluation With Completion Planned by December 2004**

Cat C13 Operation Conditions

Operational Parameters	“Cool” Operating Condition	“Normal “Operating Condition	“Hot” Operation Condition
Power, kW (bhp)	338 (456)	348 (470)	352 (475)
Test Duration, Hours	500	500	500
Engine Speed, rpm	1800	1800	1800
Coolant Out Temperature, °C	88	98	105
Intake Manifold Temperature, °C	40	55	75
Exhaust Manifold Temperature, °C	641	690	735
Oil Gallery Temperature, °C	111	119	128

Note a 18% increase in oil consumption



g/kW-Hr Initial Average: 0.18g/kW-Hr EOT Average: 0.22g/kW-Hr

