Reducing Lubricant Ash Impact on Exhaust Aftertreatment with a Oil Conditioning Filter

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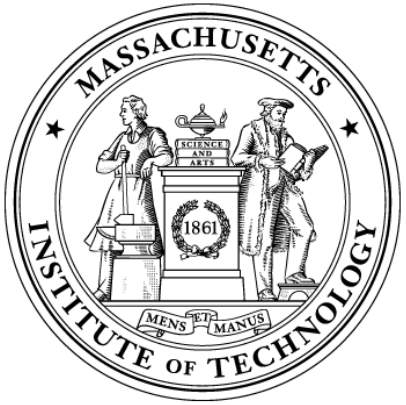
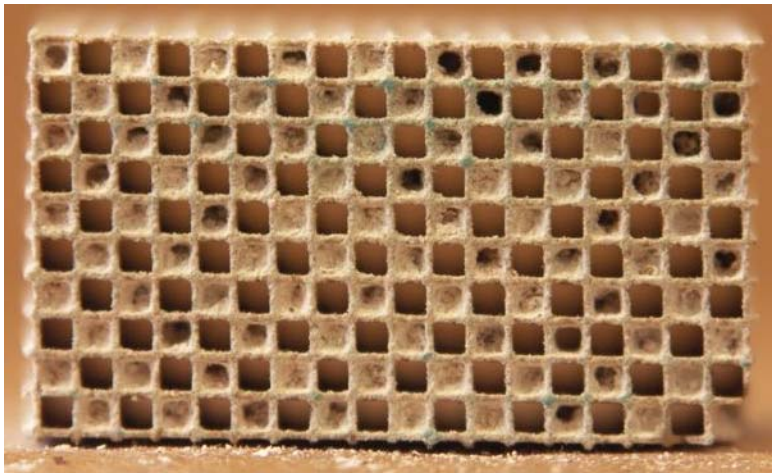


2009 Directions in Engine-Efficiency and Emissions Research (DEER) Conference
August 6th, 2009

Lubricant Derived Ash

- Ash negatively effects aftertreatment systems:
  - Increases fuel consumption and exhaust back pressure
  - Phosphorus may chemically deactivate catalysts
  - Periodic cleaning requirements and possible engine damage



(Sappok, 2009)

Diesel Particulate Filter Ash Deposits:

Inlet

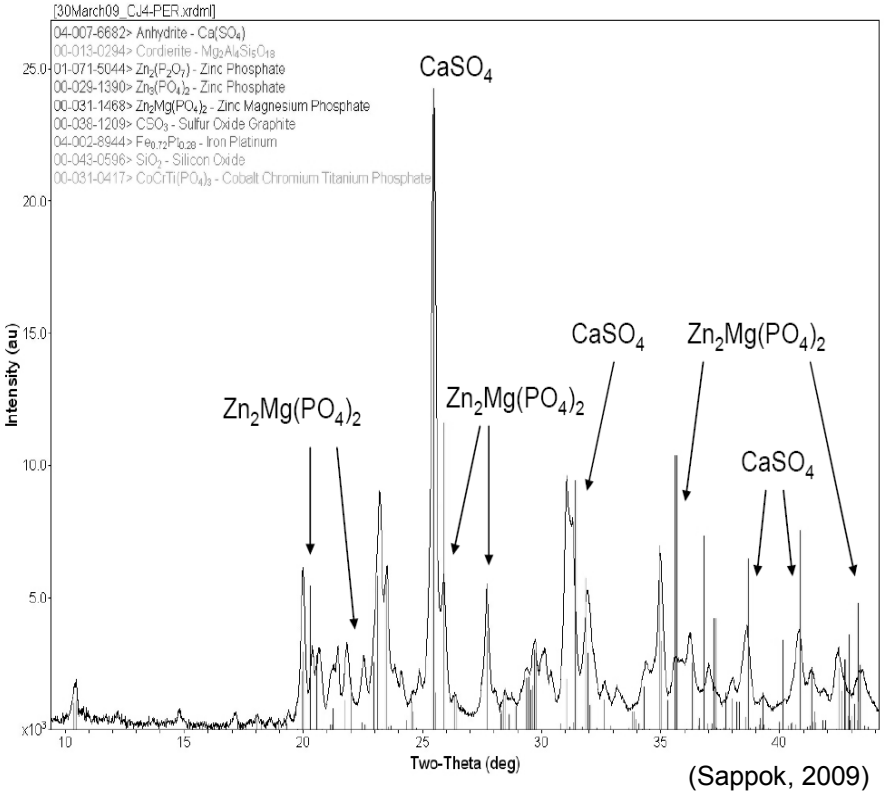
Outlet

(Aravelli, DEER 2006)

Reducing Ash Accumulation in DPF's

- Lubricant additives are the source of most DPF ash:
  - Detergents
  - Zinc Dialkyldithiophosphate (ZDDP)
- Detergents contribute about 75% of ash found in DPF's ($CaSO_4$)
- Lower detergent levels significantly reduces DPF ash

Typical DPF Ash Composition:



(Sappok, 2009)

XRD analysis of DPF ash from a CJ-4 lubricant

Are there any alternatives for additives that do not contribute to DPF ash?

- Strong Base Oil Filter
  - Strong base is anchored in the filter
  - Strong base in filter immobilizes acids
  - Releases nothing
  - Selectively sequesters acids only

- Ashless Antiwear
  - Provides protection from wear without contributing to sulfated ash (ASTM D874)

Test Program

- Long-duration steady-state testing to investigate the potential benefits of filter conditioning with reduced ash oils
- Three long-duration tests:
  - Test 2 – Zero Detergent oil, Strong base filter - 300 hrs
  - Test 3 – Zero Detergent oil, Standard oil filter - 82 hrs
  - Test 1 – CI-4 PLUS oil, Standard oil filter - 318 hrs (Reference)

Test Parameters

Load	100%FP
Speed	1800 rpm
Fuel	15 ppm Sulfur Diesel
Lubricants	1. Experimental Zero Detergent Formulation 2. Fully Formulated (CI-4 PLUS)

Experimental Zero-Detergent Oil Formulation

Description of the Components in the Zero Detergent Oil:

Component	Description
Base Oil	Blend of Americas Core Group I
Detergent	None
Dispersant	PIBSA/PAM (~10% of formulation)
Antiwear	Ashless phosphorus and sulfur containing additives
Additional Corrosion Inhibitors	None

Lubricant Properties

Lubricant Properties:

Property	Zero Detergent	CI-4 PLUS
SAE Grade	15W40	40W
API Gravity	29.1	28.9
Viscosity @ 40°C [cSt]	~	146
Viscosity @100°C [cSt]	15.2	14.9
Sulfated Ash [%] (D874)	0.057	1.35
TBN [mg KOH/g] (D2986)	5.5	10.2

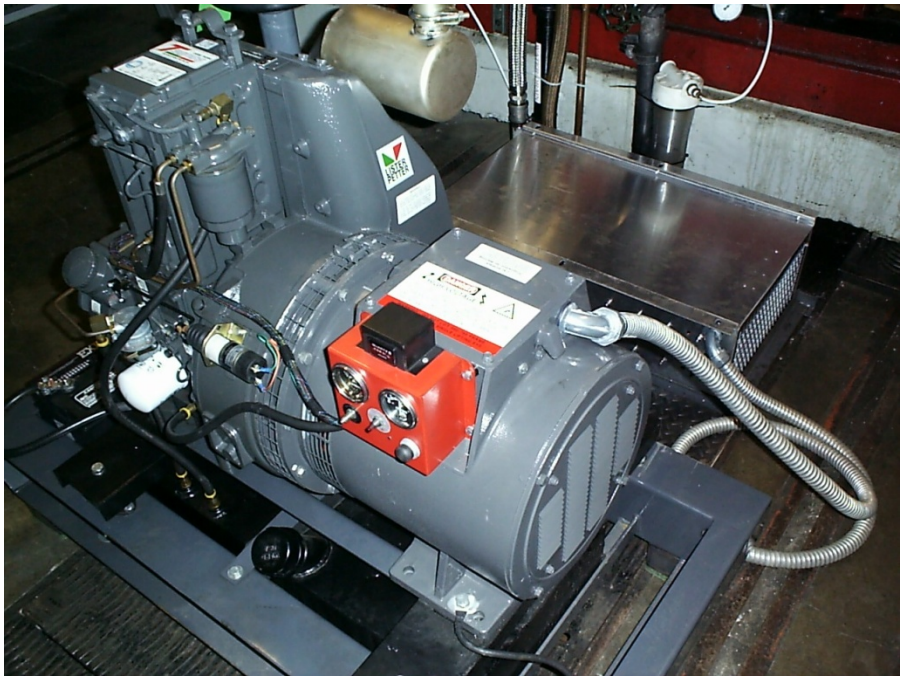
Elemental Analysis (ASTM D4951):

Element	Zero Detergent	CI-4 PLUS
Ca	0	3130
Mg	0	10
Zn	0	1350
P	480	1490

Test Engine

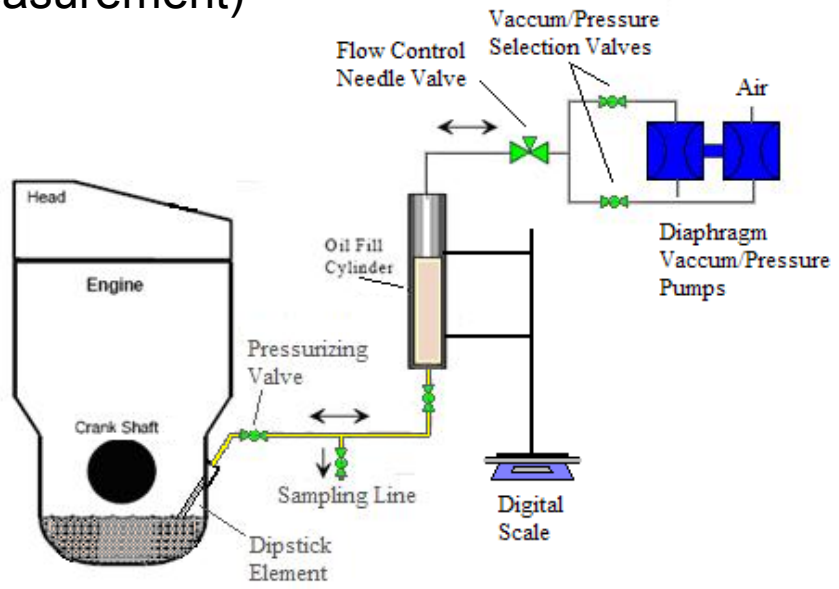
Lister Petter TR1 Generator Set

- Specifications:
  - Single Cylinder
  - Naturally Aspirated
  - Air Cooled
  - No EGR
  - Maximum Power 5.5 kW
  - Direct Fuel Injection
  - Displacement 0.773 L
  - Compression Ratio 15.5:1
  - Sump Capacity 2.4 L

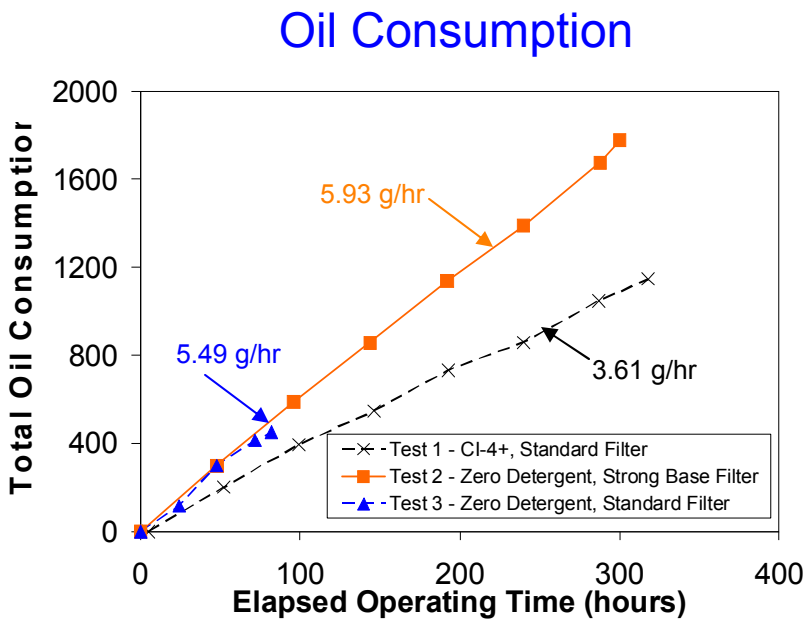


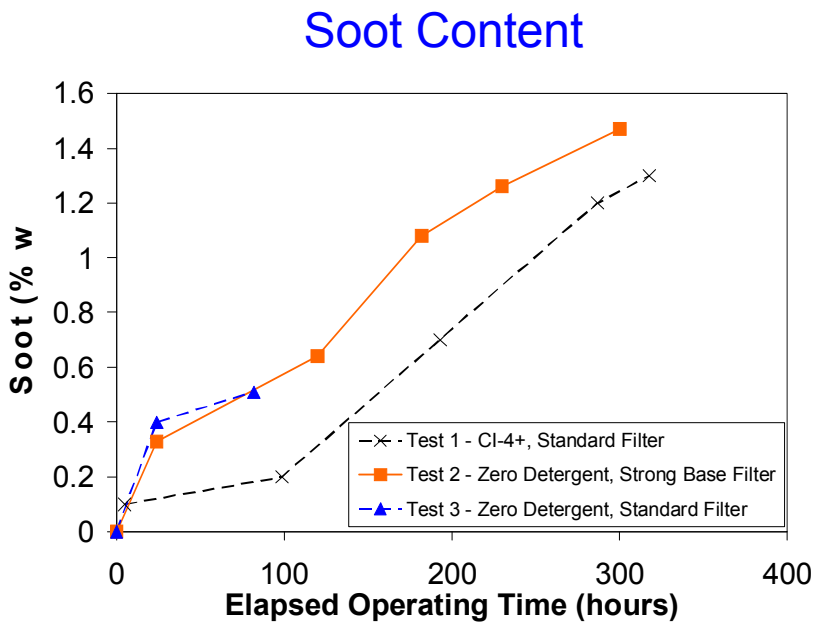
Test Procedure

- Lubrication system cleaned with triple flush between tests
- Routine maintenance performed every 24 hours
- Parameters measured every 24 hours:
  - Oil Consumption (oil mass measurement)
  - Fuel Consumption
  - Oil Temperature
- Crankcase oil samples extracted every 48 hours:
  - For Tests 1 - ~17 g
  - For Tests 2 and 3 - ~38 g
  - Samples are extracted through the dipstick opening



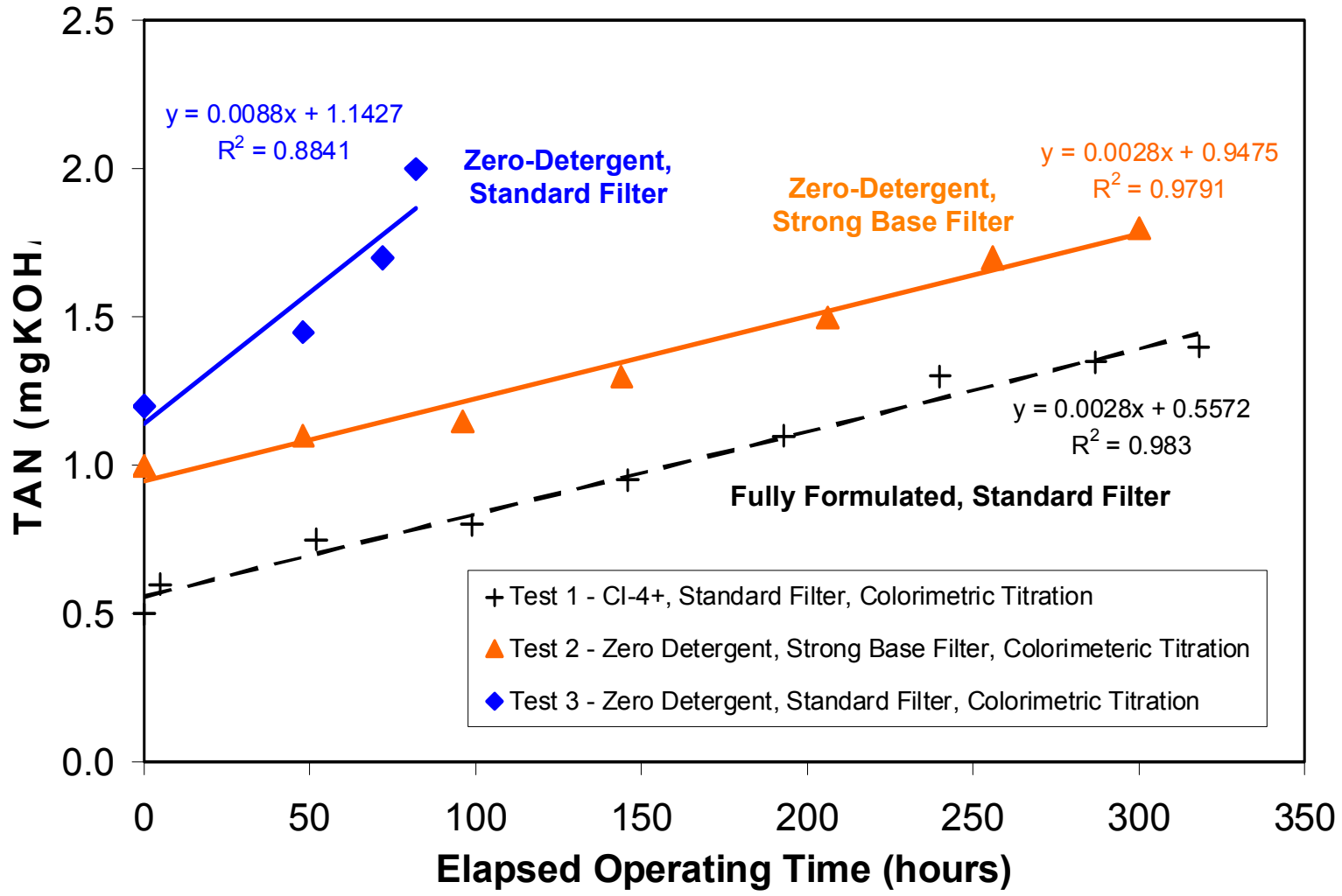
Oil Consumption and Soot Contamination



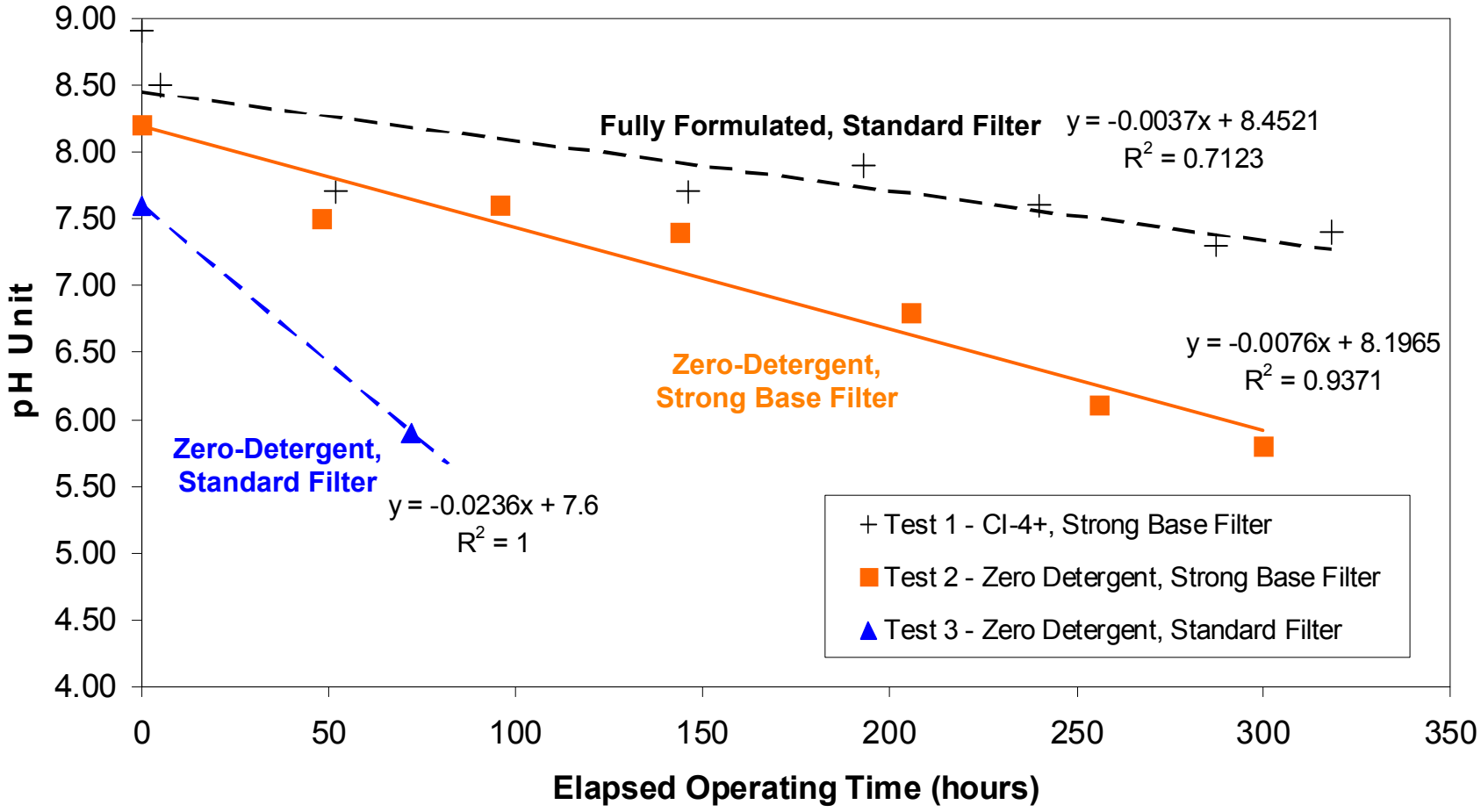


- Mean oil temperatures of tests are equal
- Mean fuel consumption of tests are equal

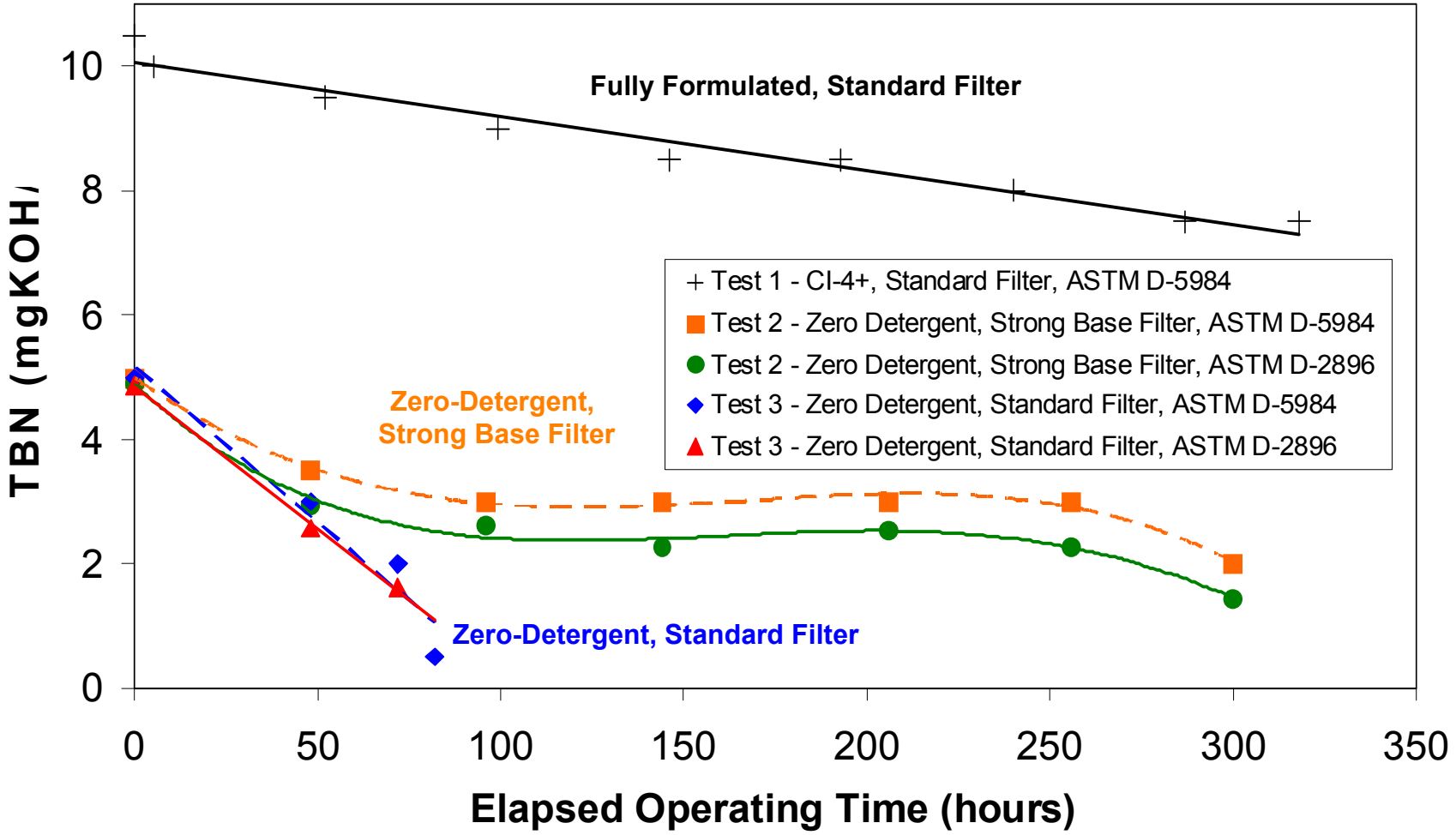
Total Acid Number



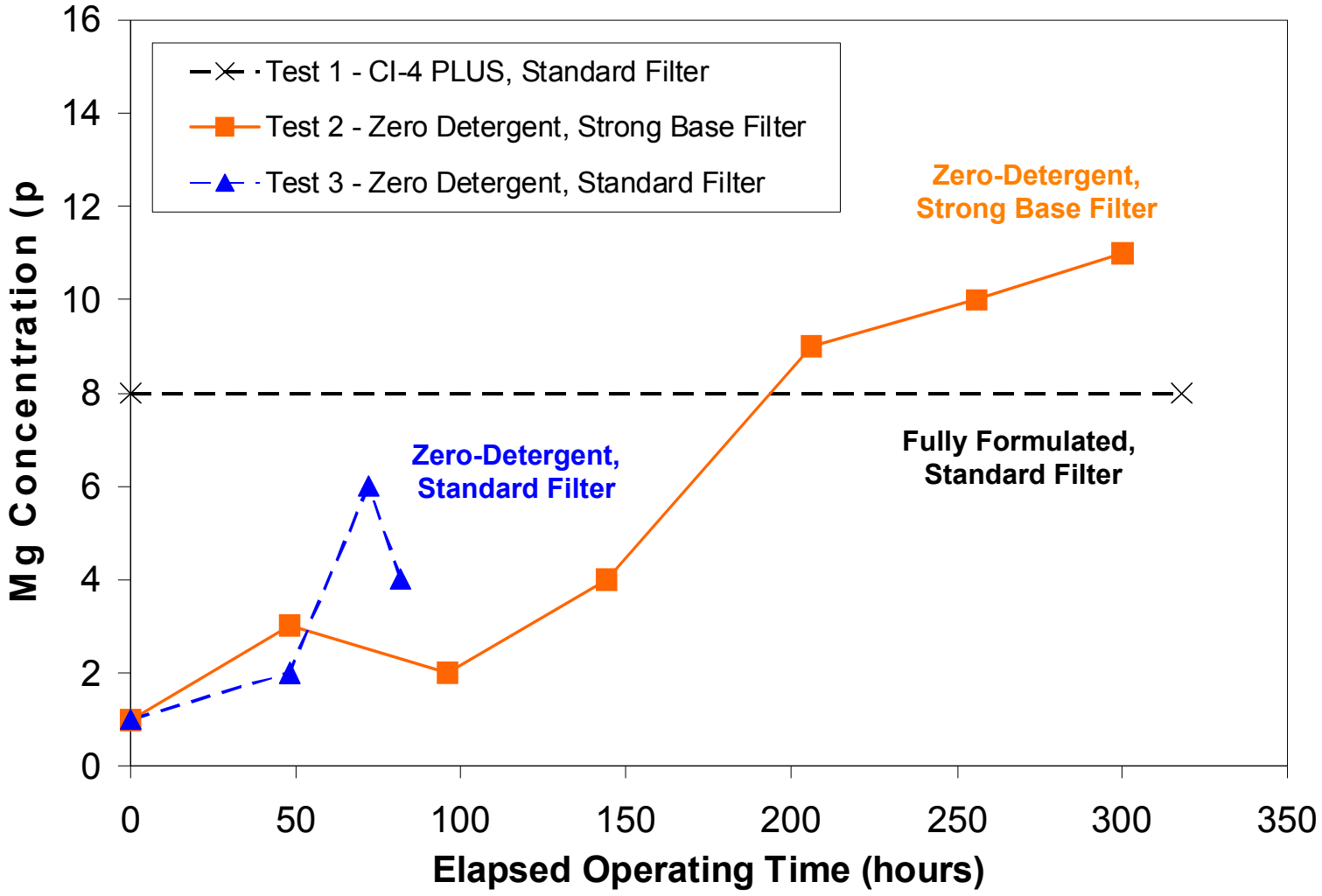
Lubricant Acidity



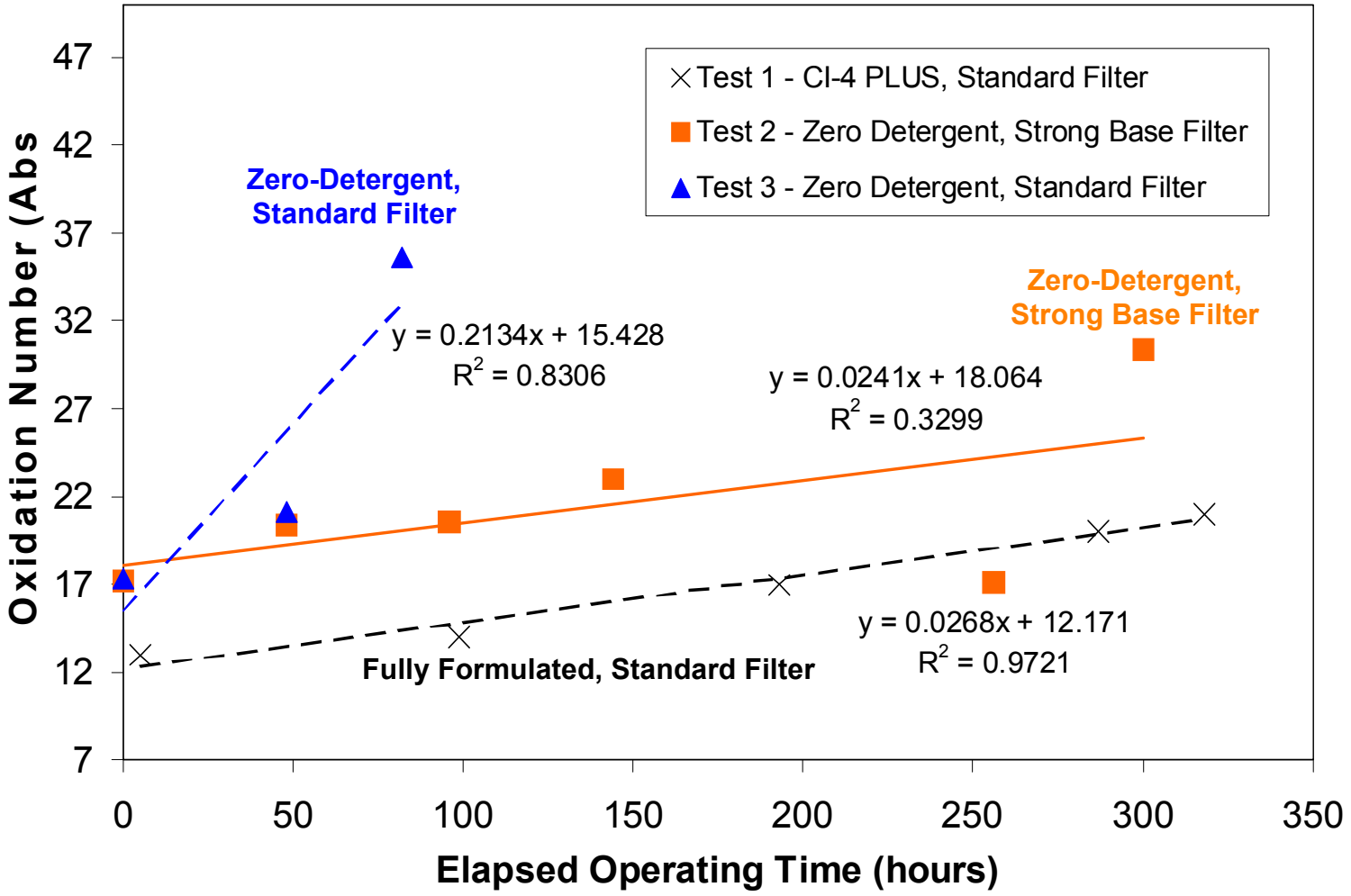
Total Base Number



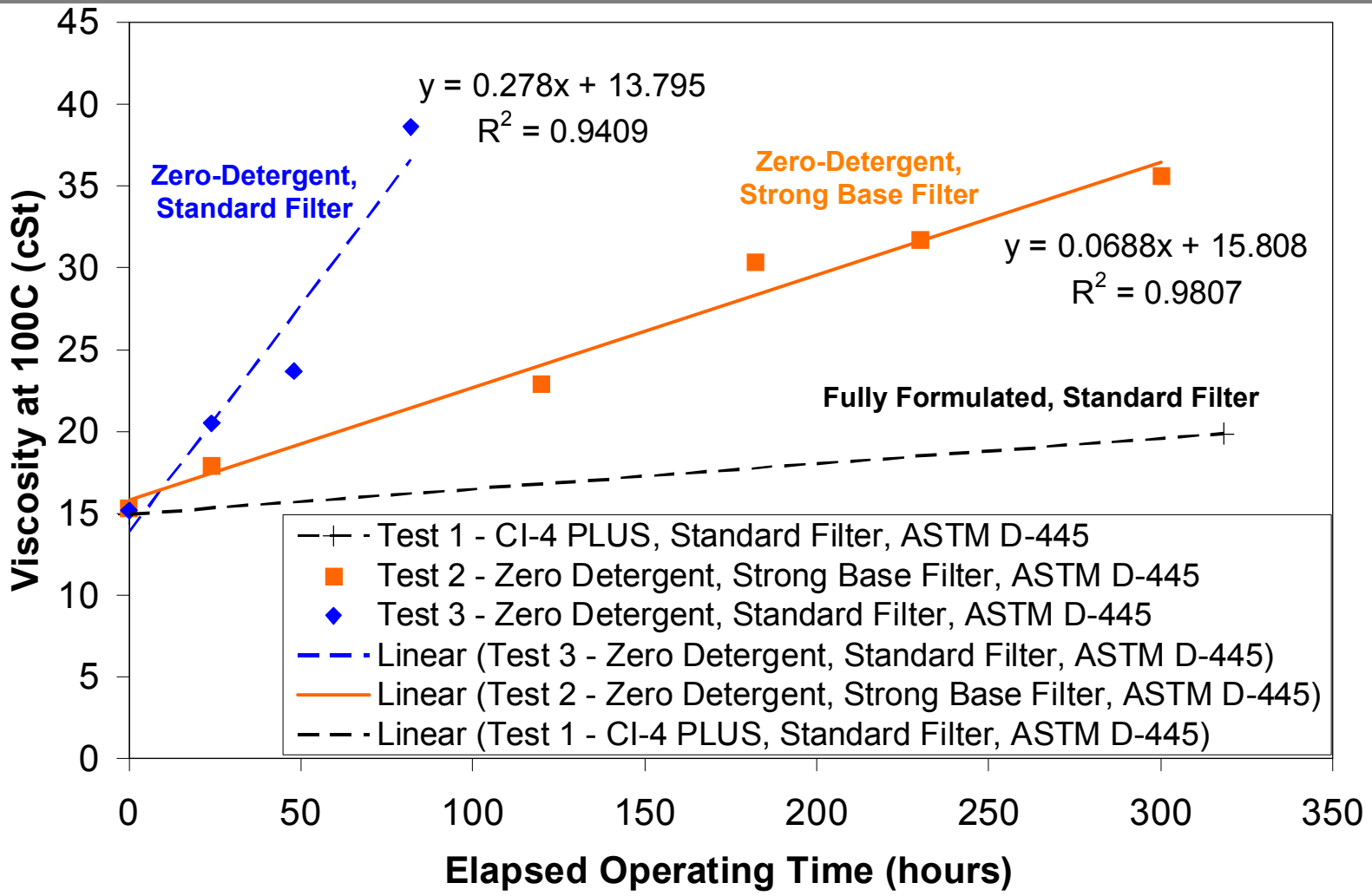
Magnesium Concentration



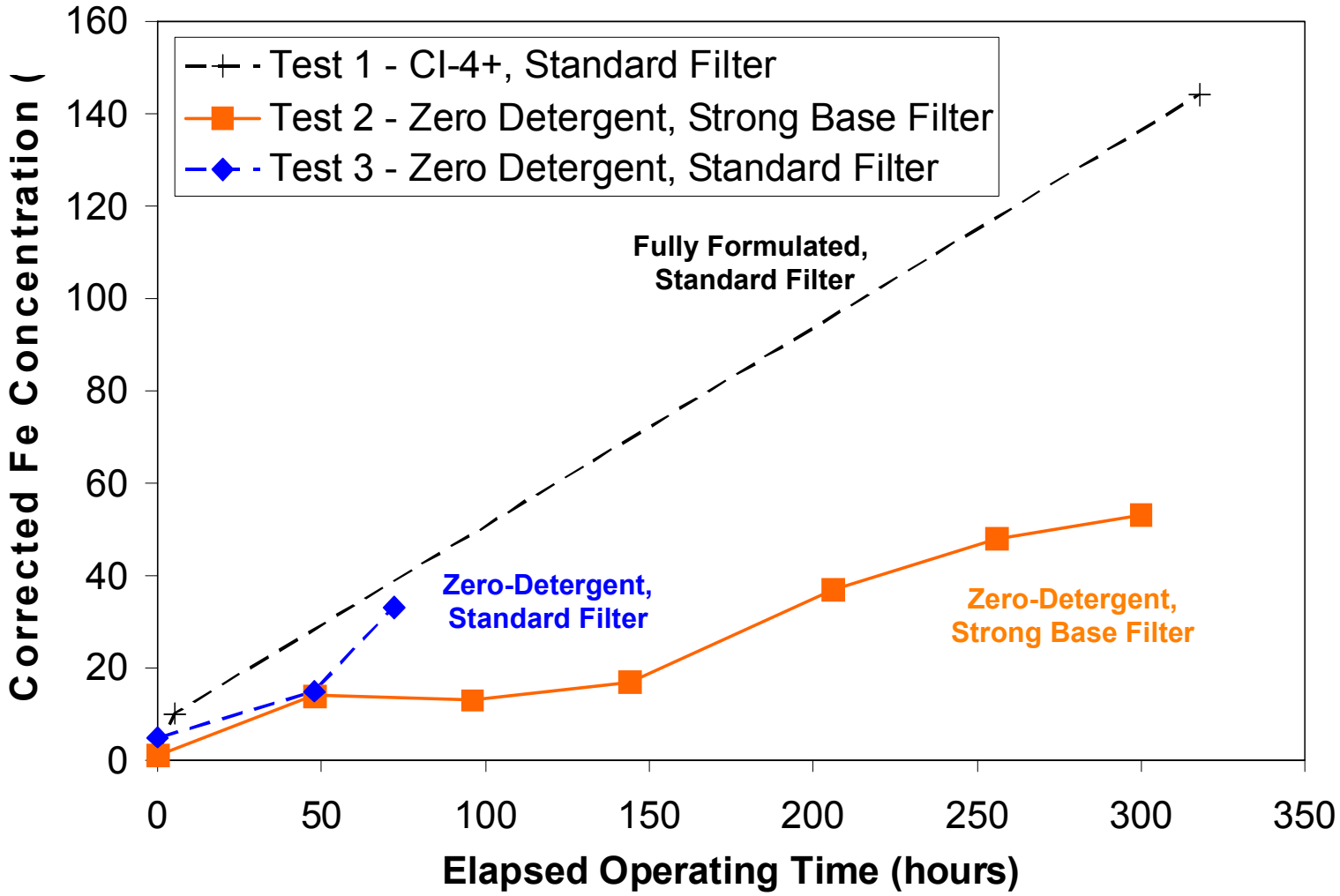
Oxidation


Test 1 - CI-4 PLUS, Standard Filter
Test 2 - Zero Detergent, Strong Base Filter
Test 3 - Zero Detergent, Standard Filter
Zero-Detergent, Standard Filter
y = 0.2134x + 15.428
R2 = 0.8306
Zero-Detergent, Strong Base Filter
y = 0.0241x + 18.064
R2 = 0.3299
Fully Formulated, Standard Filter
y = 0.0268x + 12.171
R2 = 0.9721
Oxidation Number (Abs
47
42
37
32
27
22
17
12
7
0
50
100
150
200
250
300
350
Elapsed Operating Time (hours)

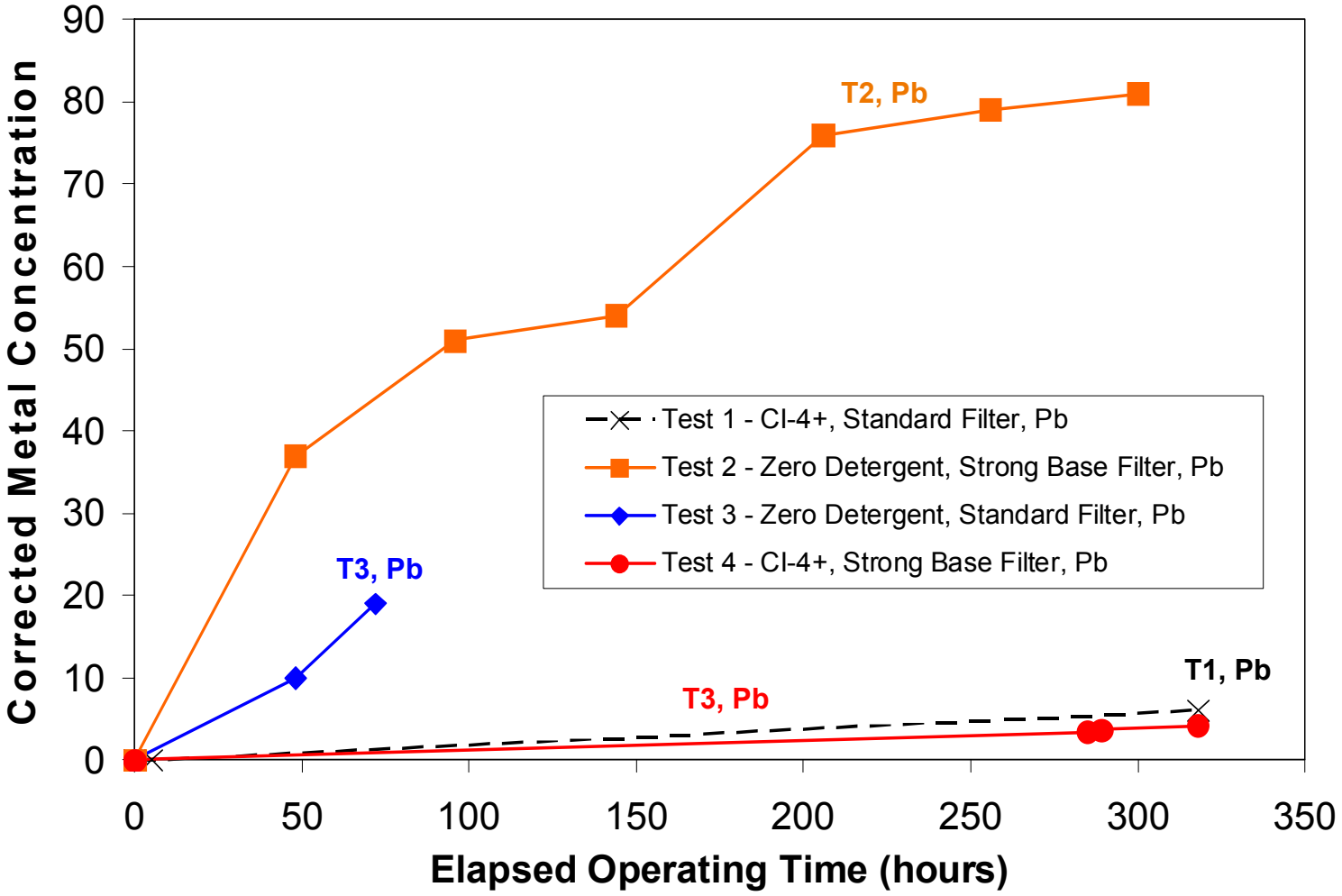
Viscosity


y = 0.278x + 13.795
R2 = 0.9409
Zero-Detergent, Standard Filter
Zero-Detergent, Strong Base Filter
y = 0.0688x + 15.808
R2 = 0.9807
Fully Formulated, Standard Filter
Test 1 - CI-4 PLUS, Standard Filter, ASTM D-445
Test 2 - Zero Detergent, Strong Base Filter, ASTM D-445
Test 3 - Zero Detergent, Standard Filter, ASTM D-445
Linear (Test 3 - Zero Detergent, Standard Filter, ASTM D-445)
Linear (Test 2 - Zero Detergent, Strong Base Filter, ASTM D-445)
Linear (Test 1 - CI-4 PLUS, Standard Filter, ASTM D-445)
Viscosity at 100C (cSt)
0
5
10
15
20
25
30
35
40
45
0
50
100
150
200
250
300
350
Elapsed Operating Time (hours)

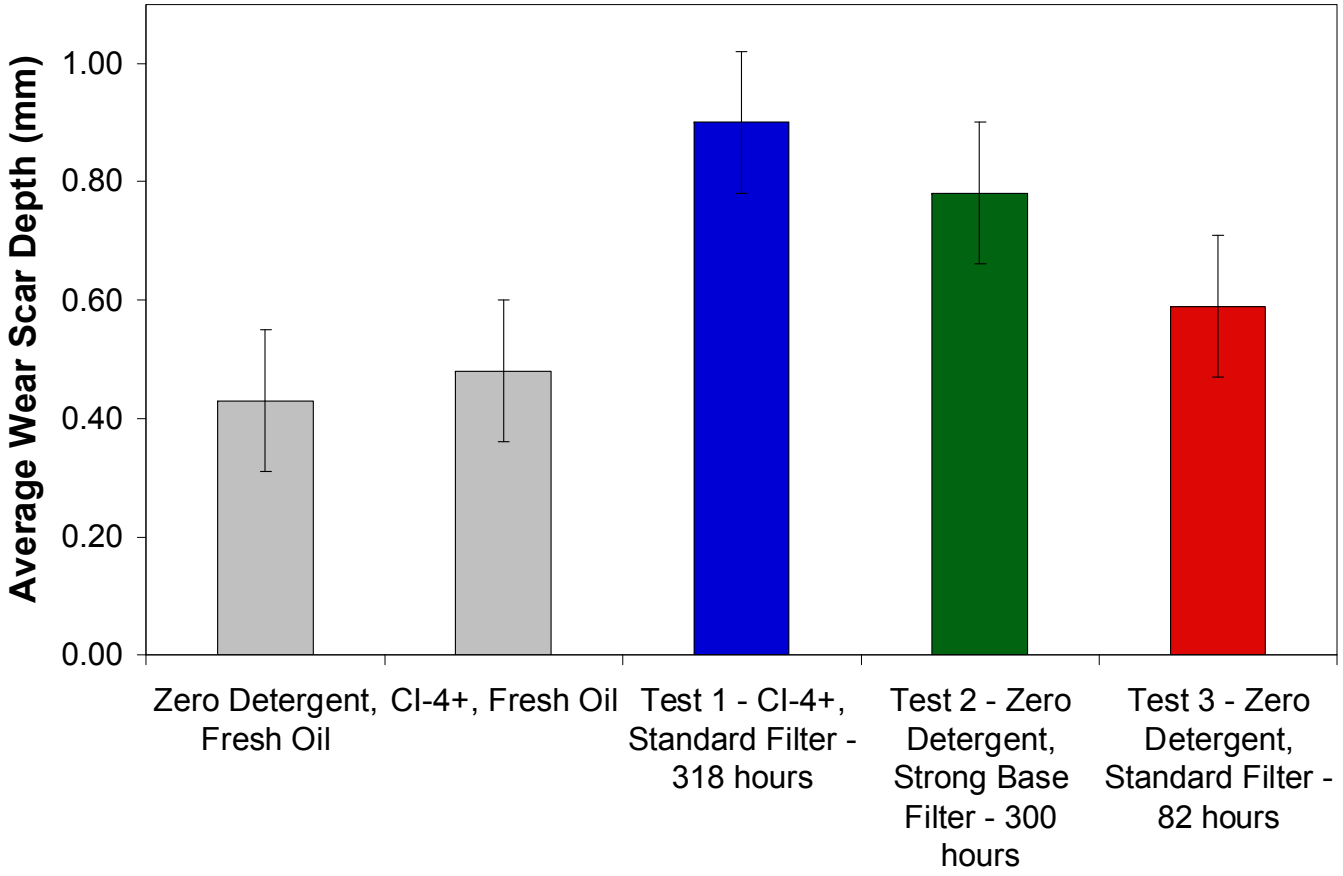
Engine Wear


Test 1 - CI-4+, Standard Filter
Test 2 - Zero Detergent, Strong Base Filter
Test 3 - Zero Detergent, Standard Filter
Fully Formulated, Standard Filter
Zero-Detergent, Standard Filter
Zero-Detergent, Strong Base Filter
Corrected Fe Concentration (
Elapsed Operating Time (hours)
0
20
40
60
80
100
120
140
160
0
50
100
150
200
250
300
350

Bearing Wear Metals



Four Ball Wear Tests



Conclusions

- Under the test conditions used in this study, the strong base filter had a significant and beneficial effect on the rate of oil degradation
- The strong base filter reduced lubricant acidity by absorbing acidic contaminants in the lubricant
- The filter performs an acid control function similar to that provided by over-based detergents, when used with a zero-detergent oil
- The zero-detergent oil (formulated with ashless antiwear additives) and the CI-4 PLUS oil provide similar levels of wear protection after aging with the strong base filter.
- With more development, it may be possible use a zero detergent oil in combination with a strong base filter; providing adequate engine protection while minimizing lubricant ash effects on aftertreatment systems

Acknowledgements

This research is supported by the *MIT Consortium to Optimize Lubricants and Diesel Engines for Robust Emission Aftertreatment Systems*

We thank for the following organizations/companies for their support:

- Department of Energy – *Vehicle Technologies Program*
- Caterpillar
- Chevron
- Ciba Specialty Chemicals
- Cummins
- Detroit Diesel
- Komatsu
- Lutek LLC.
- Sud-Chemie
- Valvoline
- *Ford*