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Lubricant Formulation and Consumption Effects on Diesel Exhaust Ash Emissions:

Measurements and Sample Analyses From a HD Diesel Engine

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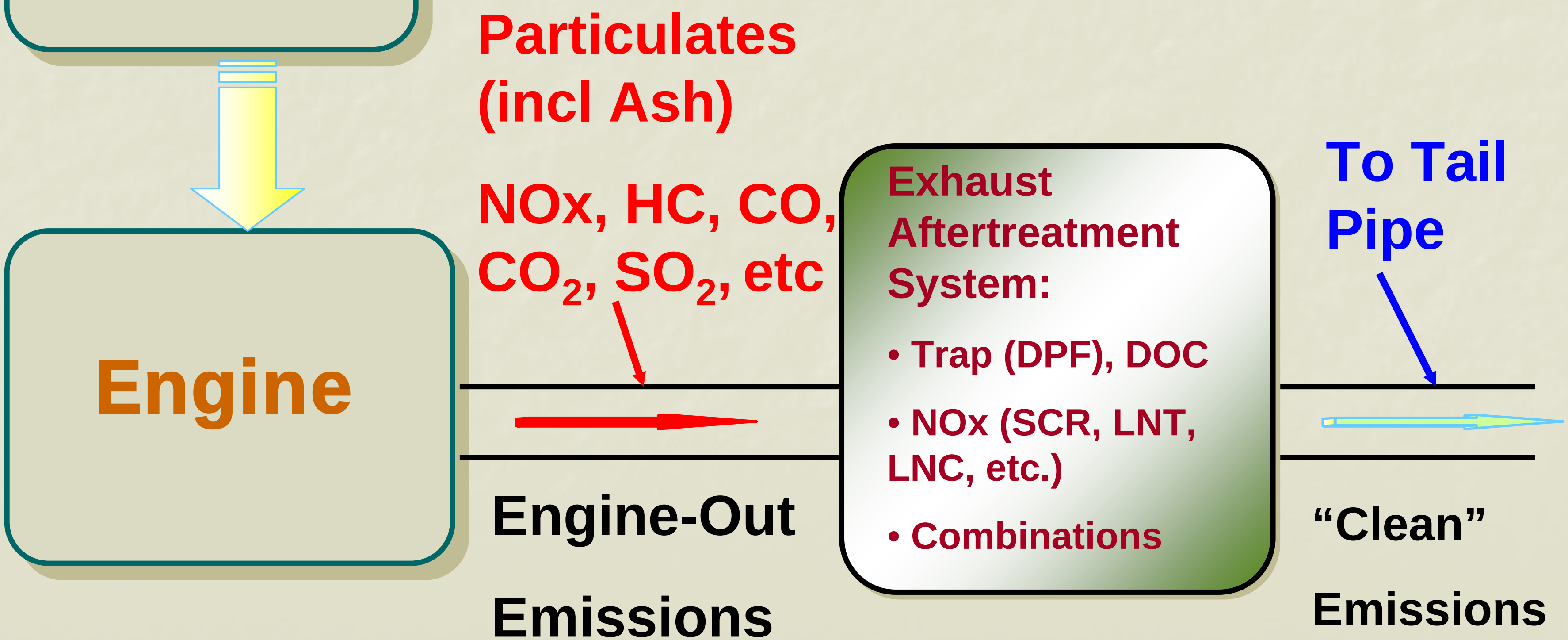
Motivation and Project Objective

- Motivation
  - DPF fouling by incombustible ash
  - Detrimental chemical and/or physical effects of ash-related compounds on DPT/DPF catalysts
- Objective
  - To determine the effects of lubricant based sulfur and ash-related compounds on particulate emissions
  - To correlate lube-oil consumption and composition to emissions of ash-related species using a rapid test method

Motivation

- DPF fouling by Ash
- Detrimental chemical effects of ash-related compounds on DPT/DPF catalysts may occur

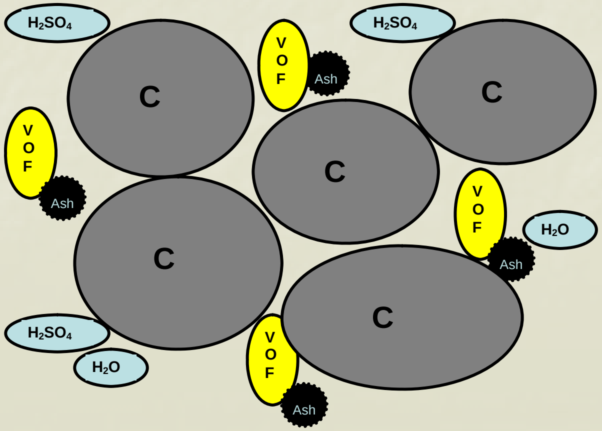


Slide courtesy of Dr Victor Wong

Diesel Particulate Ash

- Not specifically defined
  - ASTM E2403, ASTM 874, D482
  - Regeneration techniques vary

- Composition not fully understood
  - Lubricant metallics a major contributor
  - Sulfated Ash increase= Exhaust Ash increase
  - Engine wear may contribute
  - Sulfur effects



Test Equipment

ENGINE

- MY 2002 Cummins ISB 300
  - 5.9L inline 6 cyl
  - Holset variable geometry turbocharger (VGT)
  - Bosch common rail fuel injection
  - Cooled exhaust gas recirculation (EGR)

Test Equipment

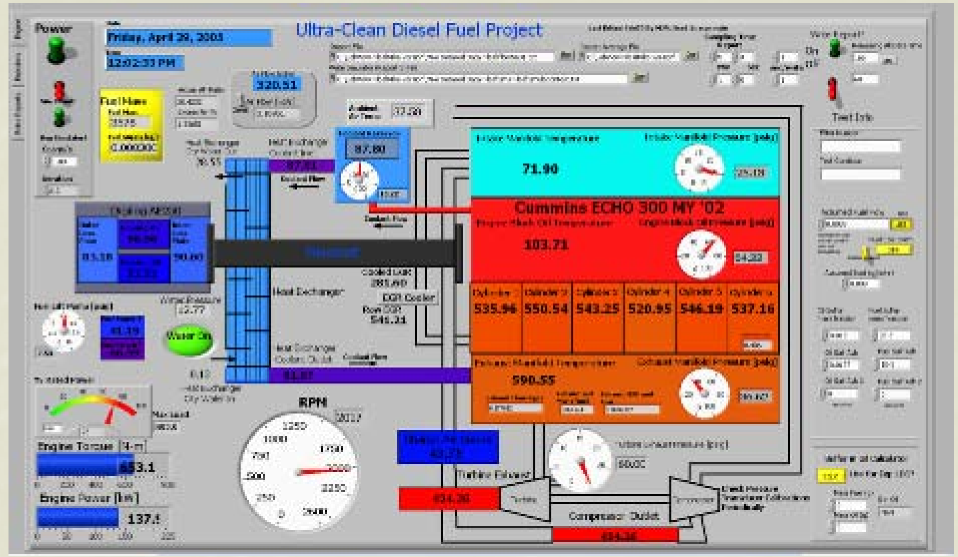
Gas Analysis

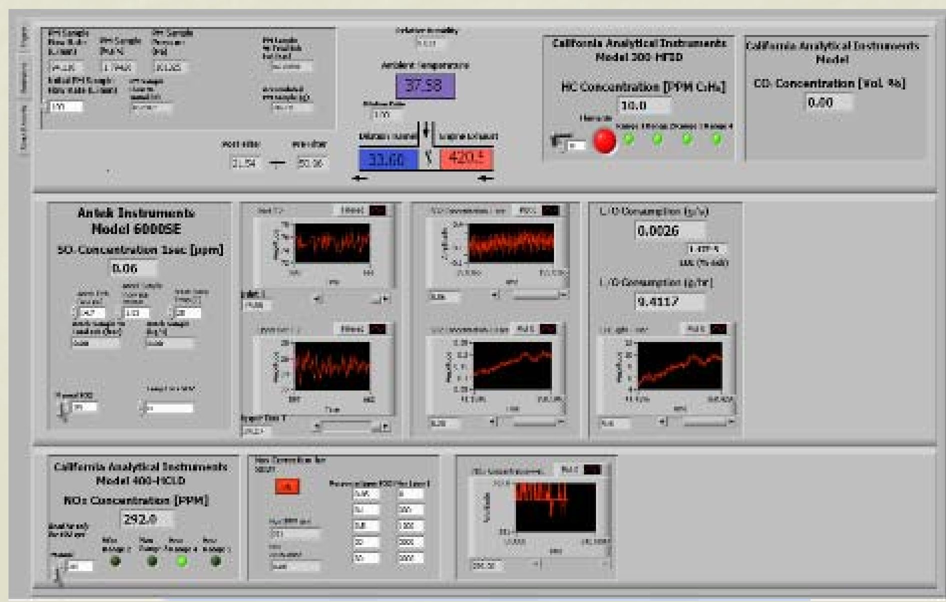
- Antek SO_2 analyzer
- CAI Gaseous Emissions Analyzers
  - 400 HCLD – NO/NOx
  - 300 HFID – Hydrocarbons
  - 602P NDIR – $CO/CO_2/O_2$

Test Equipment

Electronic Controls

- ❑Calterm II v 7.63
- ❑ECM v. 850
- ❑Extensive DAQ

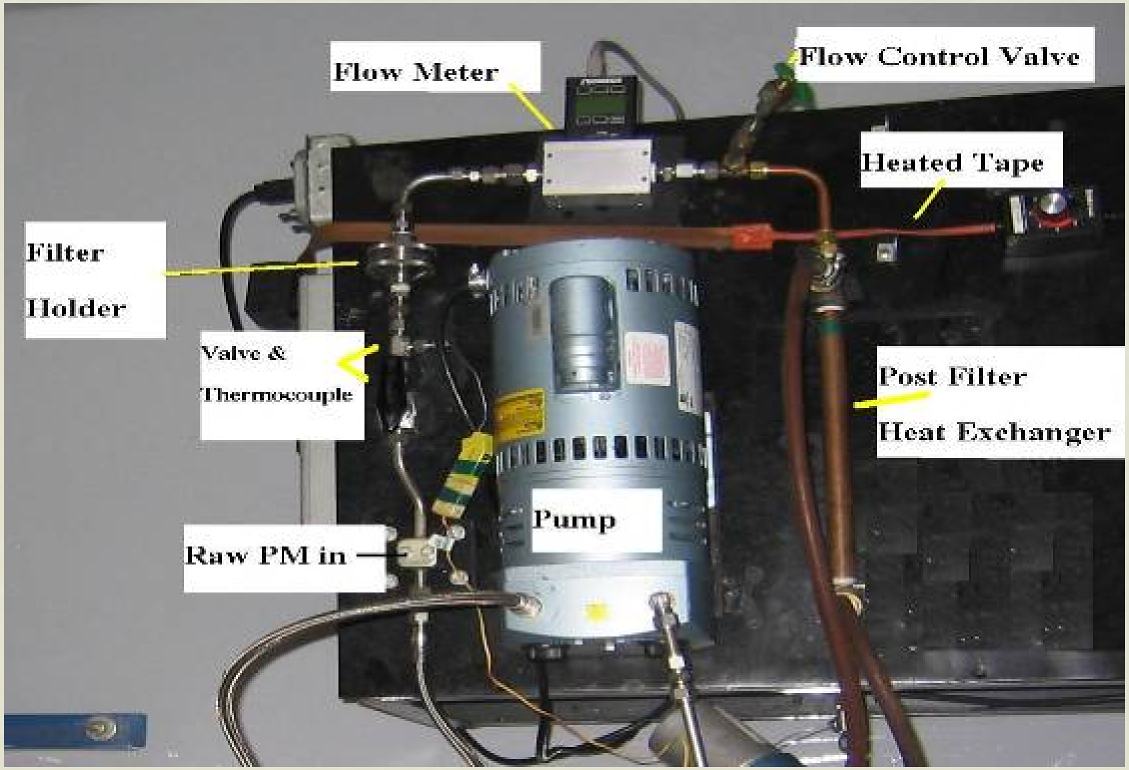




Test Equipment

Particulate Collection

- Borosilicate glass fiber filters
- Quartz fiber filters
- PTFE filters
- Sampled undiluted @ 50 to 70 deg C
- Filters conditioned in controlled environment



Test Equipment

Thermogravimetric analysis:

- VOF
- Ash

Limited elemental & molecular identification:

- X-ray diffraction
- X-ray fluorescence
- Gas chromatography
- X-ray photoelectron spectroscopy

Lubricants and Fuels Tested

Lubricants:

- Low Sulfur/Low Sulfated Ash
  - 0.35% Sulfur
  - 1.0% ash by supplier (1.14% by independent lab ASTM 482, 1.1% MIT TGA)
- High Sulfur/High Sulfated Ash
  - 1.45% Sulfur
  - 1.8% ash by supplier (1.65% MIT TGA)

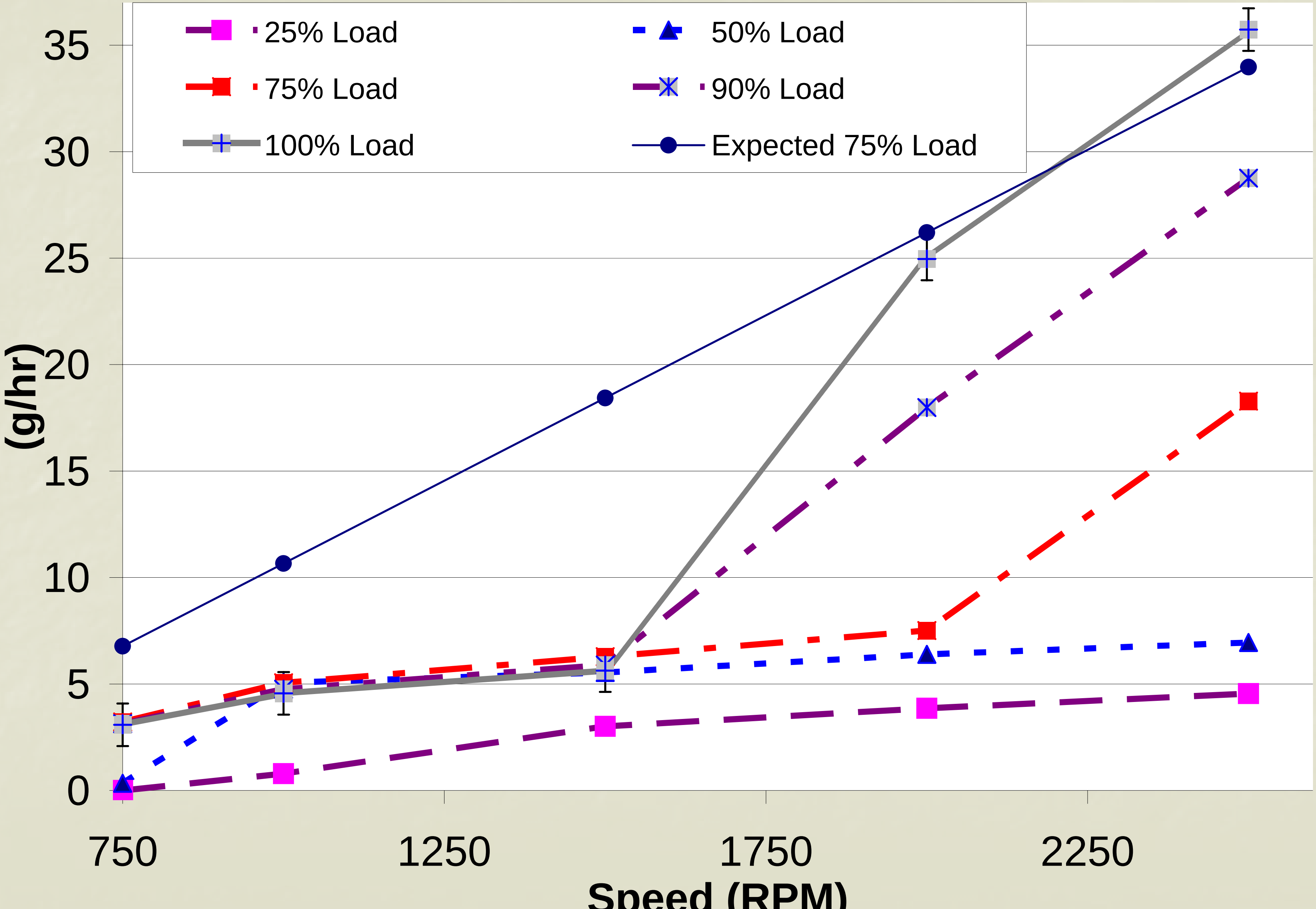
Fuels:

- Syntroleum Fischer-Tropsch (FT) Diesel - zero sulfur content
  - Comparison to 15ppm & 400ppm Low Sulfur diesel conducted at MIT

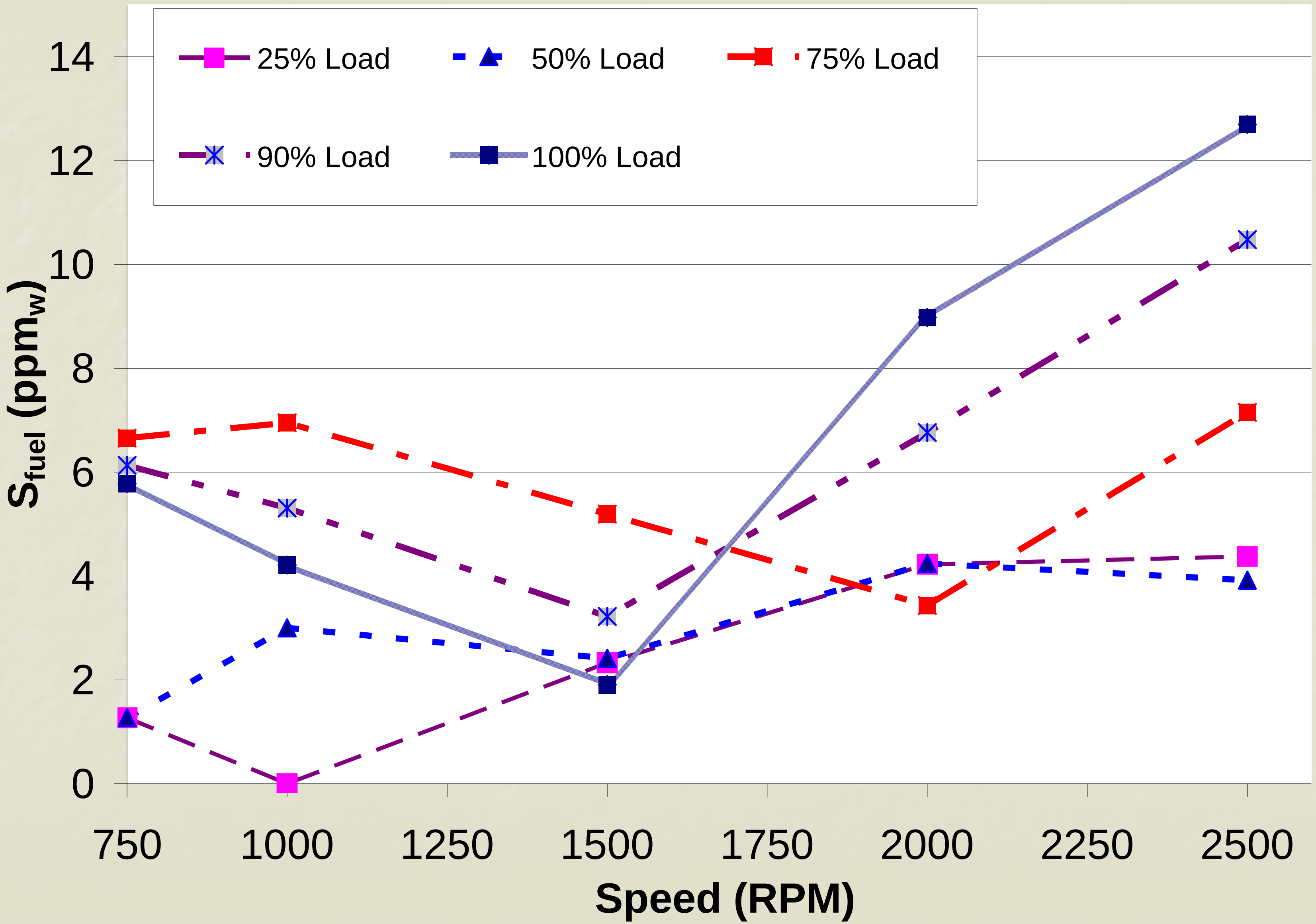
Engine Operating Conditions:

- Based on Euro-III 13 Mode Test
  - Subset chosen to represent realistic operating conditions
  - A50 (1680 RPM), B75 (2000 RPM), C75 (2345 RPM)

Results: Oil Consumption

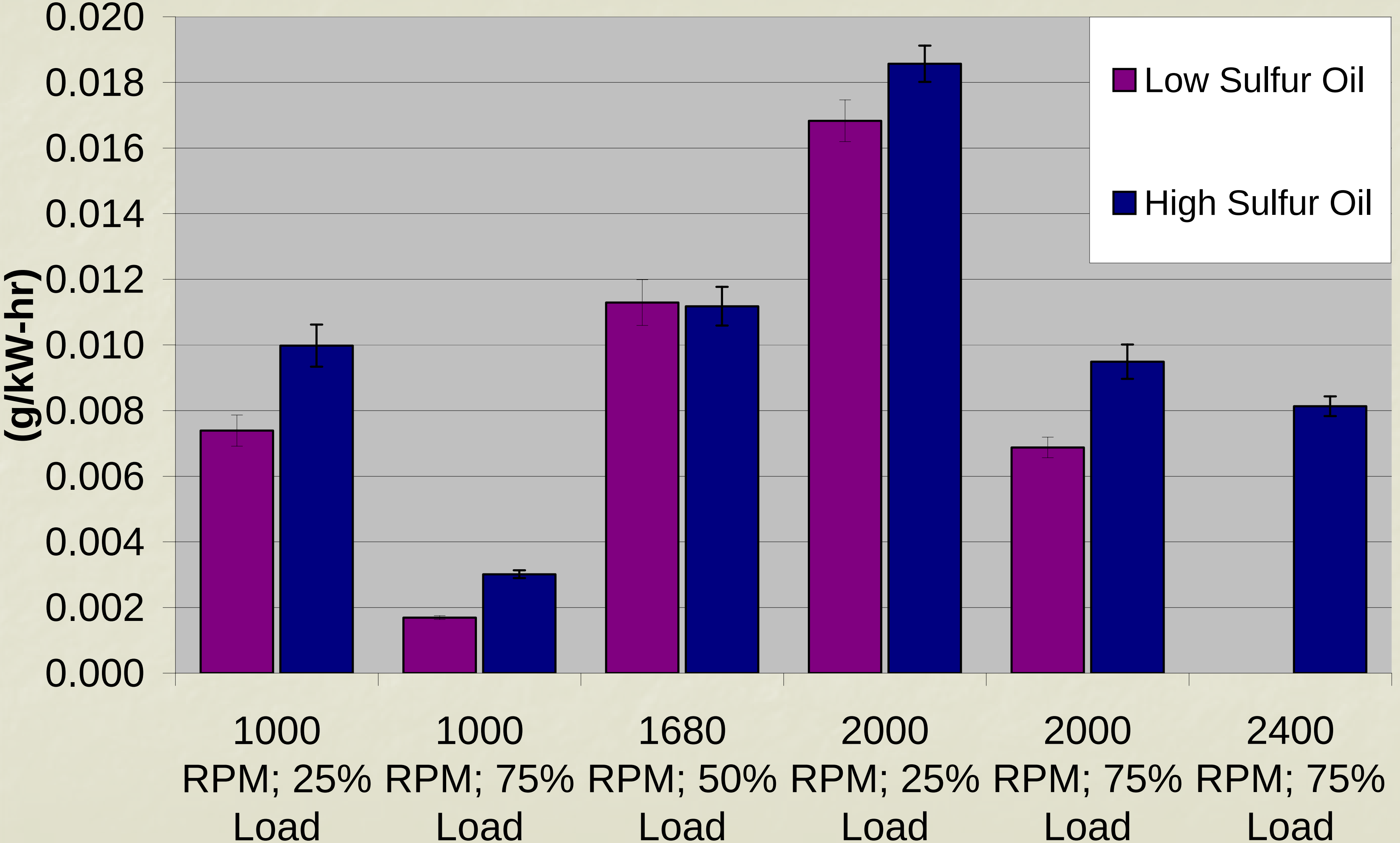


Results: Oil Derived SO_2

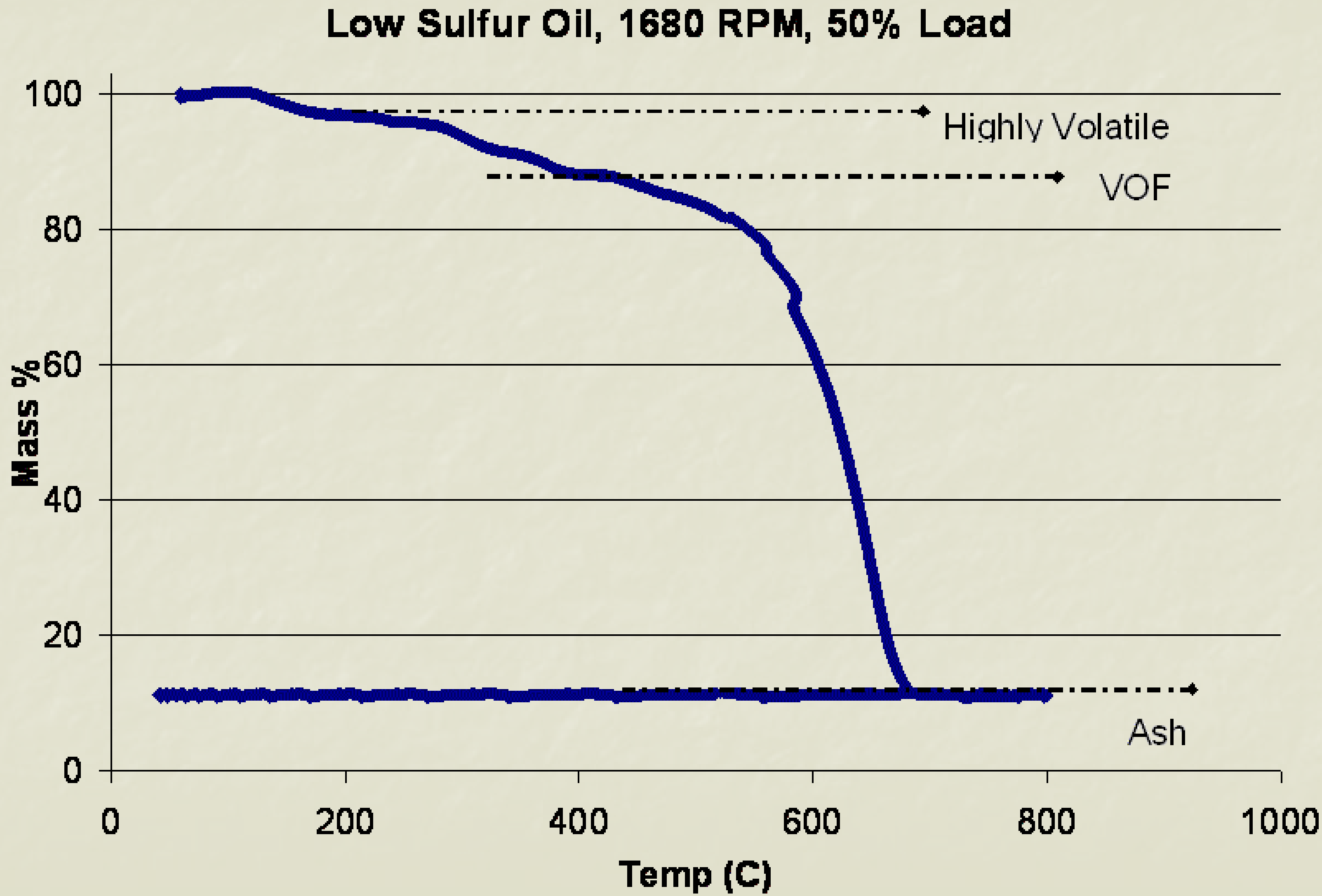


SO_2 exhaust levels measured w/ 1.5% Sulfur Oil and Zero Sulfur Fuel. Typical oil is only .5% S

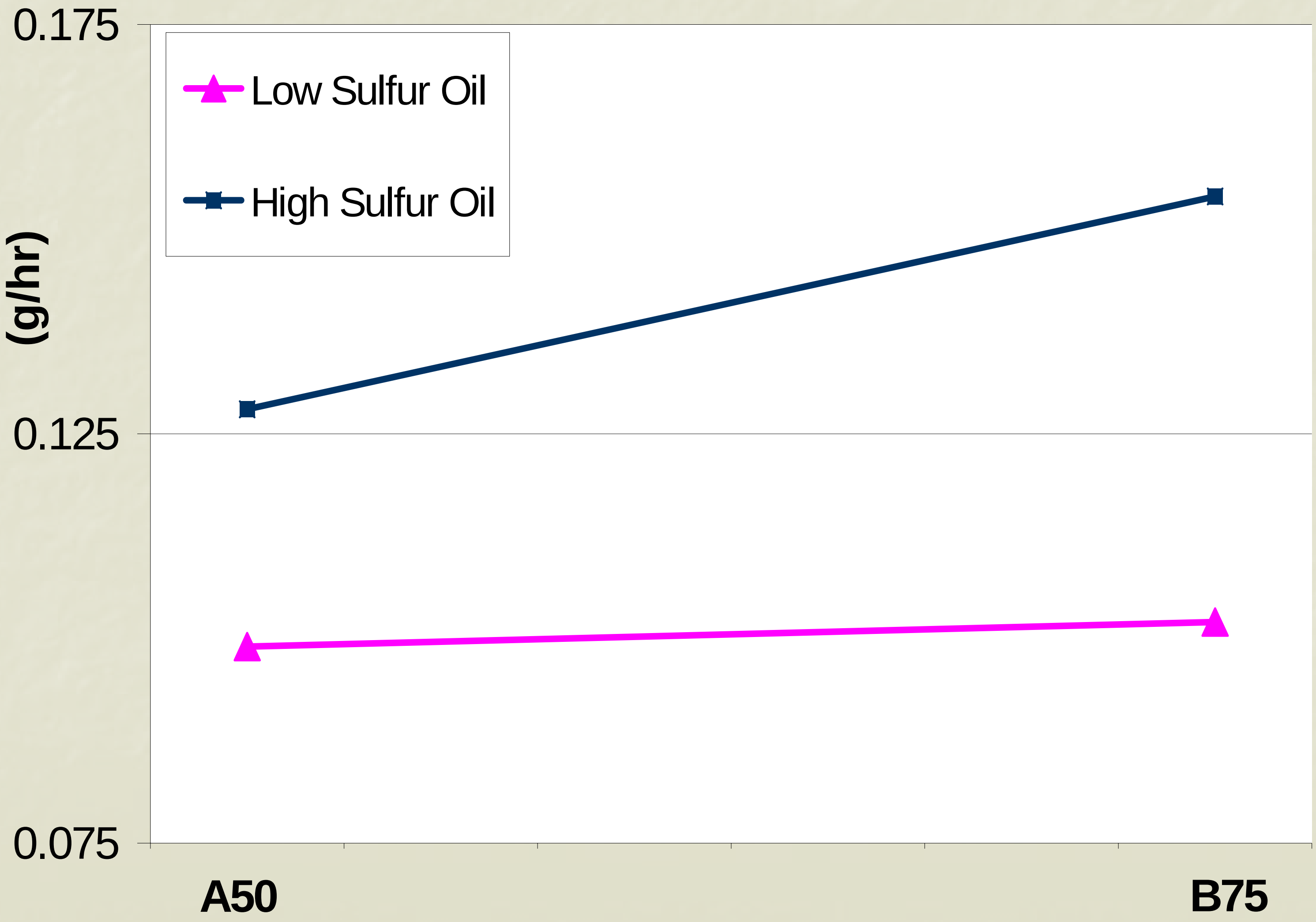
Results: PM Emission vs. Oil Chemistry



Test Method: TGA VOF & Ash



Results: Ash Emission vs Oil Sulfated Ash content



Results: Raw PM, LOC, Ash

Test Condition	Lubricant	Raw PM (g/kw-hr)	LOC (g/hr)	Ash (g/hr)
A50	Low S	.011	5.8	.099
A50	High S	.011	5.8	.128
B75	Low S	.007	7.5	.102
B75	High S	.010	7.5	.154
C75	High S	.008	12.5	.328

(Each test utilized FT fuel)

Preliminary Advanced Results: Raw PM, LOC, Ash

Test Condition	Condition	Raw PM (g/kw-hr)	LOC (g/hr)	Ash (g/hr)
A50	FT Fuel, Low S lubricant	.011	5.8	.099
A50	FT Fuel, High S lubricant	.011	5.8	.128
A50	FT Fuel doped w/ .2% L/O	.009	36.0	.124
A50	FT fuel, gasket material on sample	.011	5.8	.143
A50	High S Fuel*	.010	7.5	.173
A50	H_2SO_4 doped PM prior to TGA	.010	7.5	.173

(* test utilized Low S lubricant, all others High S)

Conclusions

- Use of FT fuel increases effectiveness of SO_2 tracer technique
- High Sulfur/Sulfated Ash oil contributes to PM increase
- Increased lubricant sulfated ash content and/or oil consumption contributes to increase of ash
- High ash capture rates and preliminary advanced results suggest additional potential sources of ash including:
    - Sulfur contribution
    - Metallics
    - Chemical structure of sulfate or sulfated metallics

Acknowledgements

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Questions...