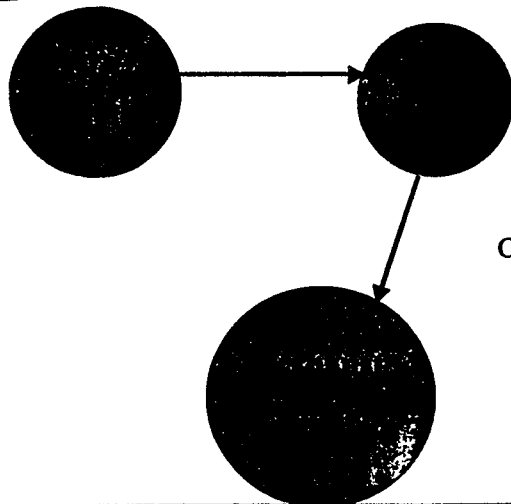


# Lube Oil Contribution to Emissions

W. S. Key  
Oak Ridge National Laboratory

# Emerging Issues



Oak Ridge National Laboratory  
W.S. Key  
Thang Dam  
John M. Storey  
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## Motivation – Future Changes Will Elevate the Importance of Lube Oil

- Further Tightening of Heavy Duty Regulations
  - Might Expect Convergence to Light Duty Regulations
- Regulation of Currently Unregulated Toxic Emissions (PAH's, etc.) and regulation of Ultrafine Particulates
- Modifications to the Engine:
  - EGR
  - High Pressure Injection
  - Addition of PCV to Heavy Duty Engines
- More Complex (and perhaps more sensitive) Emission Controls
- Evolution of Fuel & Lube Formulations Changing the Lube/Fuel Combustion Chemistry

## Motivation

- Studies to Date Are Sparse, Contradictory, or Lack Consistency
  - Northern Front Range Air Quality Study
    - Suggested That High Emitter Vehicles Had High Contributions to PM From Lube
  - "Preliminary Indications Are That the Nuclei Mode Particles Are Solid and Formed From...metallic Ash From Lubrication Oil Additives."
    - (Abdul-Khalek, et.al., SAE 980525)
  - Ultrafines Have No Solid Core Downstream of EC Devices
    - (Luders, et.al., [FEV], SAE 981374)
- Lube Oil Contribution to Exhaust is 3 – 7 ppm Fuel Equivalent
  - (DECSE)
- Lube Oil Contribution of Exhaust is ~20 ppm Fuel Equivalent
  - (Nigel Clark per Schaberg, SAE 972898)

## Issues

- What is Lube Oil's Contribution to: PM/SOF/NO<sub>x</sub>/Sulfur?
- How Does Lube Oil Formulation Change the Contribution to Emissions
  - Viscosity
  - Additives
  - Sulfur
- What is the Range of Change of Contributions to Emissions?
- What Effect Do Lube Oil Emissions Have on EC Devices
- **Will Lube Oil Need to be Reformulated?**



## Additional Issues

- What is Lube Oil's Contribution to Solid Core Ultrafines?
- How Does Lube Oil Formulation Affect the Contribution to Unregulated Toxic Emissions?
- How is the Contribution Affected by Fuel Formulation?
- How do Transient Operations Affect Lube Oil Contributions?
- **Will Lube Oil Need to be Reformulated?**

## Contributing Constituents

- Hydrocarbons
- Sulfur
  - Base Stock
  - Zinc Dithiophosphate
- Detergents
- Lubricity Agents
  - Zinc (ZDDP)
  - Calcium
  - Magnesium
- Anti Wear, pH Neutralizers, etc.

## Volatiles

- Much of Past Work Has Been With SI Engines – Probably Not Relevant to Diesel Because:
  - SI Has Lower Compression
  - Fuel More Volatile
- Studies Indicate That Consumed Lube Oil Is Emitted as Volatiles
- Lube Oil is a Greater Source of PAHs (SAE 940342)

## Particulates - Sulfur

- Lube Oil Sulfur Can Become the Dominant Source of the Sulfur in the Exhaust as Fuel Sulfur Declines, Thus:
  - May Become the Principal Source of Catalyst Poisoning or Deactivation
  - May Become the Principal Source of Particulate Sulfates

## Particulates – Ash and Metals

- Ash and Metals Can Coat EC Devices Reducing the Number of Active Sites and Reducing Performance
- Are There Metal Constituents Which Could be Subject to Regulation?



# Metals for Potential Regulation

## EPA's and ARB's Air Toxics Lists

### EPA Mobile Source HAPs

Acetaldehyde  
 Acrolein  
 As compounds  
 Benzene  
 1,3 Butadiene  
 Cr compounds  
 Dioxin/Furans  
 Diesel PM  
 Styrene  
 Ethylbenzene  
 Formaldehyde  
 n-Hexane  
 Lead Compounds

Mn compounds  
 Hg compounds  
 MTBE  
 Naphthalene  
 Ni compounds  
 POM as 7 PAHs  
 Propanal  
 Toluene  
 Xylene

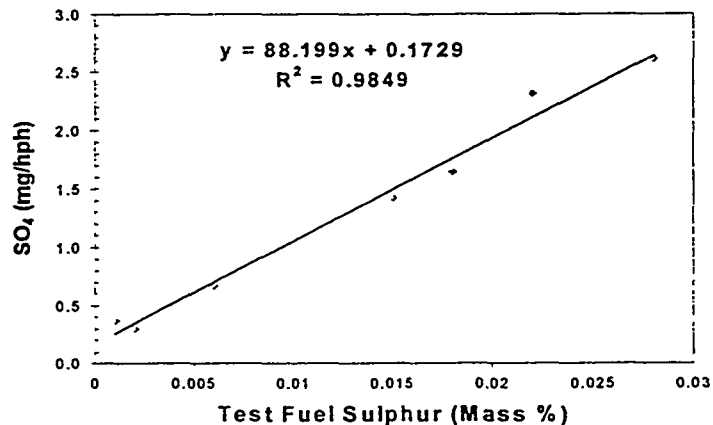
### ARB Diesel Exhaust TACs

(same as EPA plus:)

aniline  
 Antimony (Sb)  
 Be compounds  
 phthalates  
 o-xylene  
 Cadmium  
 p-xylene  
 Chlorine (?)  
 Chlorobenzene  
 Co compounds  
 methanol  
 MEK  
 4-nitrobiphenyl  
 phenol  
 P compounds  
 Se compounds  
 m-xylene  
 minus MTBE

# Sulfur Contribution

Exhaust SO<sub>4</sub> Levels As A Function of Sulphur Mass Percent For Various Diesel Test Fuels (SAE 972898)



*Plot by Nigel Clark, WVU*

## Sulfur Contribution

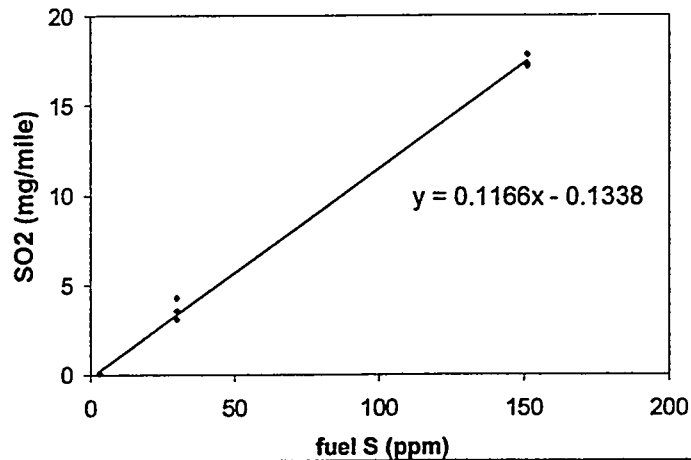
- Preliminary Finding:
  - Deduce an  $\sim 0$  ppm Fuel Sulfur Equivalent

## Sulfur Contribution Mercedes A170



## Sulfur Contribution

Preliminary data suggest engine out SO<sub>2</sub> due to lube is insignificant for modern LD Diesel



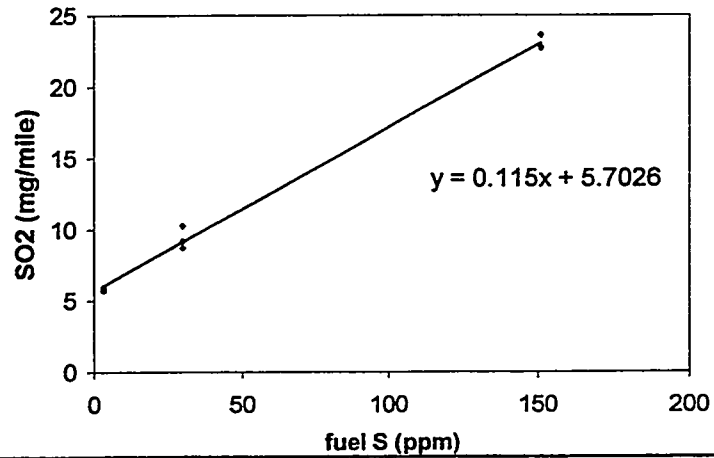
## Measuring Sulfur Contribution

- Method Using SO<sub>2</sub> Measurement
  - Initial assumption is that dilute exhaust is similar to ambient air; use ambient SO<sub>2</sub> analyzer (pulsed fluorescence type)
  - Pro: sensitive to 50 ppb
  - Con: slow (2 min) so only suitable for bag or steady-state measurement
  - Ambient NO is small so no significant interference
  - Dilute NO is not small, so correction curve developed – makes a big difference



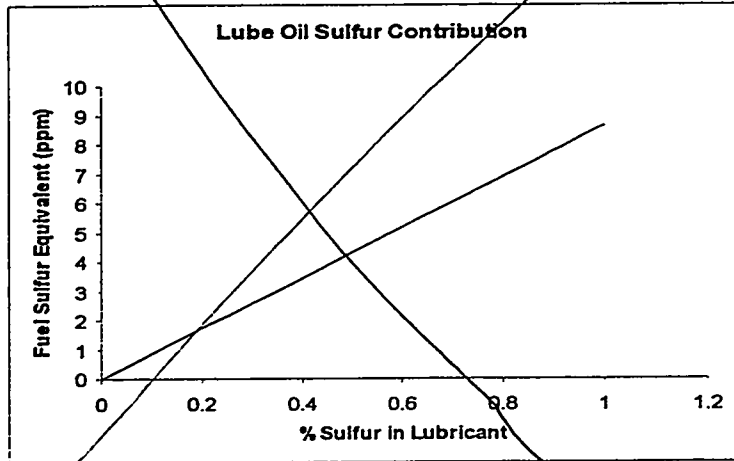
# Measuring Sulfur Contribution

Without correction for NO in analyzer,  
different conclusion!



# Sulfur Contribution

Lube Oil Sulfur Contribution



## Current Projects

- Ad Hoc Auto/Energy Test:
  - Determine the Contribution of Lube Oil to PM and NOx in an Advanced Diesel Engine
  - Will Synthetic Engine Oils Reduce the VOF of PM as well as NOx and Other Regulated Gas Emissions?
- Advanced Petroleum Based Fuels Lube Oil Testing (Preliminary):
  - Effect of Lube Oil Properties & Composition on Emissions
  - Effect of the Emissions on EC Device Performance (w/EGR)
  - Influence of Oil Age on Emissions and Subsequently on ECs
- Comparative Toxicity Study (SwRI, DRI)
- Dayton Research Institute – Study Under Development

## What Needs to be Done

- Standardize Test Procedures and Test Methods
- Add Longevity Testing to Current Plans to Develop Aging Effects (Wear) During a Vehicles Regulated Life
- Characterize the Effect of Lube Oil Age (Oil Change Interval) on Lube Oil Contributions to Emissions
- Configure HD Engines with/without EGR and PCV to Quantify Effects
- Perform Fundamental Combustion Experiments to Determine Effects of Interactions of Fuel and Lube Oil Formulations on Exhaust Products
- Conduct Transient Testing to Determine Lube Oil Contributions During this Driving Mode