



# **Diesel Fuel Lubricity Requirements for Light Duty Fuel Injection Equipment**

**CARB Fuels Workshop**

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**This presentation covers the interests of**

- Robert Bosch GmbH**
- Delphi Diesel Systems**
- Denso Corporation**
- SiemensVDO Automotive AG**
- Stanadyne Automotive Corporation**



**Our Mission is to increase the number of  
Diesel vehicles in the USA  
especially Passenger Cars + SUVs + Light Duty (LD)**

- Build a Cleaner Environment
- Conserve Energy Resources
- Reduce Fuel Consumption / CAFE
  - Lower CO<sub>2</sub> Emission
  
- For Diesel Fuel Injection Equipment (DFIE)  
**Lubricity**  
is the most valuable and crucial property



## Scope of Presentation

### Introduction

### Experience in Europe

### Comparing USA and Europe

- Vehicles and DFIE
- Survey Data

### Requirements

- HFRR method
- Sensitivity of DFIE to HFRR
- Rating Table for Assessed Pump Wear
- Endurance Performance

### Data for Diesel Fuels with HFRR between 400 - 650 $\mu\text{m}$

- Pump Performance: Rotary pumps, Common Rail Systems

### Engine Results

### Conclusions



## A Brief Review

- Sweden introduced sulphur-free fuels in 1990, California followed in 1993 with low-sulphur fuels
  - Failures of fuel-lubricated injection pumps (for passenger and light duty vehicles)
- Lubricity identified as cause
  - Hydroprocessing for desulphurization reduces lubricity enhancing fuel components
- All DFIE manufacturers **afflicted**
- Process to define wear test method and lubricity limit for fuel spec:  
HFRR (ISO 12156-1, -2, ASTM D-6079)  
® **EN 590 et al.    Lubricity Limit =460 µm**  
SLBOCLE (ASTM D-6078/99)



## Current Situation in EU

- In Europe **40 %** of new cars are **Diesel** vehicles:
  - Passenger and Light Duty vehicles (e.g. SUV)
- EN 590 lubricity spec. (**HFRR 460 μm max.**) successfully prevents field problems
- Diesel vehicles improve fuel consumption **by 30 %** compared to SI engines
- Diesel vehicles have low fuel consumption (**up to 78 mpg**)
- Diesel vehicles produce **lower CO<sub>2</sub>** emissions
- Diesel vehicles provide low service costs and high service intervals
  
- Drivers enjoy driving diesel vehicles due to superior torque characteristics
- Majority of High Pressure DFIE is **fuel-lubricated**



## Main Differences in Diesel Vehicles

	Today		Future	
	U.S. / California	EU	U.S. / California	EU
<b>Vehicles</b>	<ul style="list-style-type: none"> <li>• <b>Heavy Duty</b></li> <li>• Light Duty</li> </ul>	<ul style="list-style-type: none"> <li>• <b>Passenger</b></li> <li>• Light Duty</li> <li>• Heavy Duty</li> </ul>	<ul style="list-style-type: none"> <li>• <b>Light Duty</b></li> <li>• Heavy Duty</li> <li>• Passenger</li> </ul>	<ul style="list-style-type: none"> <li>• <b>Passenger</b></li> <li>• Light Duty</li> <li>• Heavy Duty</li> </ul>
<b>DFIE</b>	<ul style="list-style-type: none"> <li>• <b>Inline pumps</b></li> <li>• UIS/UPS</li> <li>• Common Rail</li> <li>• Rotary pumps</li> </ul>	<ul style="list-style-type: none"> <li>• <b>Common Rail</b></li> <li>• UIS/UPS</li> <li>• <b>Rotary pumps</b></li> </ul>	<ul style="list-style-type: none"> <li>• Inline pumps</li> <li>• UIS/UPS</li> <li>• <b>Common Rail</b></li> <li>• <b>Rotary pumps</b></li> </ul>	<ul style="list-style-type: none"> <li>• <b>Common Rail</b></li> <li>• UIS/UPS</li> <li>• <b>Rotary pumps</b></li> </ul>
<b>Lubricity requirement</b>	(+)	++	++	++
<b>Lubricity specification</b>	U.S.A.: none CA: SLBOCLE guideline	HFRR 460 µm max.	HFRR 460 µm max.	HFRR 460 µm max.



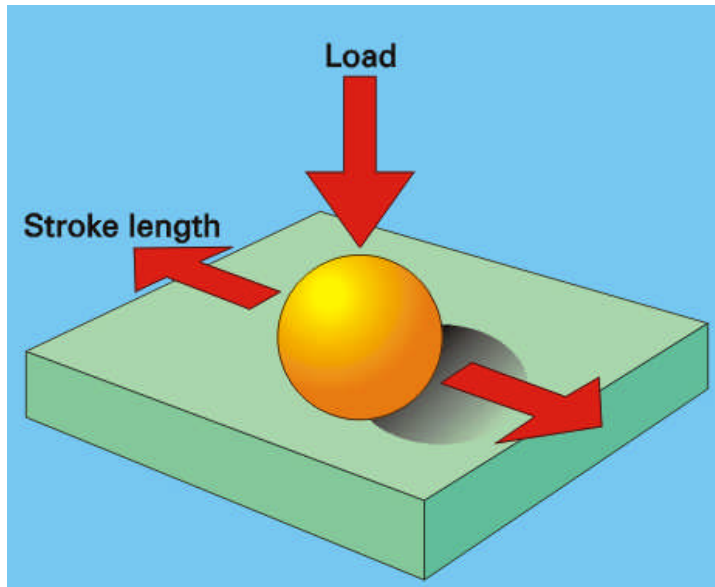
## Samples from Summer 2002

Property	Unit	U.S.A.	Europe (EN 590)	Assessment of U.S.A. Quality
Density	kg/m <sup>3</sup>	813 ... 863	820 ... 845	wide range
Viscosity	c.St. (40 °C)	2.1 ... 3.2	2.0 ... 4.5	o.k.
Dist. 95% vol rec.	°C	324 ... 344	< 360	o.k.
Total Aromatic Cont.	%	16 ... 46	n.a.	many high numbers
Cetane No.		44 ... 57	> 51	many low numbers
Sulphur	mg/kg	23 ... 416	< 350	not o.k. for aftertreatment
Water	mg/kg	42 ... 96	< 200	o.k.
Total Contamination (particulates)	mg/kg	0.8 ... 3.1	< 24	some high numbers (EN590 limit too high)
Lubricity	µm (HFRR 60C)	351 ... 648	< 460	80% of samples > 460 µm
Alcohol	% vol.	< 0.1	n.a.	o.k.





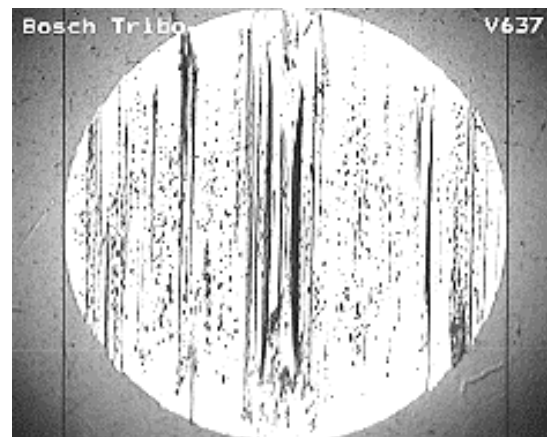
## ISO 12156-1 Method



Test conditions:

Applied load	200 g ± 0.01 g
Stroke length	1 ± 0.02 mm
Frequency	50 ± 1 Hz
Test duration	75 ± 0.1 min
Fluid temperature	60 ± 2 °C
Fluid volume	2 ± 0.20 ml
Bath surface	6 ± 1 cm <sup>2</sup>

®

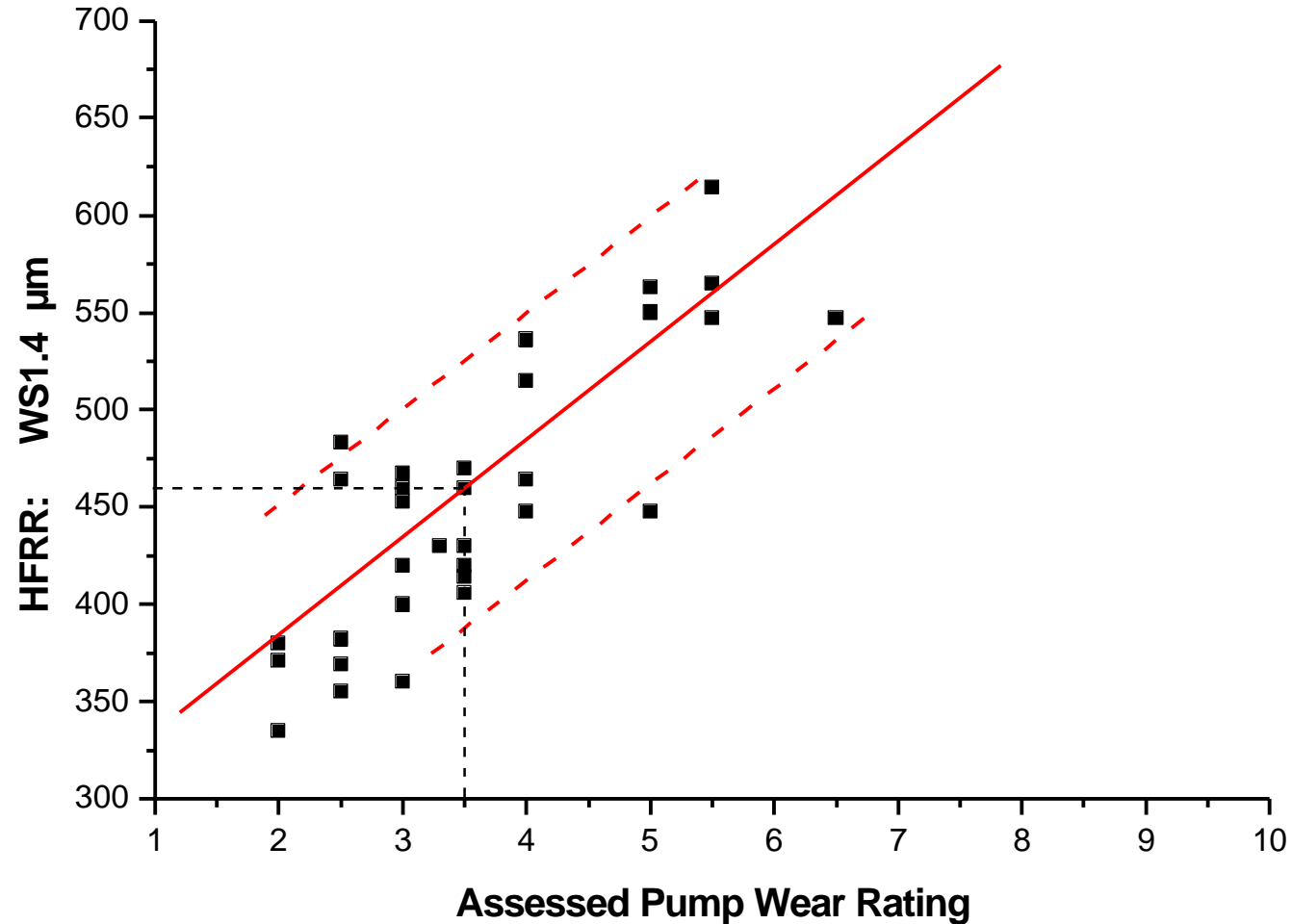


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**WS1.4 μm**



# Sensitivity of DFIE to HFRR



→ Linear regression: Pump wear 3.5 ==> WS1.4 = 454 μm



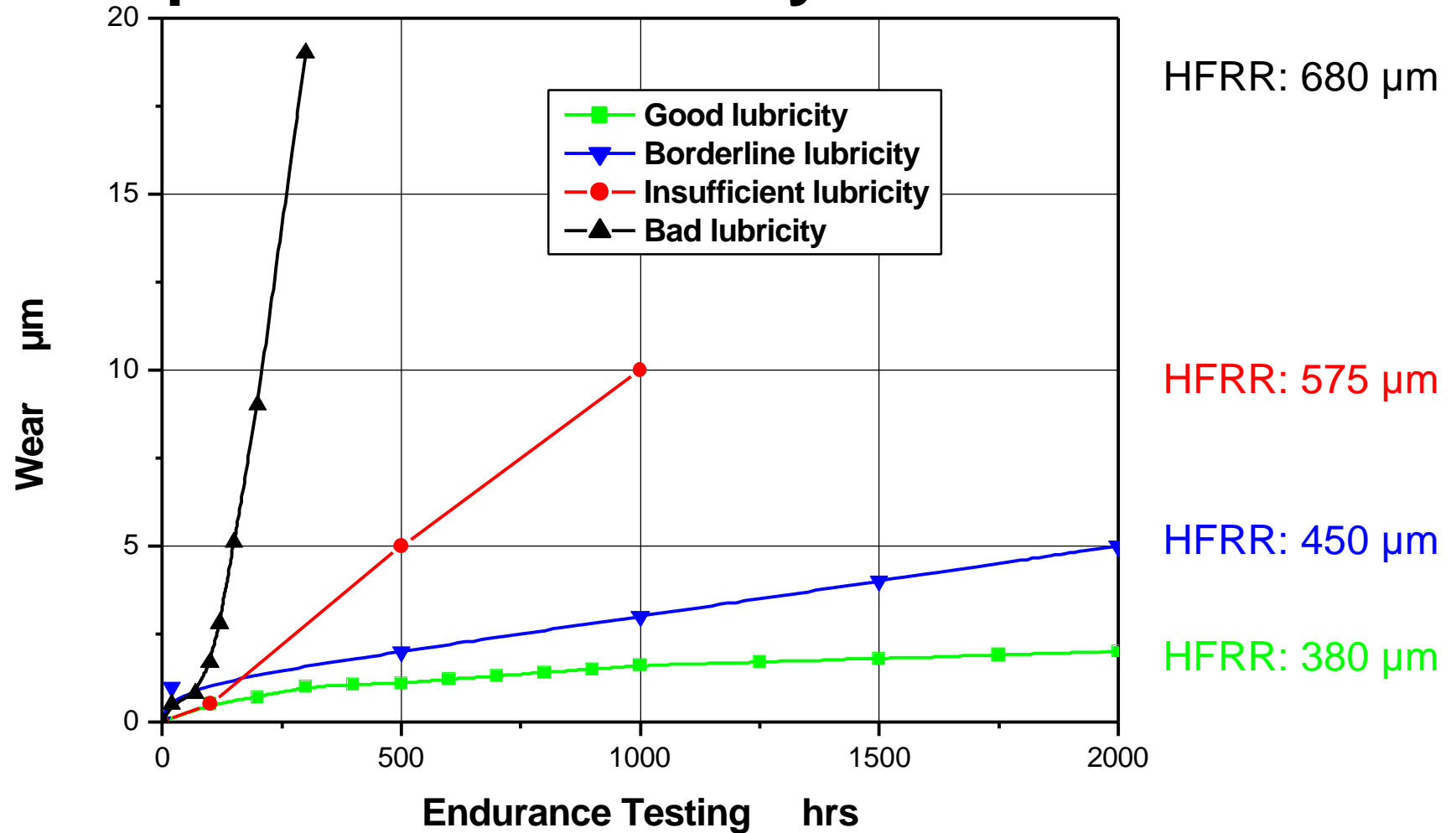
## Table to Assess Pump Wear

Component	Wear rating: 1 – 3.5 Durability + performance = 100 %		Wear rating: 4 – 6 Durability reduced to 20 %		Wear rating: 7 – 10 Durability reduced to 1 % Immediate failure	
	Type of wear	Wear rate	Type of wear	Wear rate	Type of wear	Wear rate
<b>Cam plate</b>						
runway	rolling and abrasive	< 1 µm	seizure and fatigue	1 – 30 µm	fatigue	not determinable
cam plate centre	fretting	1 - 3 µm	fretting	3 - 10 µm	fretting	> 10 µm
cam plate claws	fretting	< 10 µm	rolling and fretting	10 - 20 µm	seizure	not determinable
<b>Roller</b>	rolling	< 1 µm	seizure and fatigue	1 - 5 µm	seizure and fatigue	not determinable
<b>Roller bolt</b>						
- point of contact to roller	rolling	< 1 µm	fretting and seizure	1 - 10 µm	seizure	>10 µm
- point of contact to roller ring	fretting	< 10 µm	fretting	10 - 15 µm	seizure	>15 µm
<b>Fuel pump</b>						
- blades	fretting	< 10 µm	fretting	10 - 200 µm	fretting and seizure	not determinable
- raceway	fretting	1 – 2 µm	fretting	2 - 100 µm	fretting and seizure	not determinable

→ Pump wear must not exceed “green” zone to meet customer expectation



# Pump Wear vs. Lubricity over Lifetime



→ New DFIE designed to operate with “blue --” fuel



## VE - Rotary Pump with HFRR 450 $\mu\text{m}$ Fuel



Wear rating = 3.5

Bolts: slight scuffing    Supply pump vanes: increased abrasive wear

→ Fuel represents borderline EU quality

→ Fuel adequate for purpose



## VE - Rotary Pump with **HFRR 650 $\mu\text{m}$ Fuel**



**Wear rating = 8**

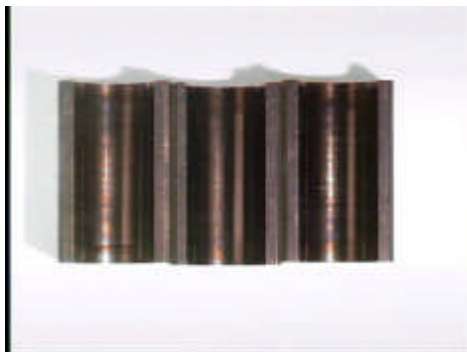
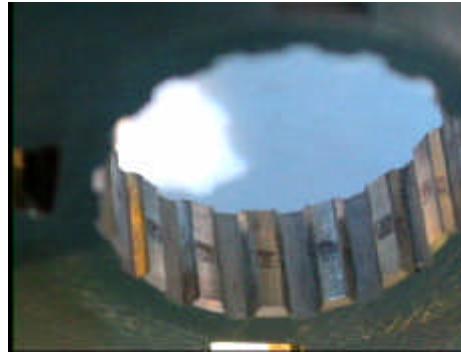
Cam plate: 30  $\mu\text{m}$     Rollers: Seizure    Bolt: 15  $\mu\text{m}$     Piston: Broken

→ **Fuel represents worst case U.S. lubricity**

→ **Fuel unfit for purpose**



## VP44 - Rotary Pump with **HFRR 400 $\mu\text{m}$ Fuel**



**Wear rating = 3.0**

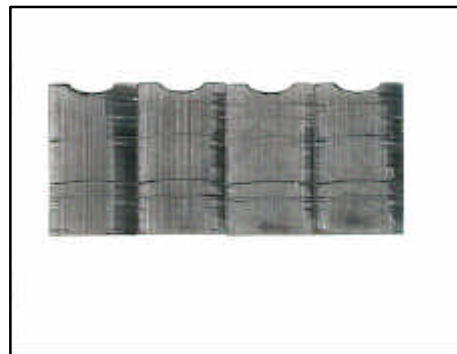
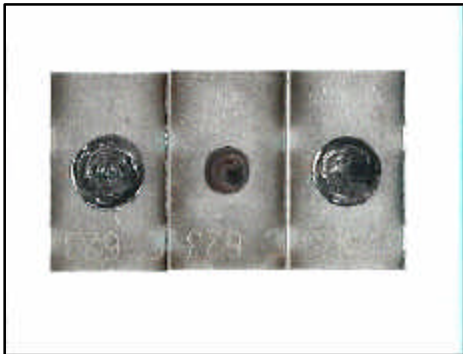
Supply pump, roller shoes, feed pump tooth system, and timing piston: minor polishing

→ **Fuel represents typical EU quality**

→ **Fuel fit for purpose**



## VP44 - Rotary Pump with **HFRR 650 $\mu\text{m}$ Fuel**



**Wear rating = 7.0**

Supply pump, feed pump tooth system, high pressure piston and vanes: severe wear

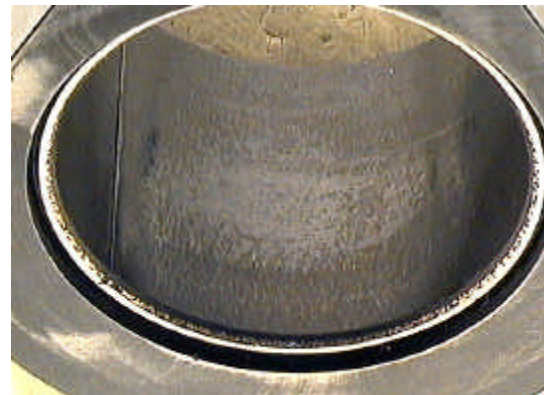
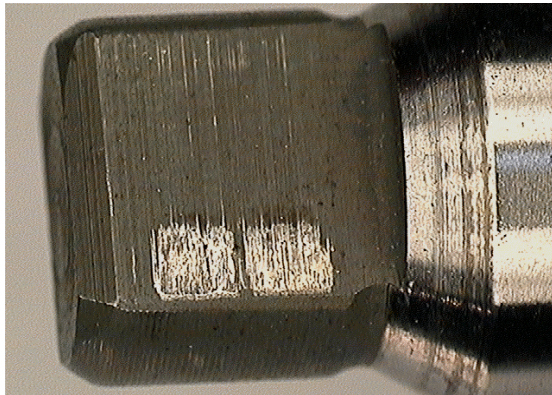
→ **Fuel represents worst case U.S. lubricity**

→ **Fuel unfit for purpose**





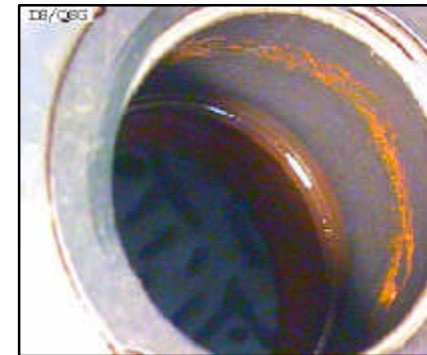
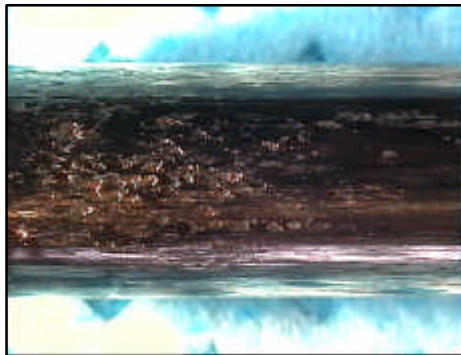
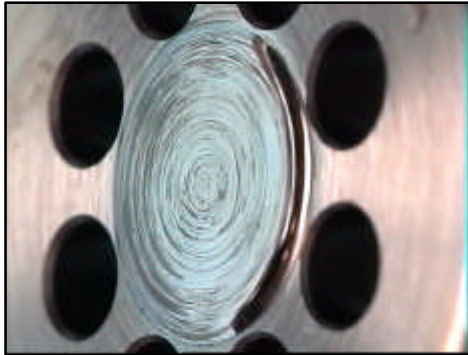
## Common Rail System with HFRR 460 $\mu\text{m}$ Fuel



- Fuel represents borderline EU quality
- Fuel adequate for purpose



## Common Rail System with **HFRR 650 $\mu\text{m}$ Fuel**



**Wear rating = 9.0**

Piston: Seizure    Piston bottom center: 15  $\mu\text{m}$ ;    Bearing shell: Seizure; Polygon:  $\geq 1000 \mu\text{m}$

→ **Fuel represents worst case U.S. lubricity**

→ **Fuel unfit for purpose**

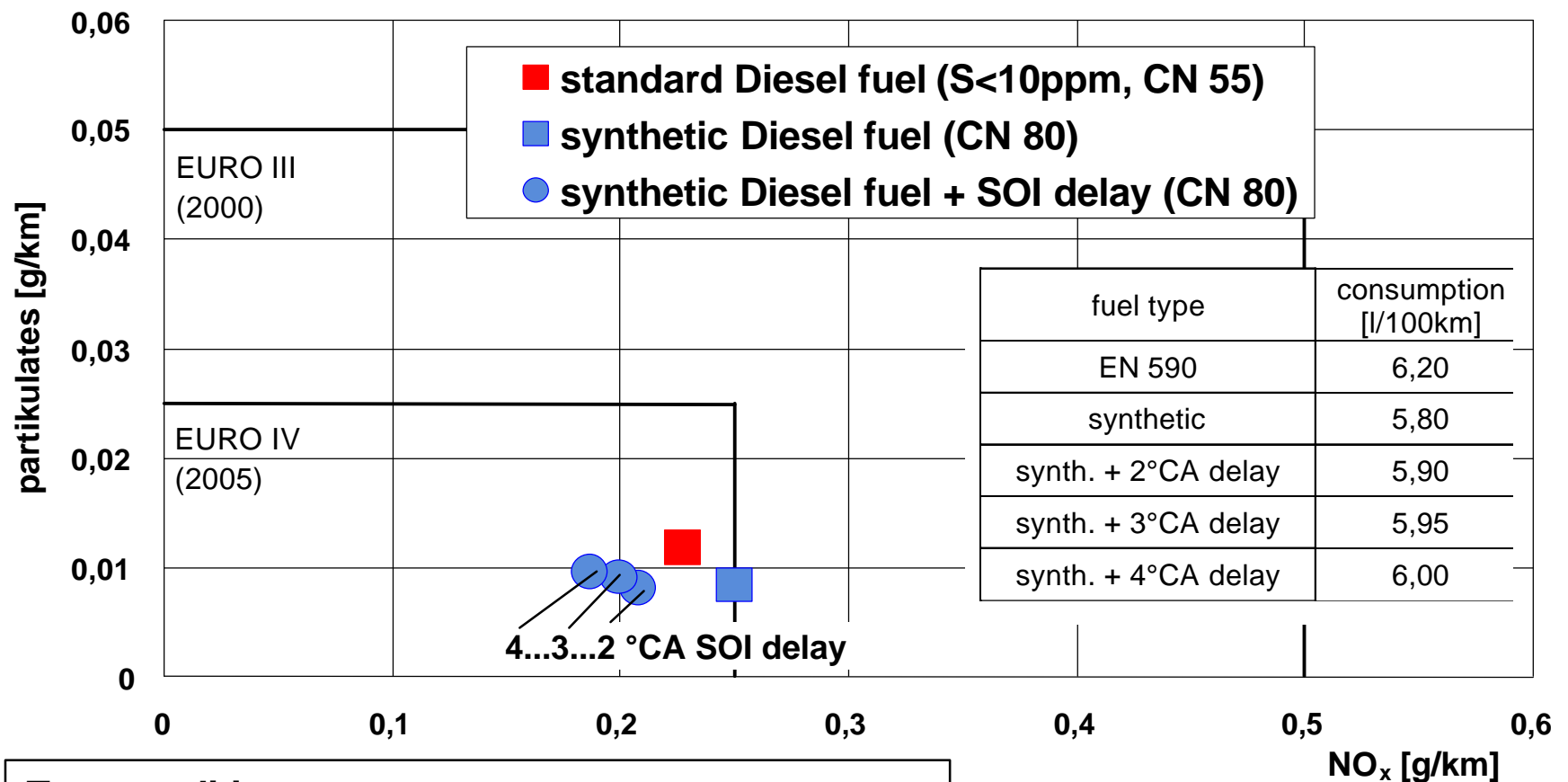


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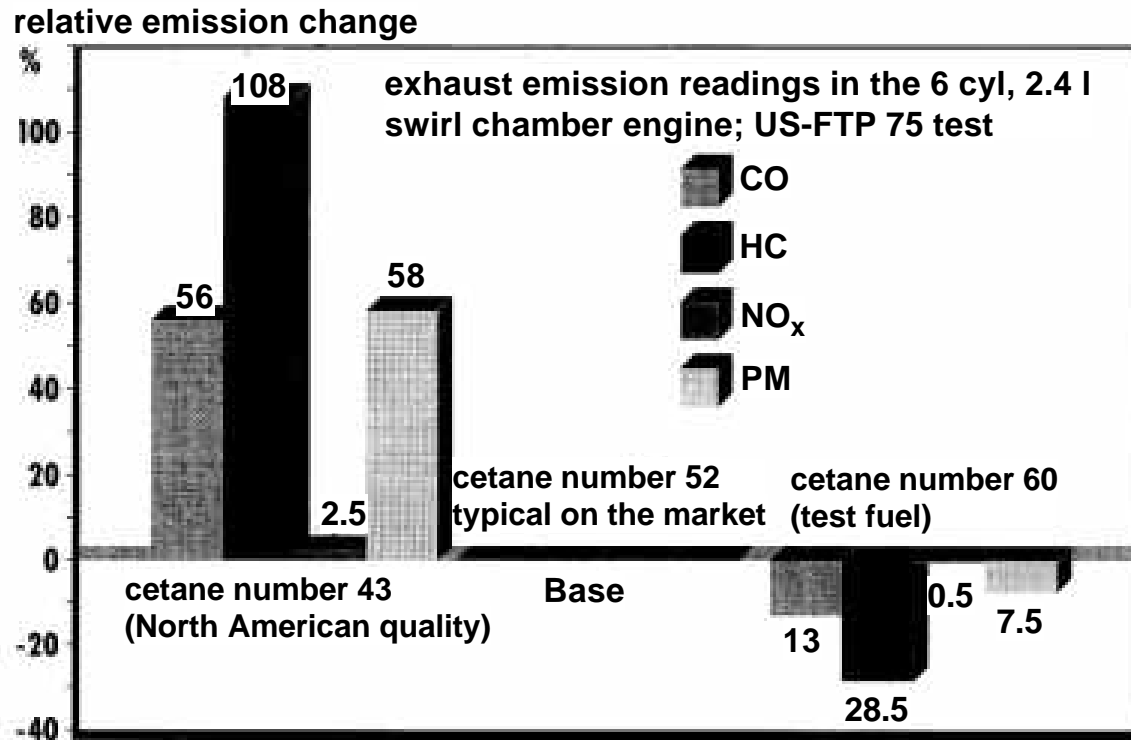
## NO<sub>x</sub> and PM Reduction with CN 55 and 80 Fuels



**Test conditions:**  
 2.2 l DI engine  
 European test cycle; MNEDC ( cold test with PI)



## NO<sub>x</sub> and PM Reduction with CN 60 Fuels



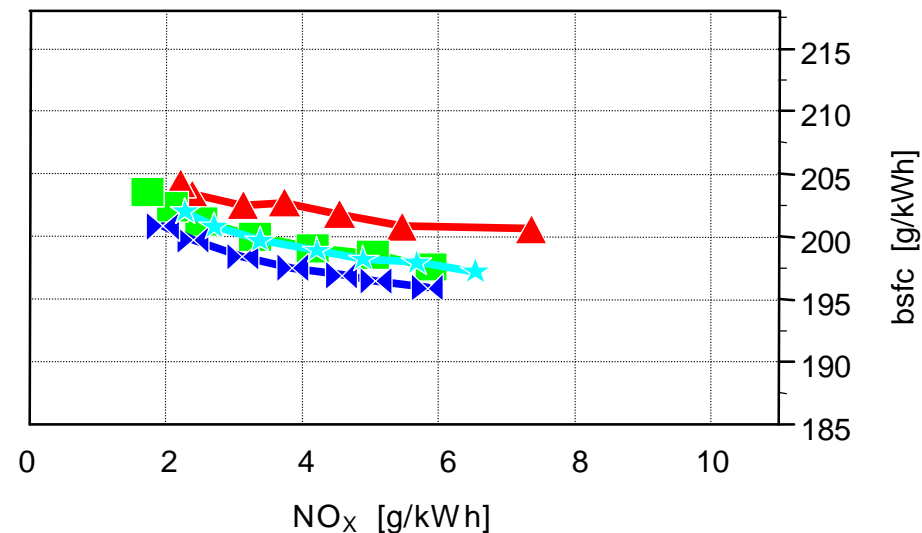
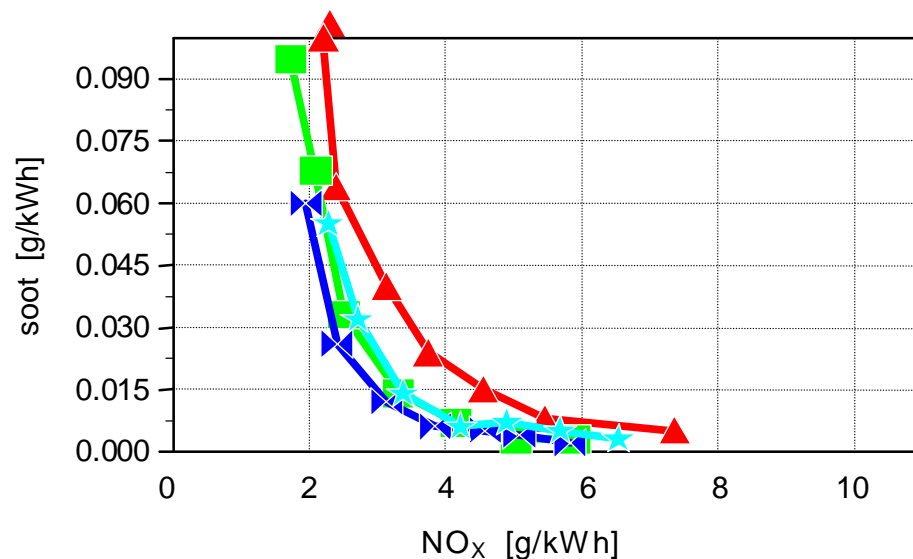
### Test conditions:

6 cyl., 2.4 l, swirl chamber engine

U.S.-FTP75 test



## Better Trade-offs for Soot/ NO<sub>x</sub> and Fuel Consumption/ NO<sub>x</sub> with CN 52 <sup>®</sup> 59 Fuels



Test conditions:

1 Cyl. HD engine; V<sub>d</sub> ca. 2 l, with EGR

Speed = 1710 rpm, Load = 100%

EGR rate ≤ 18 %

	fuel 1	S = 350ppm; CN = 52; T.AH.25%
	fuel 4	S = 10ppm; CN = 53; T.AH. 20%
	fuel 2	S = 10ppm; CN = 55; T.AH.12%
	fuel 3	S = 10ppm; CN = 59; T.AH. 7%



## Reasoning for HFRR

- HFRR is an **adequate** test method
- HFRR provides **customer satisfaction**
- **HFRR 460 µm max.** known to prevent field problems
- All high-pressure fuel-lubricated injection systems are exceedingly lubricity-sensitive  
**and require clean fuels** (no free water and/or contamination)
- Common-rail and Rotary pumps require the same level of lubricity
- Lubricity specification in ASTM D975 needed **ASAP**
- **Spec.** should not exceed HFRR: WS1.4 £ 460 µm (ISO 12156-1)
  
- **Bosch and DFIE industry willing to**
  - **share and validate experience**
  - **offer more tests and**
  - **cooperate with regulators (CARB, ...)**



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