



Diesel Fuel Lubricity Requirements for Light Duty Fuel Injection Equipment

CARB Fuels Workshop

**Sacramento, CA
Feb. 20, 2003**

**Klaus Meyer and Thomas C. Livingston
Robert Bosch GmbH**



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 CO₂ 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 μm

- 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 CO₂** 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
Vehicles	<ul style="list-style-type: none"> • Heavy Duty • Light Duty 	<ul style="list-style-type: none"> • Passenger • Light Duty • Heavy Duty 	<ul style="list-style-type: none"> • Light Duty • Heavy Duty • Passenger 	<ul style="list-style-type: none"> • Passenger • Light Duty • Heavy Duty
DFIE	<ul style="list-style-type: none"> • Inline pumps • UIS/UPS • Common Rail • Rotary pumps 	<ul style="list-style-type: none"> • Common Rail • UIS/UPS • Rotary pumps 	<ul style="list-style-type: none"> • Inline pumps • UIS/UPS • Common Rail • Rotary pumps 	<ul style="list-style-type: none"> • Common Rail • UIS/UPS • Rotary pumps
Lubricity requirement	(+)	++	++	++
Lubricity specification	U.S.A.: none CA: SLBOCLE guideline	HFRR 460 µm max.	HFRR 460 µm max.	HFRR 460 µm max.

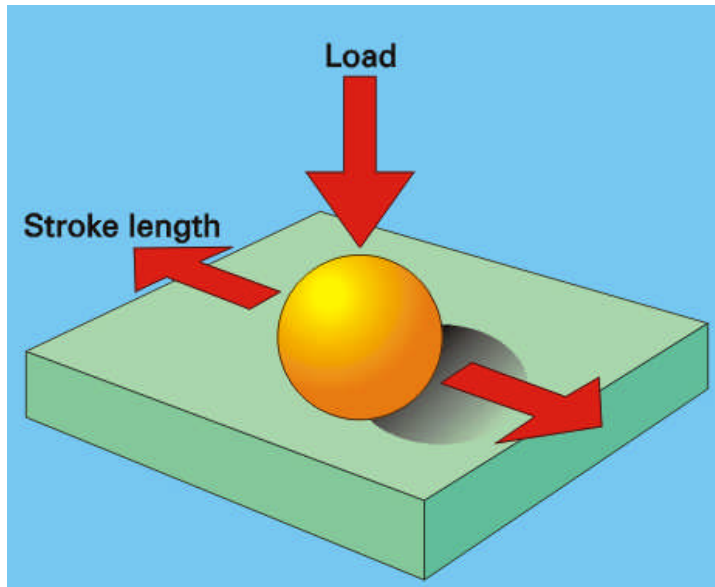


Samples from Summer 2002

Property	Unit	U.S.A.	Europe (EN 590)	Assessment of U.S.A. Quality
Density	kg/m ³	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.



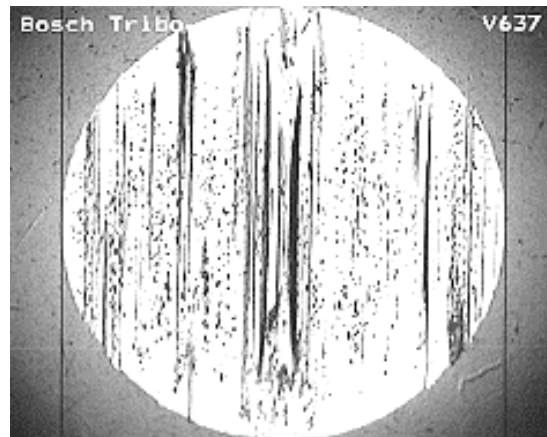
ISO 12156-1 Method



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 ²

®

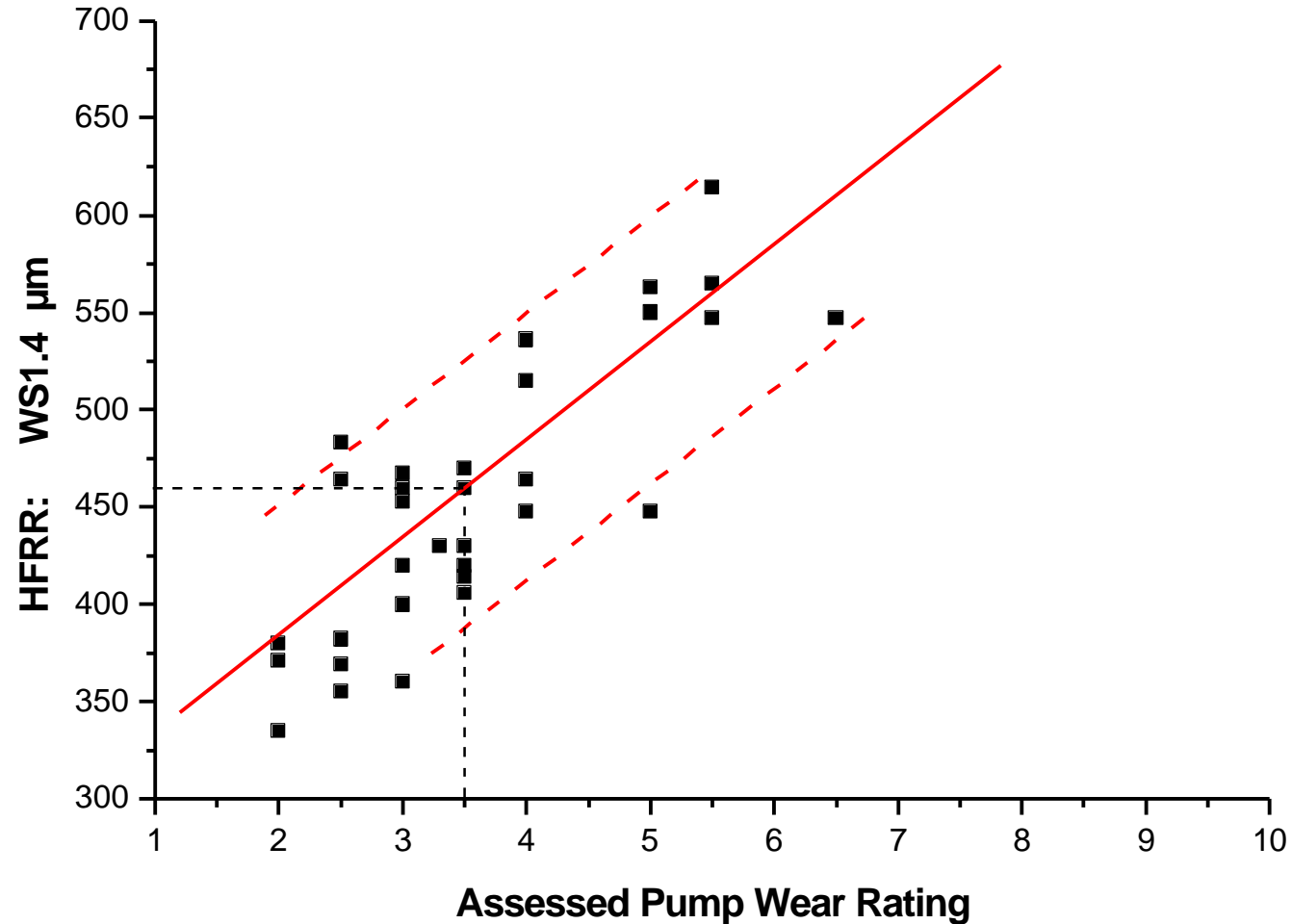


®

WS1.4 μm



Sensitivity of DFIE to HFRR



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



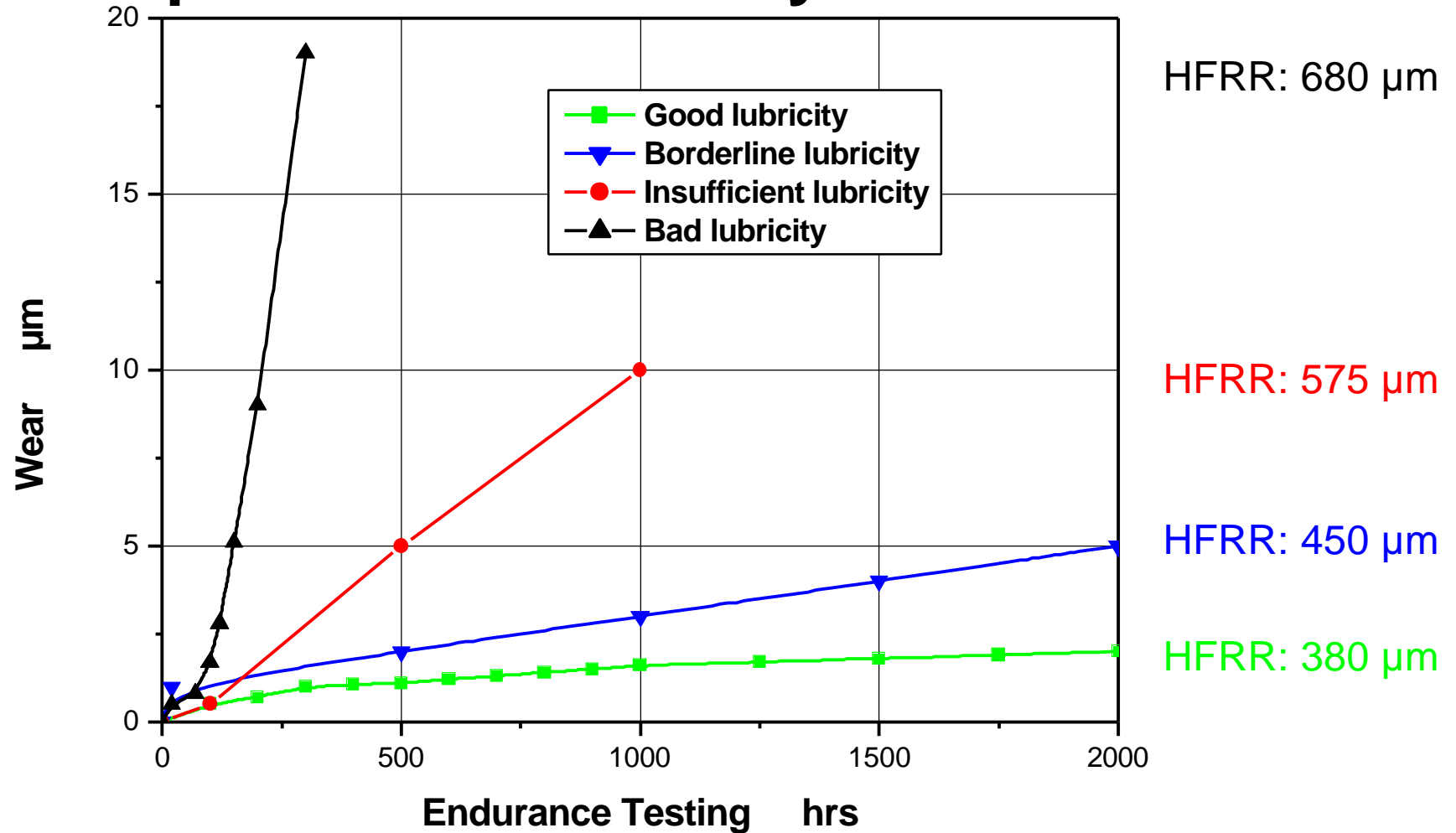
Table to Assess Pump Wear

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
Cam plate						
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
Roller	rolling	< 1 µm	seizure and fatigue	1 - 5 µm	seizure and fatigue	not determinable
Roller bolt						
- 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
Fuel pump						
- 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 μm Fuel



Wear rating = 3.5

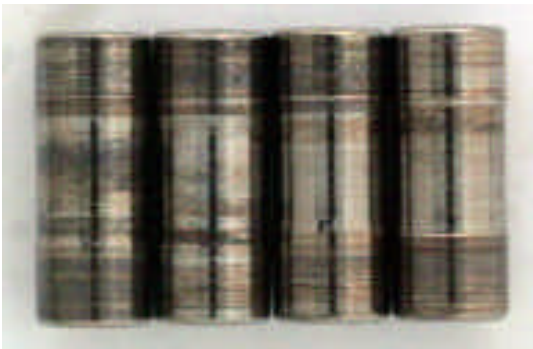
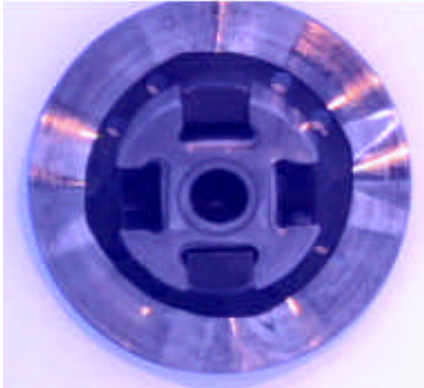
Bolts: slight scuffing Supply pump vanes: increased abrasive wear

→ Fuel represents borderline EU quality

→ Fuel adequate for purpose



VE - Rotary Pump with **HFRR 650 μm Fuel**



Wear rating = 8

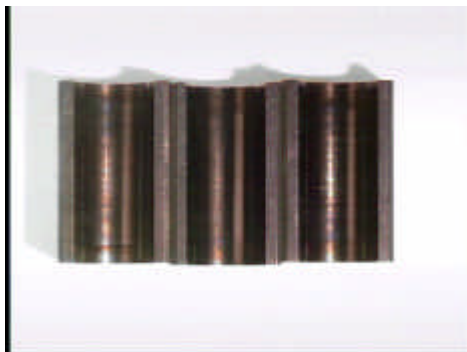
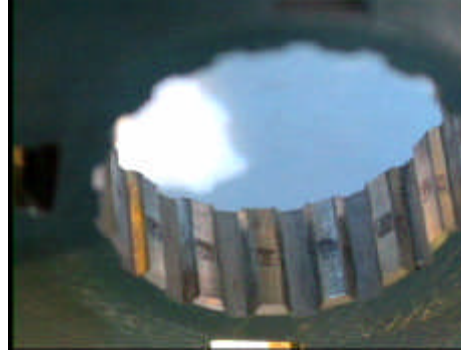
Cam plate: 30 μm Rollers: Seizure Bolt: 15 μm Piston: Broken

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

→ **Fuel unfit for purpose**



VP44 - Rotary Pump with **HFRR 400 μm Fuel**



Wear rating = 3.0

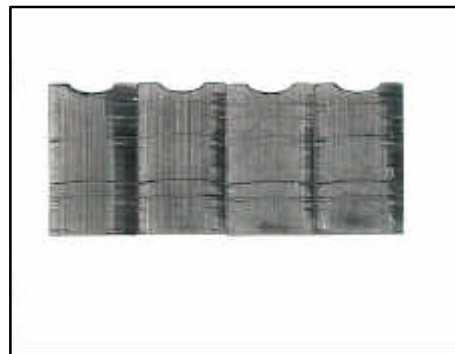
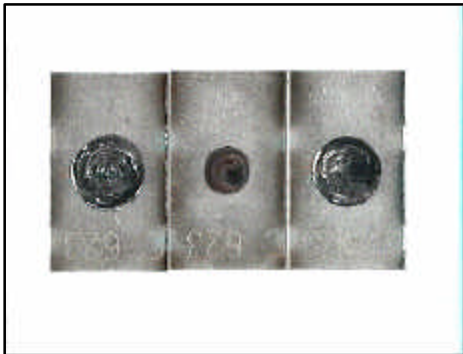
Supply pump, roller shoes, feed pump tooth system, and timing piston: minor polishing

→ **Fuel represents typical EU quality**

→ **Fuel fit for purpose**



VP44 - Rotary Pump with **HFRR 650 μm Fuel**



Wear rating = 7.0

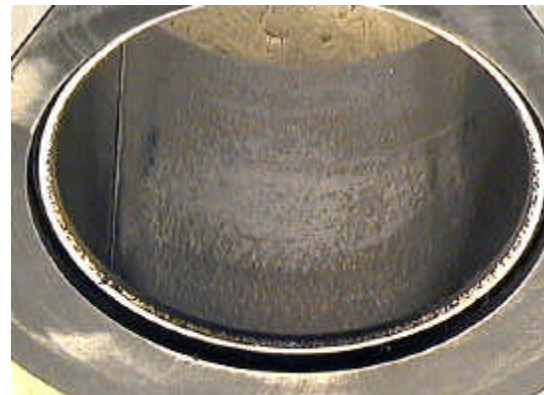
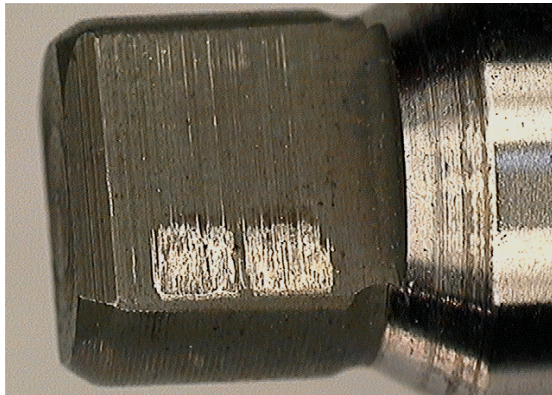
Supply pump, feed pump tooth system, high pressure piston and vanes: severe wear

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

→ **Fuel unfit for purpose**



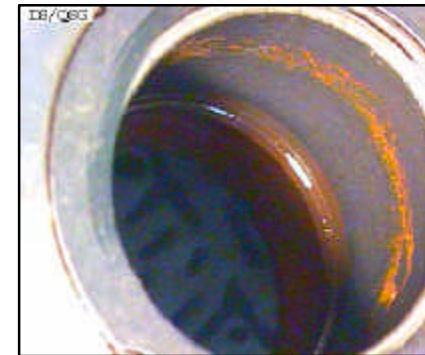
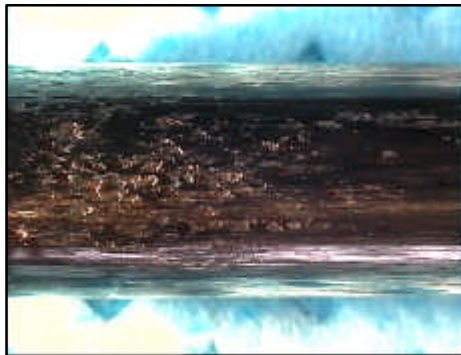
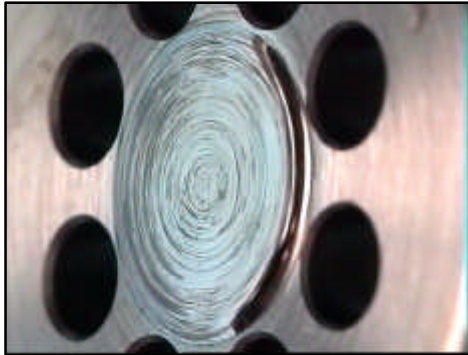
Common Rail System with HFRR 460 μm Fuel



- Fuel represents borderline EU quality
- Fuel adequate for purpose



Common Rail System with **HFRR 650 μm Fuel**



Wear rating = 9.0

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

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

→ **Fuel unfit for purpose**

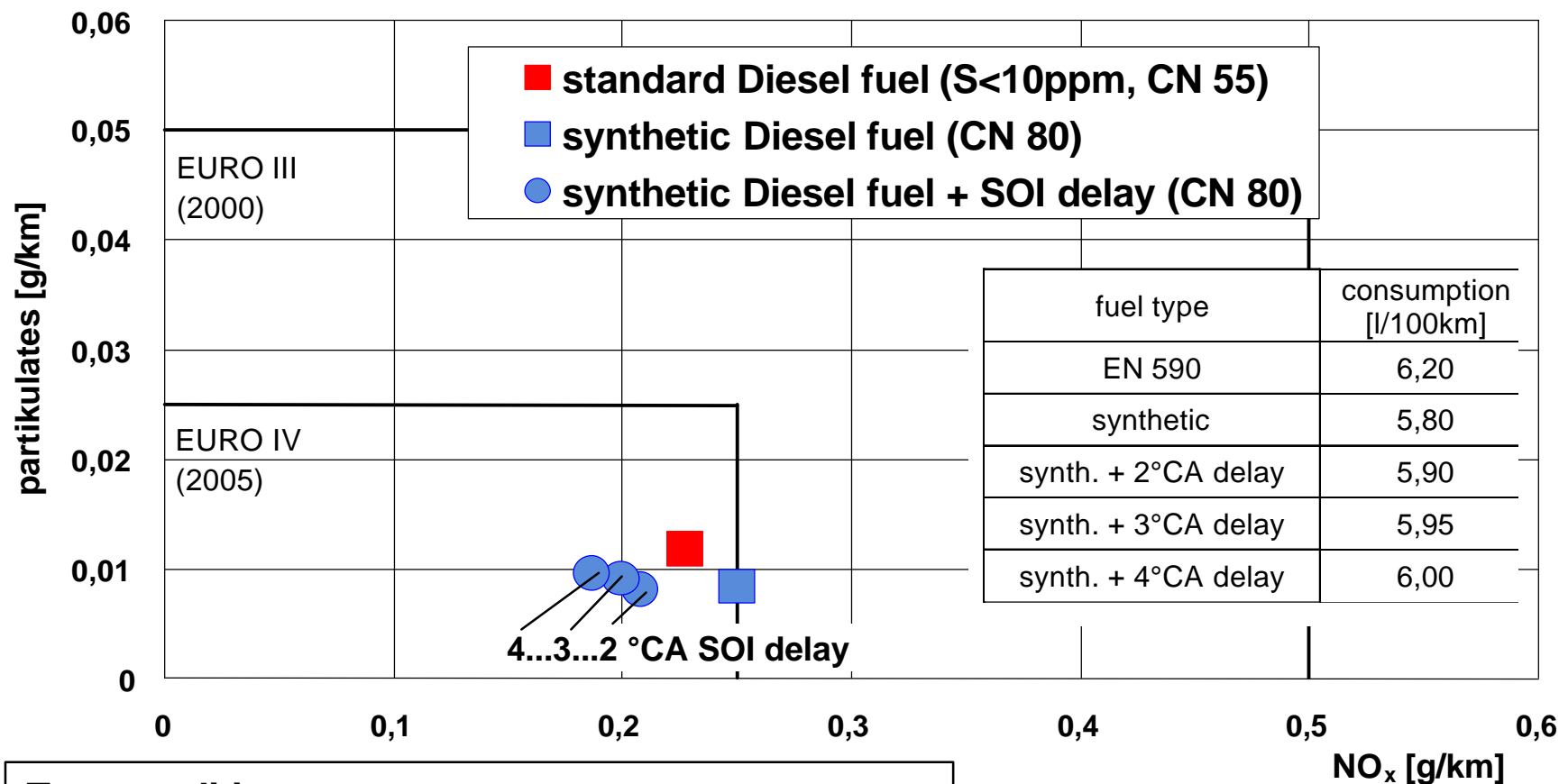


Samples from Summer 2002

Property	Unit	U.S.A.	Europe (EN 590)	Assessment of U.S.A. Quality
Density	kg/m ³	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.



NO_x and PM Reduction with CN 55 and 80 Fuels



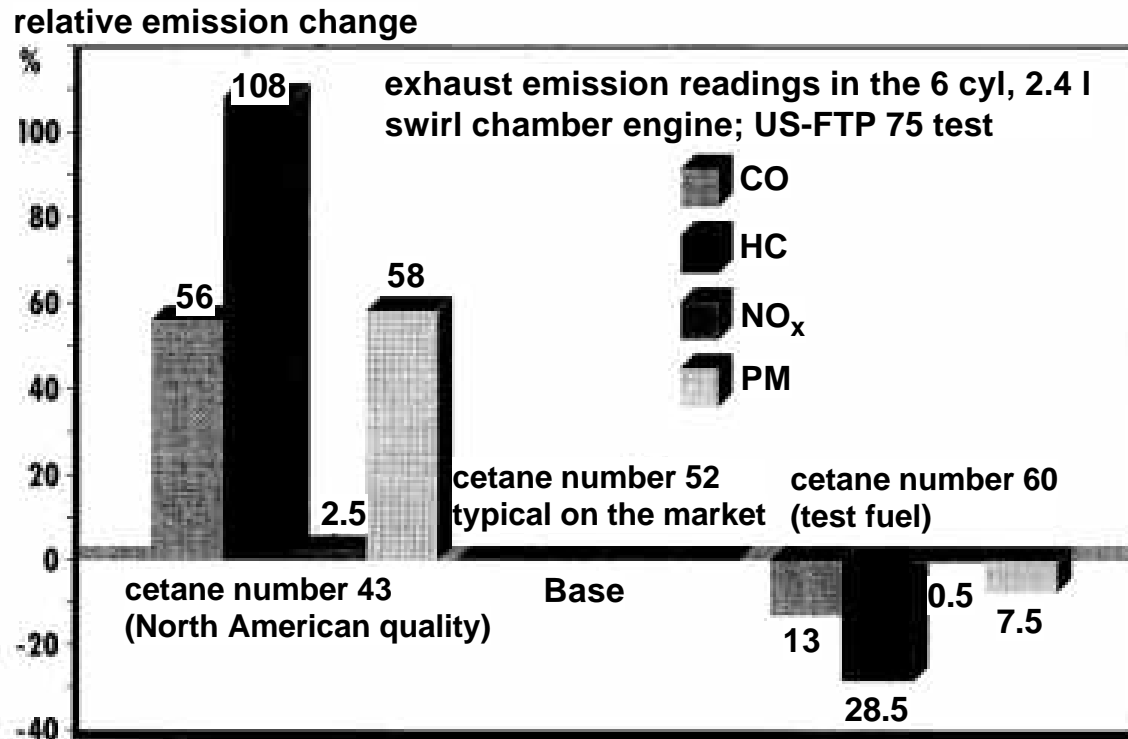
Test conditions:

2.2 l DI engine

European test cycle; MNEDC (cold test with PI)



NO_x and PM Reduction with CN 60 Fuels

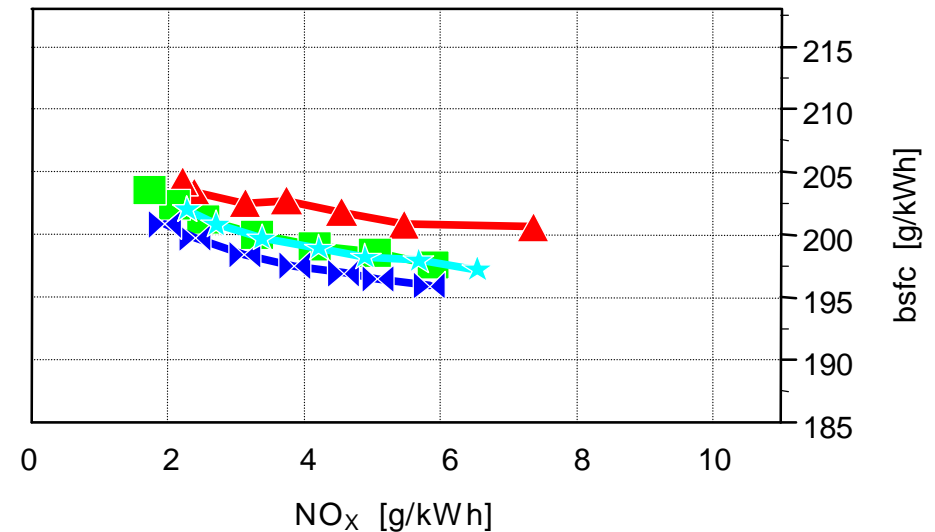
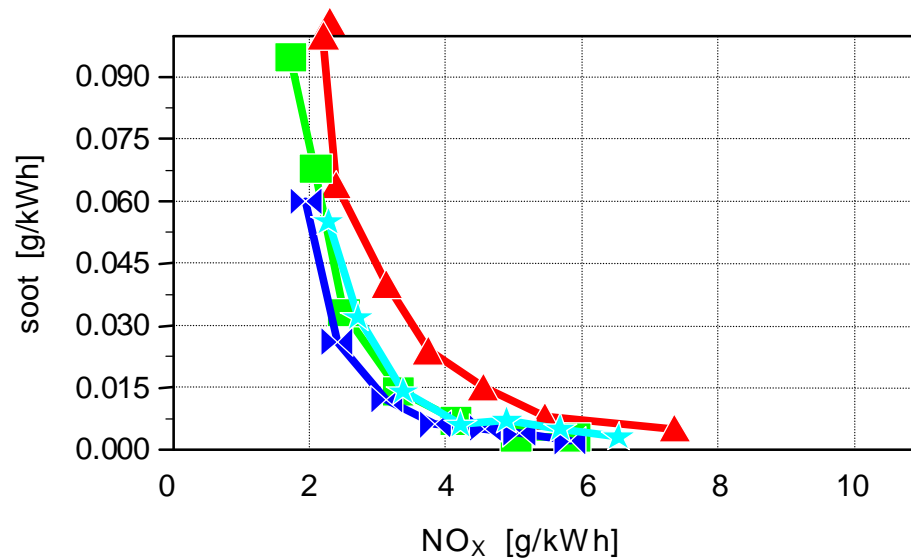


Test conditions:

6 cyl., 2.4 l, swirl chamber engine
U.S.-FTP75 test



Better Trade-offs for Soot/ NO_x and Fuel Consumption/ NO_x with CN 52 [®] 59 Fuels



Test conditions:

1 Cyl. HD engine; V_d 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, ...)**



Klaus Meyer

c/o Robert Bosch GmbH
Corporate Research
Dept. FV/FLM
P.O.B. 106050
D - 70049 Stuttgart
Germany

phone: +49-(0)711-811-6030
fax: +49-(0)711-811-267626
email: klaus.meyer@de.bosch.com

Thomas C. Livingston

c/o Robert Bosch Corporation
Dept. AP/EHD2.1
38000 Hills Tech Drive
Farmington Hills
Michigan 48331
U.S.A.

phone: (248)-553-1386
fax: (248)-324-7288
email: tom.livingston@us.bosch.com