Diesel Fuel Lubricity

Requirements for Light Duty Fuel Injection Equipment

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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_2 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 CO_2** 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**

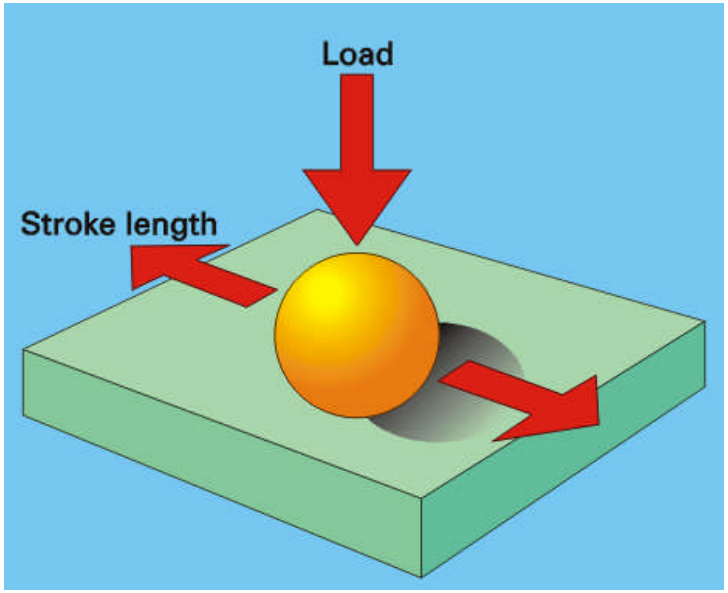
Main Differences in Diesel Vehicles

	Today ↓		Future ↓	
	U.S. / California	EU	U.S. / California	EU
Vehicles	• **Heavy Duty** • Light Duty	• **Passenger** • Light Duty • Heavy Duty	• **Light Duty** • Heavy Duty • Passenger	• **Passenger** • Light Duty • Heavy Duty
DFIE	• **Inline pumps** • UIS/UPS • Common Rail • Rotary pumps	• **Common Rail** • UIS/UPS • **Rotary pumps**	• Inline pumps • UIS/UPS • **Common Rail** • **Rotary pumps**	• **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

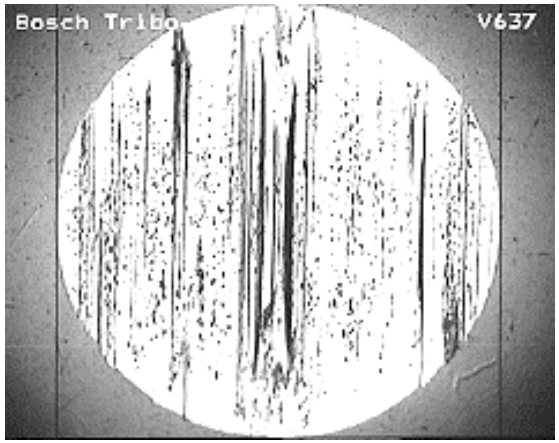
Property	Unit	U.S.A.	Europe (EN 590)	Assessment of U.S.A. Quality
Density	kg/m³	813 ... 863	820 ... 845	wide range
Viscosity	c.St. (40 °C)	2.1 ... 3.2	2.0 ... 4.5	o.k.
Dist. 95% vol rec.	°C	324 ... 344	< 360	o.k.
Total Aromatic Cont.	%	16 ... 46	n.a.	many high numbers
Cetane No.		44 ... 57	> 51	many 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



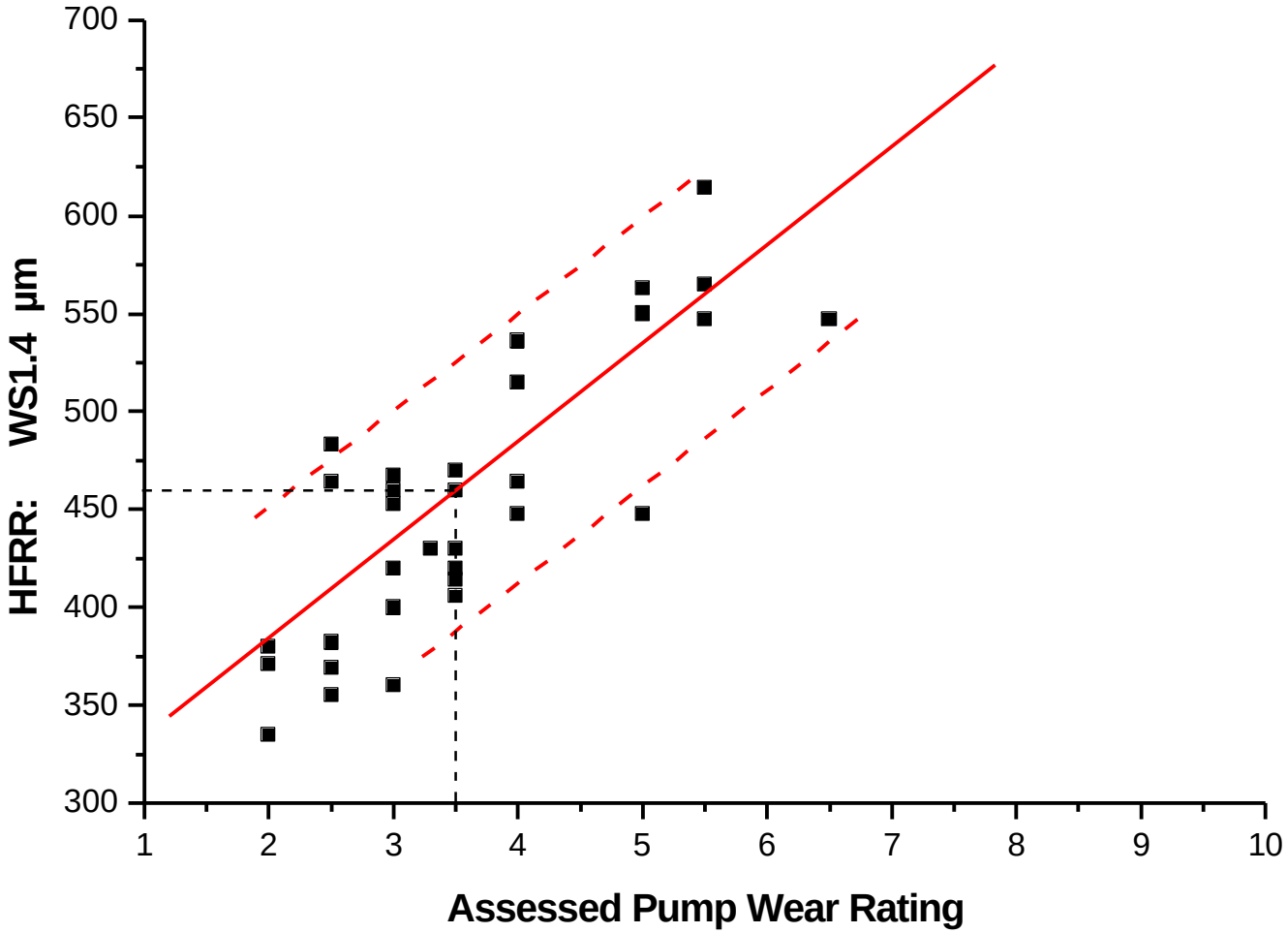
Test conditions:

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 cm²**



® ® **WS1.4 µm**

Sensitivity of DFIE to HFRR



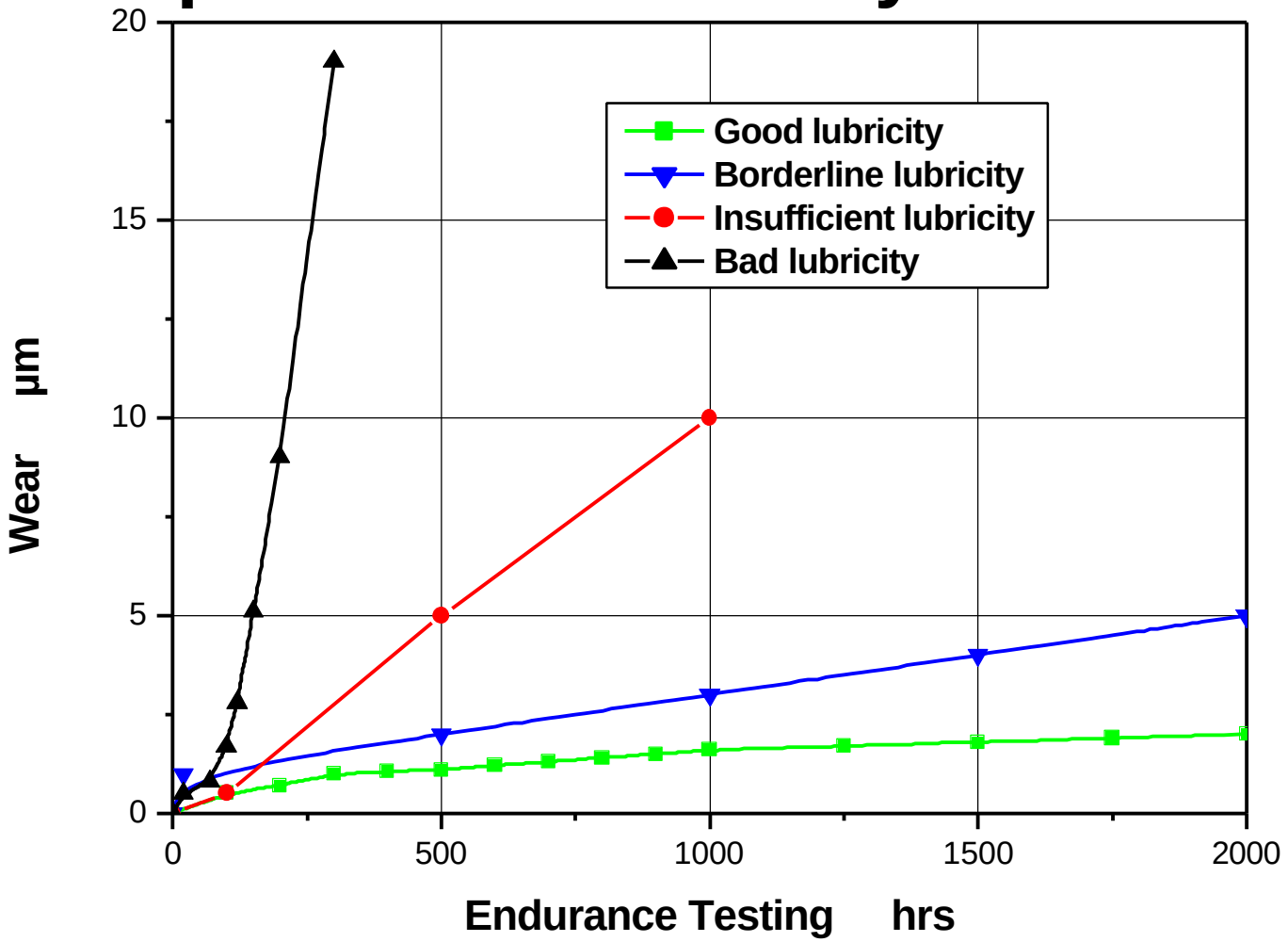
➔ **Linear regression: Pump wear 3.5 ==> WS1.4 = 454 µm**

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



HFRR: 680 µm

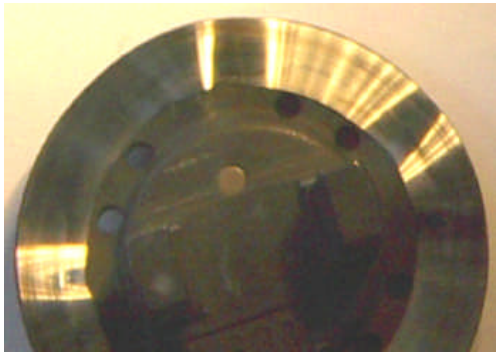
HFRR: 575 µm

HFRR: 450 µm

HFRR: 380 µm

➔ **New DFIE designed to operate with "blue --" fuel**

VE - Rotary Pump with HFRR 450 µm Fuel

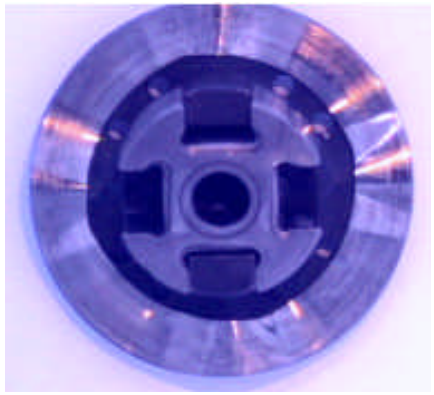


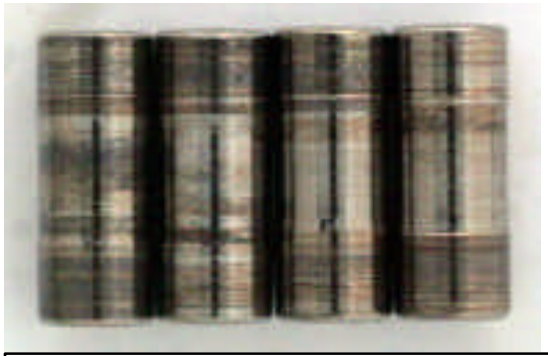
Wear rating = 3.5

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



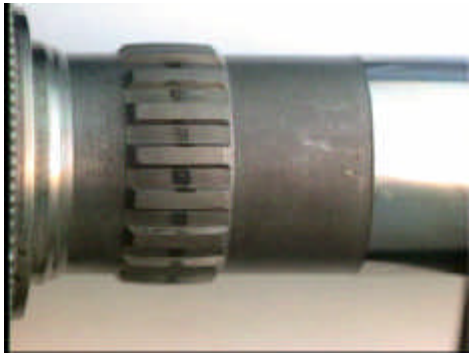


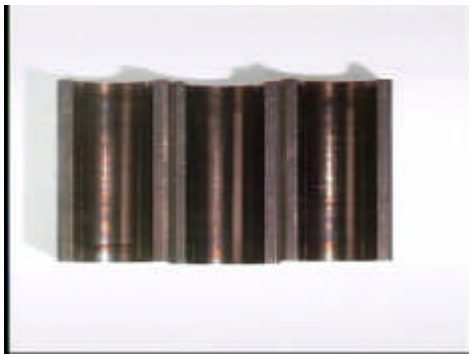
Wear rating = 8

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



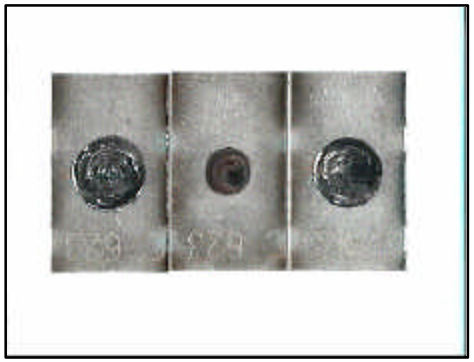


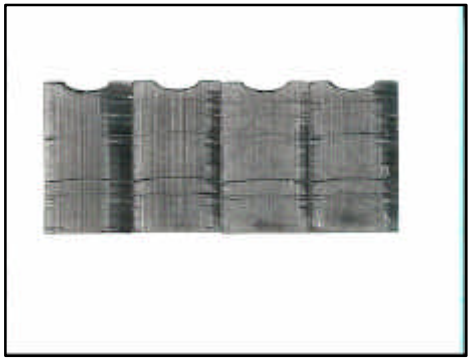

Wear rating = 3.0

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



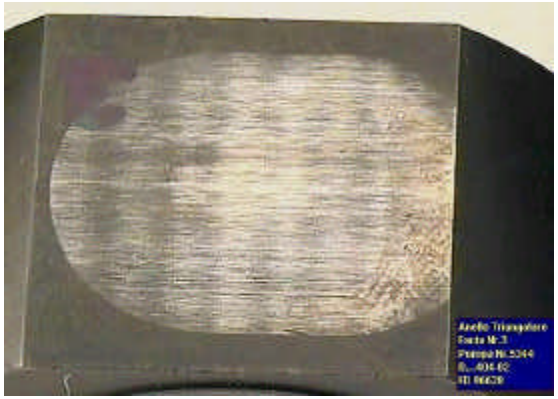


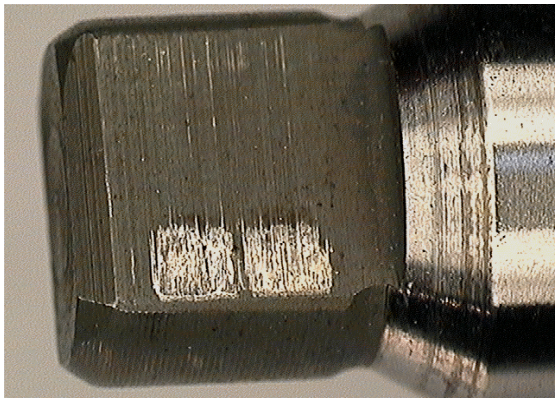
Wear rating = 7.0

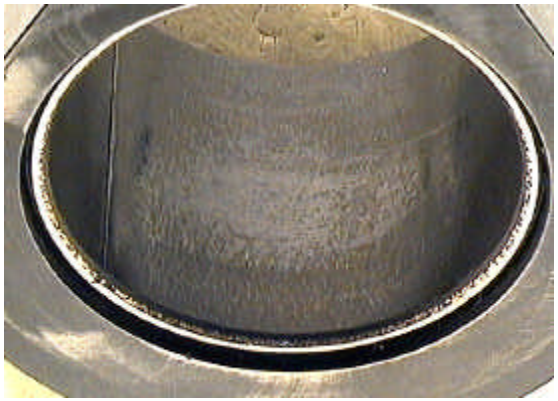
Supply pump, feed pump tooth system, high pressure piston and vanes: severe wear

- **Fuel represents worst case U.S. lubricity**
- **Fuel unfit for purpose**

Common Rail System with HFRR 460 µm Fuel

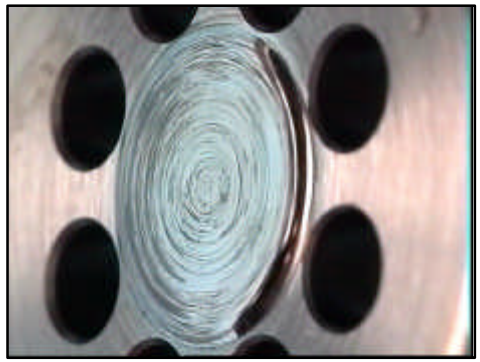
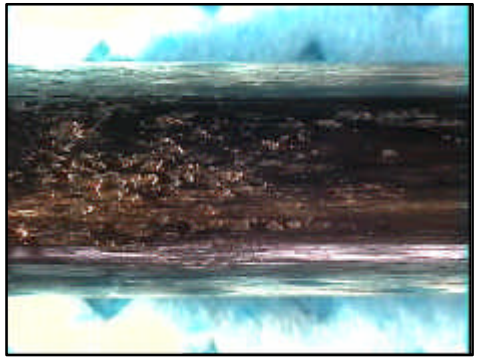
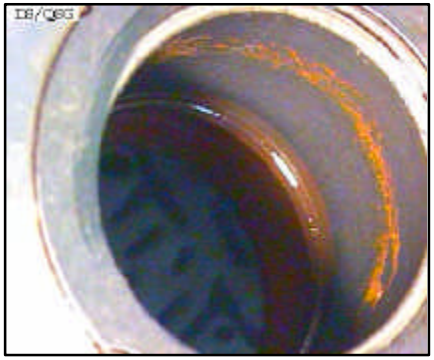


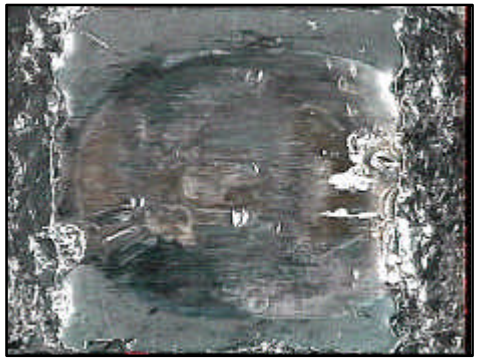




- Fuel represents borderline EU quality
- Fuel adequate for purpose

Common Rail System with HFRR 650 µm Fuel




Wear rating = 9.0

Piston: Seizure Piston bottom center: 15 µm; Bearing shell: Seizure; Polygon: ≥ 1000 µm

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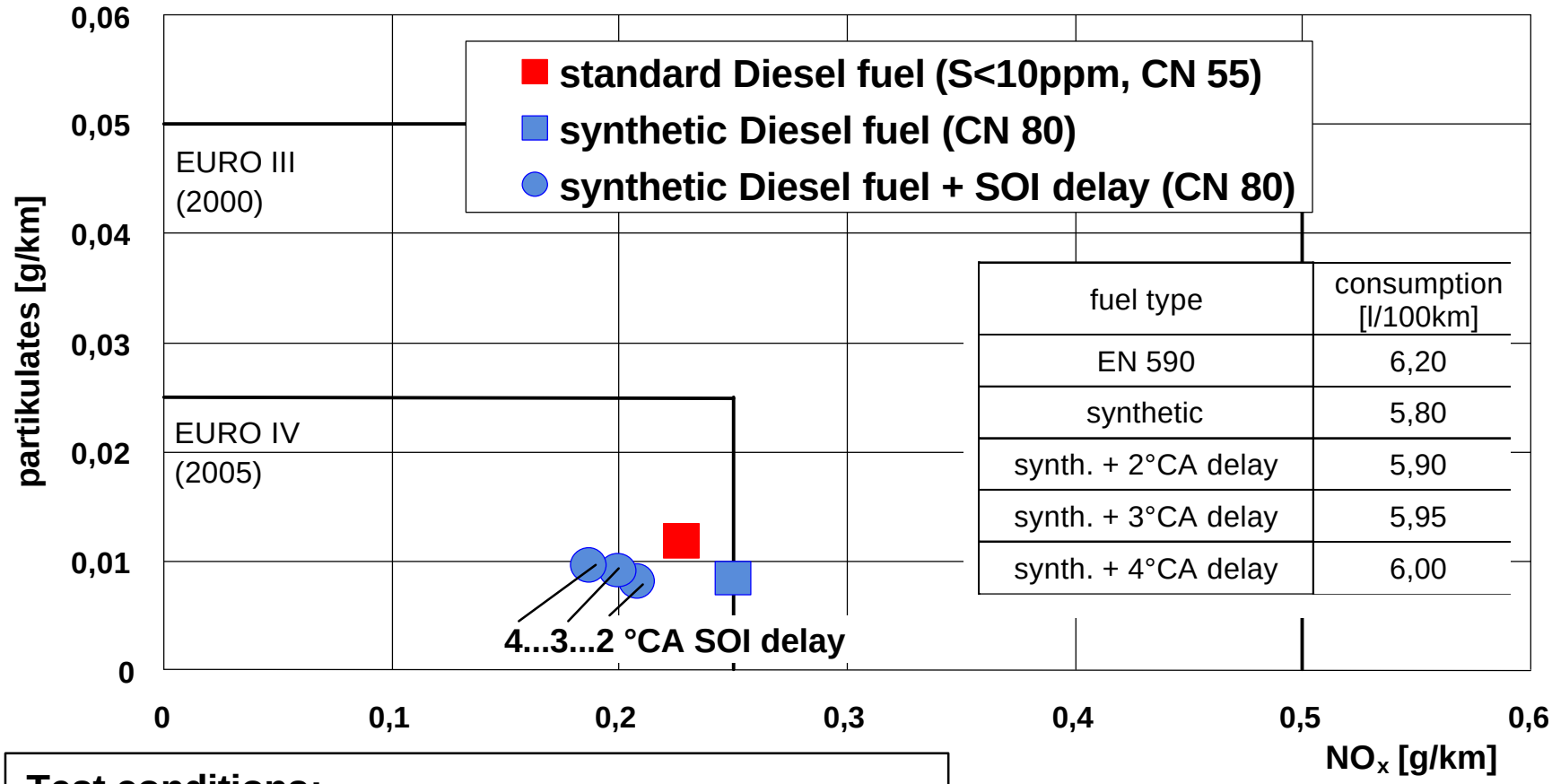
Total Contamination (particulates)	mg/kg	0.8 ... 3.1	< 24	some high numbers (EN590 limit too high)
Lubricity	µm (HFRR 60C)	351 ... 648	< 460	80% of samples > 460 µm
Alcohol	% vol.	< 0.1	n.a.	o.k.

NO_x and PM Reduction with CN 55 and 80 Fuels



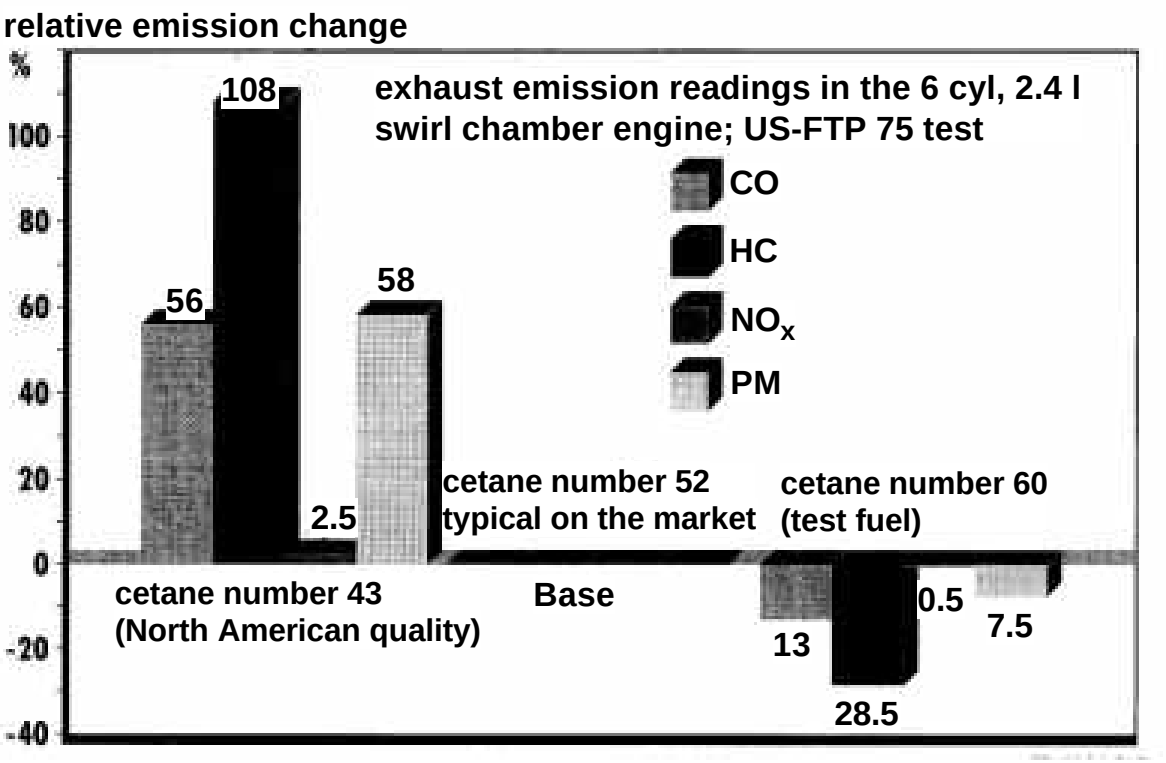
fuel type	consumption [l/100km]
EN 590	6,20
synthetic	5,80
synth. + 2°CA delay	5,90
synth. + 3°CA delay	5,95
synth. + 4°CA delay	6,00

Test conditions:

2.2 l DI engine

European test cycle; MNEDC (cold test with PI)

NO_x and PM Reduction with CN 60 Fuels

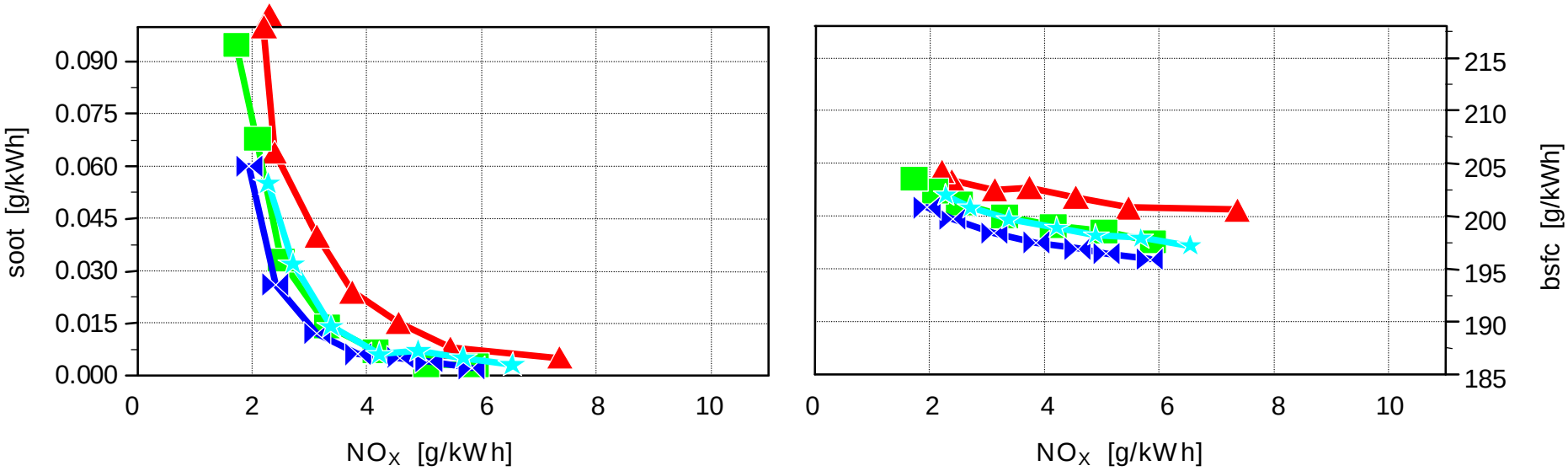


Test conditions:

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%

BOSCH

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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