

Heavy Duty Diesel Engines Developed from Euro 3 to Euro 4

SIAT 2005

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Content

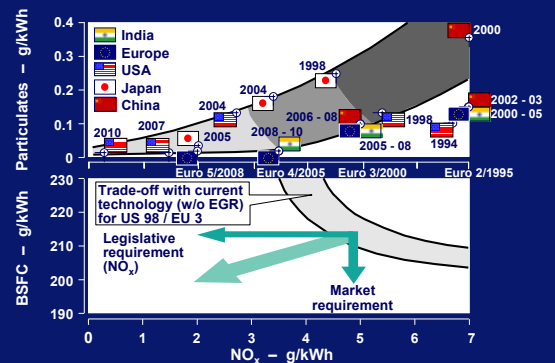
- Emission Legislation
- Euro 4 Emission Development Strategy Options
- Emission Reduction Technology
- Results from AVL R&D Work
- Conclusion and Summary

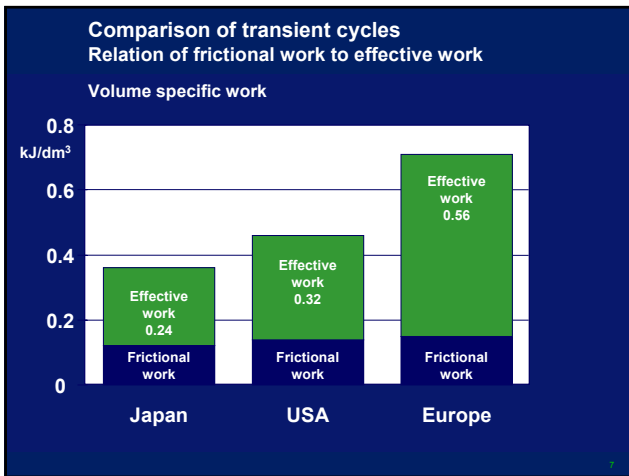
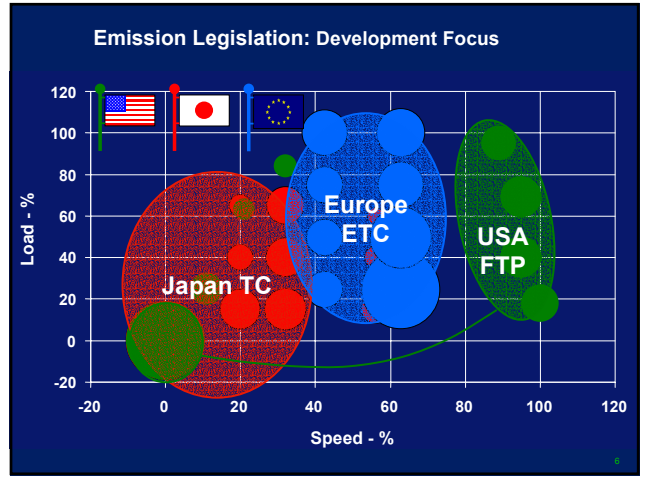
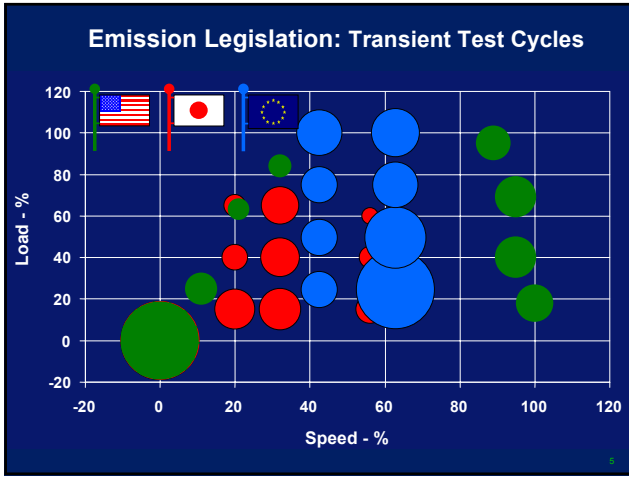
Heavy Duty Diesel Engines Developed from Euro 3 to Euro 4

Content

- Emission Legislation
 - Limits and Fuel Economy
 - Transient Test Cycles
- Euro 4 Emission Development Strategy Options
- Emission Reduction Technology
- Results from AVL R&D Work
- Conclusion and Summary

Emission Legislation Limits and fuel economy





- ### Heavy Duty Diesel Engines
- #### Developed from Euro 3 to Euro 4
- #### Content
- Emission Legislation
 - Euro 4 Emission Development Strategy Options
 - Cooled EGR and Particulate reduction
 - NO_x reduction with SCR
 - Emission Reduction Technology
 - Results from AVL R&D Work
 - Conclusion and Summary

Cooled EGR and Particulate Reduction Hardware Requirements with DPf for Euro 4

Euro 3

Base engine:

- Mechanically sound engine
- Lube oil consumption < 0,1g/KWh
- Peak firing pressure potential 200 bar

Displacement
0.9 - 1.4 liter / cyl.

Rated speed
2200 - 2600 rpm

+

- High performance EGR-system
- Improved vehicle cooling system
- Fully flexible FIE with > 1600 bar
- 2-stage turbocharging for > 32 kW/l

+

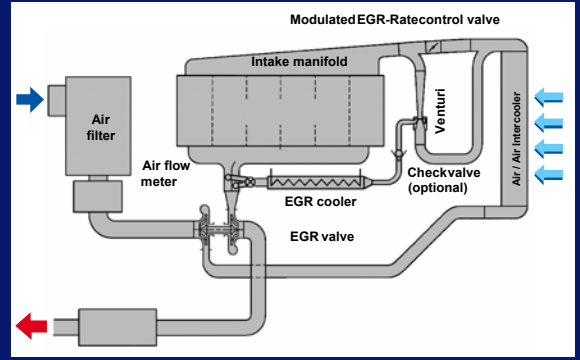
- Combustion system
- high EGR tolerance
 - combustion bowl for low soot in oil
 - alternative combustion at part load for temperature management

+

Diesel particulate filter >70% eff.

Euro 4

Cooled High Pressure EGR

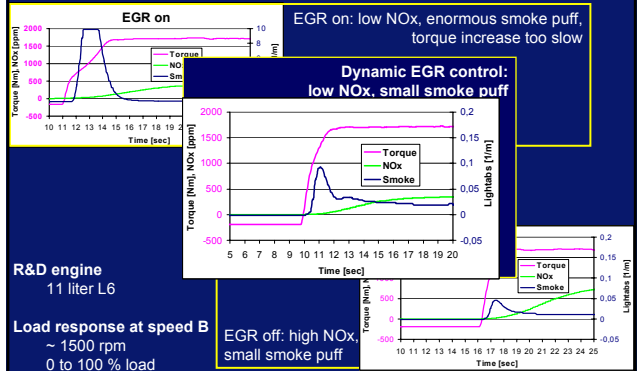


Cooled High Pressure EGR ESC Test Results, 300 kW HDDE

	NOx	HC	CO	PM - after Oxicat			BSFC
				tot	insol	sol	
EURO 4 Limits	3.50	0.46	1.50	0.02			
Test results	3.30	0.02	0.04	0.015	0.010	0.005	210

Prerequisite: Conversion Rate of Oxicat > 60 %

Cooled High Pressure EGR Dynamic EGR Control: Model Based Controller



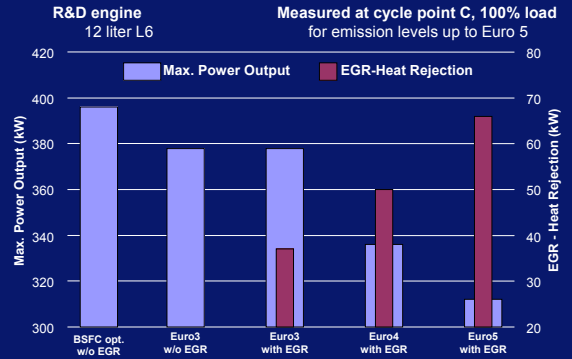
Cooled High Pressure EGR ETC Test Results, 300 kW HDDE

	NOx	HC	CO	PM - after Oxicat			BSFC
				tot	insol	sol	
EURO 4 Limits	3.50	0.55	4.0	0.030			
Test results	3.30	0.03	0.06	0.025	0.016	0.009	220

Prerequisite: Conversion Rate of Oxicat > 60 %

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Cooled High Pressure EGR EGR Heat Rejection



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Cooled EGR and Particulate Reduction Hardware Requirements with POC for Euro 4

Euro 3

- Base engine:
- Mechanically sound engine
 - Lube oil consumption < 0,1g/KWh
 - Peak firing pressure potential 200 bar

Displacement
0.9 - 1.4 liter / cyl.

Rated speed
2200 - 2600 rpm

- +
- High performance EGR-system
 - Improved vehicle cooling system
 - Fully flexible FIE with > 1800 bar
 - 2-stage turbocharging for > 32 kW/l

- +
- Combustion system
- high EGR tolerance
 - combustion bowl for low soot in oil
 - alternative combustion at part load for temperature management

+

Particulate oxidation catalyst > 50%

Euro 4

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Engine Concept Requirements Hardware Requirements with SCR for Euro 4

Euro 3

- Base engine:
- Mechanically sound engine
 - Lube oil consumption < 0,1g/KWh
 - Peak firing pressure potential 135 bar

Displacement
0.9 - 1.4 litre / cyl.

Rated speed
2200 - 2600 rpm

- +
- No EGR-system
 - Fully flexible FIE with > 1600 bar
 - Peak firing pressure potential 145 bar
 - 4 Valve cylinder head

Specific power
26.4 kW / litre

- +
- Combustion system
- Combustion bowl for low soot in oil
 - Alternative combustion at part load for temperature management

+

SCR system > 60%NO_x, 50%PM eff.

Euro 4

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Heavy Duty Diesel Engines Developed from Euro 3 to Euro 4

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- Emission Legislation
- Euro 4 Emission Development Strategy Options
- Emission Reduction Technology
 - Base engine
 - Exhaust gas aftertreatment
- Results from AVL R&D Work
- Conclusion and Summary

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Technical Requirements for Emission Reduction

NO_x-Reduction

- Injection timing retardation
- Turbo-charging and intercooling
- Cooled EGR
- Smoother combustion as achievable e.g. by injection rate shaping

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Technical Requirements for Emission Reduction

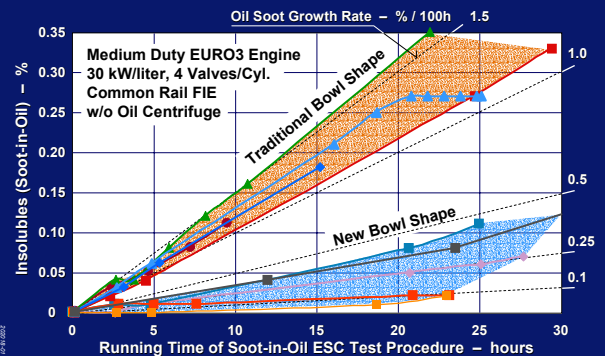
Soot-Reduction:

Maintaining

- sufficiently high burnt-gas temperature towards the end of combustion to promote in-cylinder soot burn-up (post injection)
- high oxygen content and high cylinder pressure by higher boost pressure for higher overall air-fuel ratio
- higher injection pressure for higher local air-fuel ratio

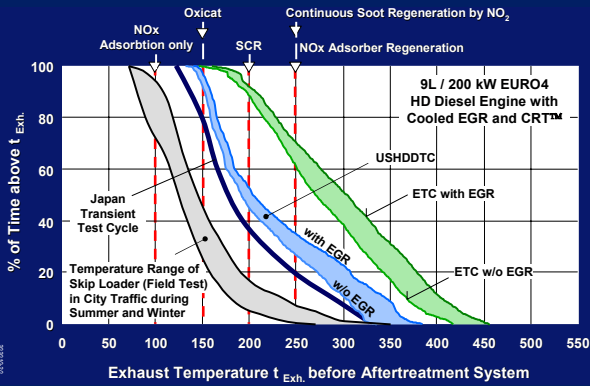
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Solving the Soot-In-Oil Problem: Effect of Combustion Bowl Shape

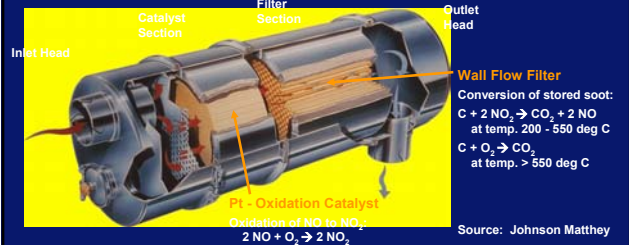


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Emission Development: Requirements for Euro 4 - Critical Temperatures for Exhaust Aftertreatment



Emission Reduction Technology EGR + Particulate Reduction with DPF

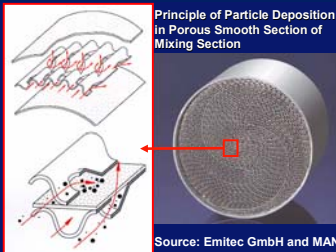


- | | |
|-------------------|--|
| Advantages | <ul style="list-style-type: none"> High PM conversion rates |
| Challenges | <ul style="list-style-type: none"> Regeneration: min. 250°C exhaust gas temperature Low sulfur fuel required to avoid too frequent maintenance due to ash accumulation |

Emission Reduction Technology EGR + Particulate Reduction with POC

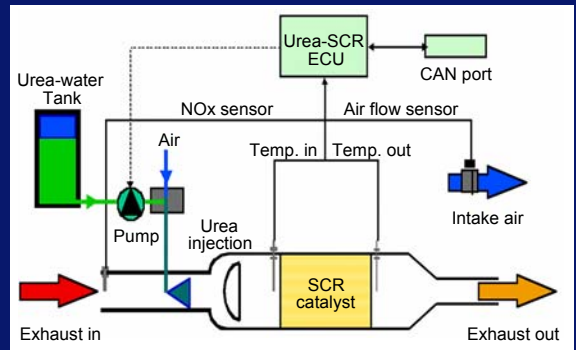
Mechanism and Effectiveness:

- Carbon-PM oxidized by NO₂ being formed in Oxicat
- HC, Sol-PM and CO oxidized in Oxicat
- Conversion Rates (ESC & ETC):
 - Particulates: $\eta_{PM} \approx 50\%$, Target: $\eta_{PM} \approx 70\%$ by further development
 - Hydrocarbon: $\eta_{HC} \approx 85\%$
 - Carbon monoxide: $\eta_{CO} \approx 90\%$

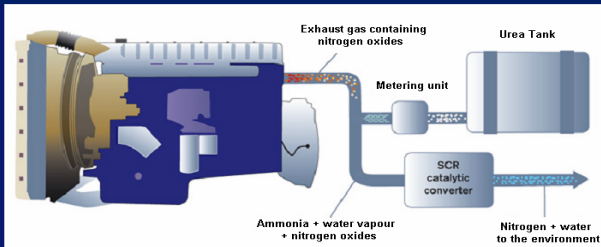


- | | |
|-------------------|---|
| Advantages | <ul style="list-style-type: none"> No risk of filter blocking, no active regeneration Small packaging volume |
| Challenges | <ul style="list-style-type: none"> Lower conversion rates compared to DPF Requires higher fuel injection pressure Low sulfur fuel required |

SCR - Selective Catalytic Reduction

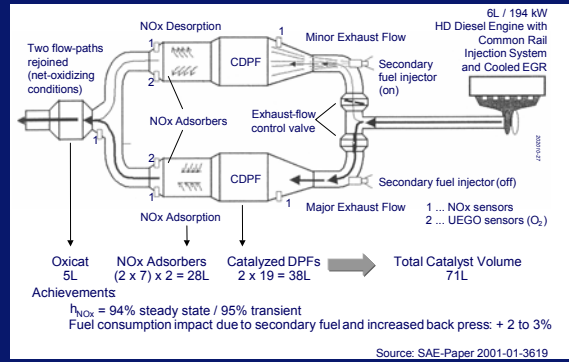


Emission Reduction Technology Selective Catalytic Reduction - SCR



Advantages	<ul style="list-style-type: none"> Better fuel economy compared to EGR + part. reduction
Challenges	<ul style="list-style-type: none"> Urea infrastructure required Regeneration: min. 200°C exhaust gas temperature Low sulfur fuel required

US-EPA No_x Adsorber Concept Schematic representation

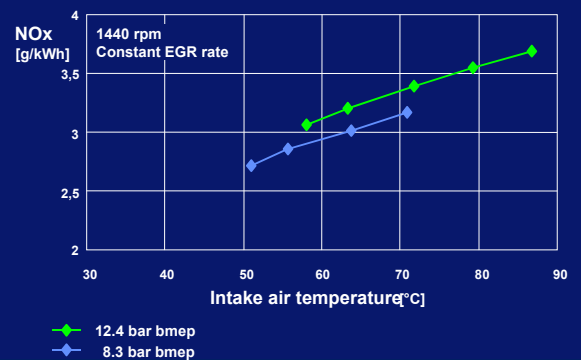


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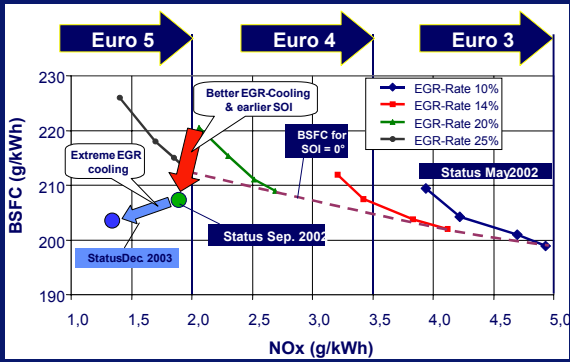
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 - Potential of cooled EGR
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Potential of low intake air temperature



Potential of cooled EGR



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Conclusion and Summary

- The development for Euro 4 compliance can start from a well developed Euro 3 engine
- Exhaust gas aftertreatment must be applied

Two options for the Indian market are recommended:

- Cooled EGR and the Particulate Oxidation Catalyst, requiring an 1800 bar common rail injection system
- SCR, requiring the logistics for Urea supply

AVL

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Thank you for your attention!

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