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SUMMARY

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Effect of Internal EGR on the Exhaust Particle Number and Size Distribution of an Off-Road Diesel Engine

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In the present study, a turbocharged, intercooled off-road diesel engine of below 75 kW was developed in order to get the engine to comply with the US Tier 3 emissions standards.

The cylinder bore of the four-cylinder engine was 108 mm and stroke 120 mm. The compression ratio was 18.5. A rotary-type mechanical injection pump was used. The engine was loaded according to the ISO 8178 C1 cycle, having eight (8) loading points and intended for off-road engines.

The test fuel was low-sulfur diesel fuel oil with a sulfur content of 60 ppm by mass. The total content of the aromatic compounds was approximately 23 mass-%. The ash content was very low, below 0.001 mass-%. The cetane number was approximately 56.

Internal EGR (iEGR) was the main method to reduce NO_x. The injection timing was appropriately adjusted. Additionally, a waste-gate turbocharger (WG TC) was tested parallel with the standard TC.

Six different camshafts were tested, some of them generating deliberate iEGR and the others being ordinary camshafts. NO_x did reduce when iEGR was used and injection timing and turbo-charging were optimized. At the same time, HC, however, also increased. Nevertheless, the sum of non-methane hydrocarbons (NMHC) and NO_x – defined as a limited criterion within the Tier 3 – decreased below the limit given by the emissions legislation.

CO and PM emissions also increased with iEGR and adopted adjustments, but specific fuel oil consumption slightly decreased. Particulate matter (PM) was still below the given limit and CO was very low compared with the limit, as is usual for diesel engines.

At rated power, the exhaust particle number slightly increased with iEGR within the entire particle size range, but not at full load at the intermediate speed (1320 rpm). Here, the particle number decreased relative to the standard camshaft without deliberate iEGR.

At half load at rated speed, major iEGR slightly increased the ultra-fine particle number, but large particles were reduced. At 50 % load at 1320 rpm, major iEGR was also advantageous at large particle size categories, and ultra-fine particles were very similar independent of iEGR.

At 10 % load at rated speed, the highest iEGR again resulted in the smallest amount of large particles, but in a slightly higher ultra-fine particle numbers than the smaller iEGR or standard camshaft.

At 10 % load at 1320 rpm, the medium iEGR led to the highest particle numbers within the whole particle size range. High iEGR, in contrast, was the best at large particles. Within the ultra-fines, the high iEGR and standard camshaft were almost equal.

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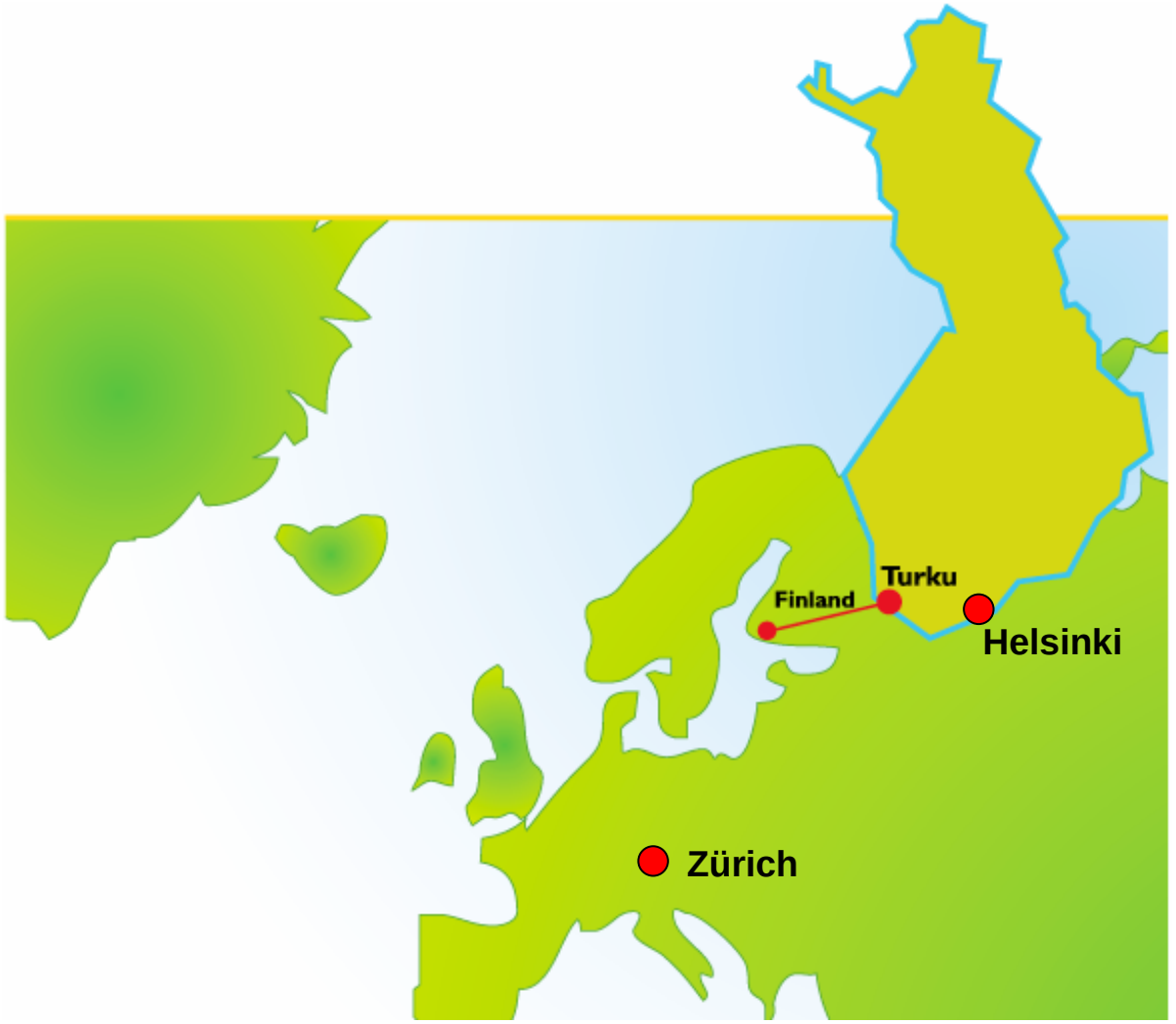

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Background, objectives, experimental set-up

Background

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- The emissions legislation becomes more stringent year by year
- Cost-effective means must be found for emissions reduction
  - After-treatment methods cause additional initial and O&M costs
  - In-cylinder methods should be preferred

Objectives

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1. To reduce the regulated exhaust emissions of an off-road diesel engine down to the US Tier 3 level
   - Output < 75 kW
   - NMHC + NO_x < 4.7 g/kWh
   - CO < 5.0 g/kWh
   - PM < 0.4 g/kWh

2. To clarify how the in-cylinder emissions reduction methods affect the exhaust particle number and size distribution

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Test engine

Cylinder number		**4**
Swept volume	**dm^3**	**4.4**
Bore	**mm**	**108**
Stroke	**mm**	**120**
Rated speed	**rpm**	**2200**
Compression ratio		**18.5**
Maximum torque	**Nm**	**470**
Maximum power	**kW**	**75**
Injection pump		**Mechanically-controlled distributor pump**
Turbochargers		**Standard and Waste-Gate, charge air cooling**
Camshafts		**Six different**

Properties of the test fuel

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Carbon	**mass-%**	**85.7**
Hydrogen	**mass-%**	**13.6**
Monoaromatics	**mass-%**	**19.6**
Diaromatics	**mass-%**	**2.7**
Tri+aromatics	**mass-%**	**0.3**
Polyaromatics (Di+, Tri+)	**mass-%**	**3**
Total aromatics	**mass-%**	**22.6**
Nitrogen	**mg/kg**	**21**
Sulphur	**mg/kg**	**60**
Ash	**mass-%**	**< 0.001**
Cetane number		**55.5**

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Tested components and parameters

1. Injection timing
2. Camshafts with and without internal EGR
3. Turbochargers
   - Standard (Std)
   - Waste-Gate (WG)

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Main results

EGR at rated speed

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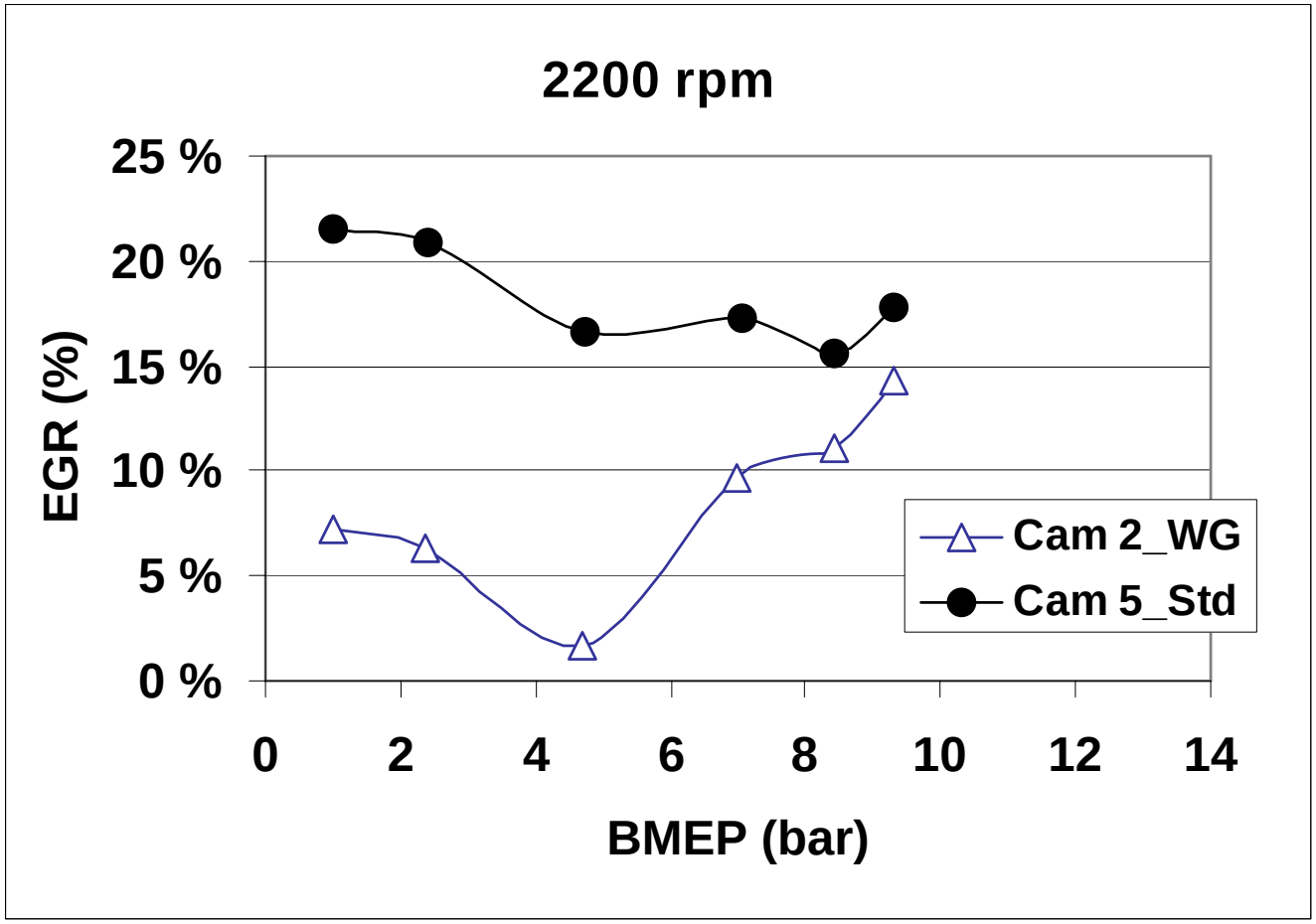

EGR at intermediate speed

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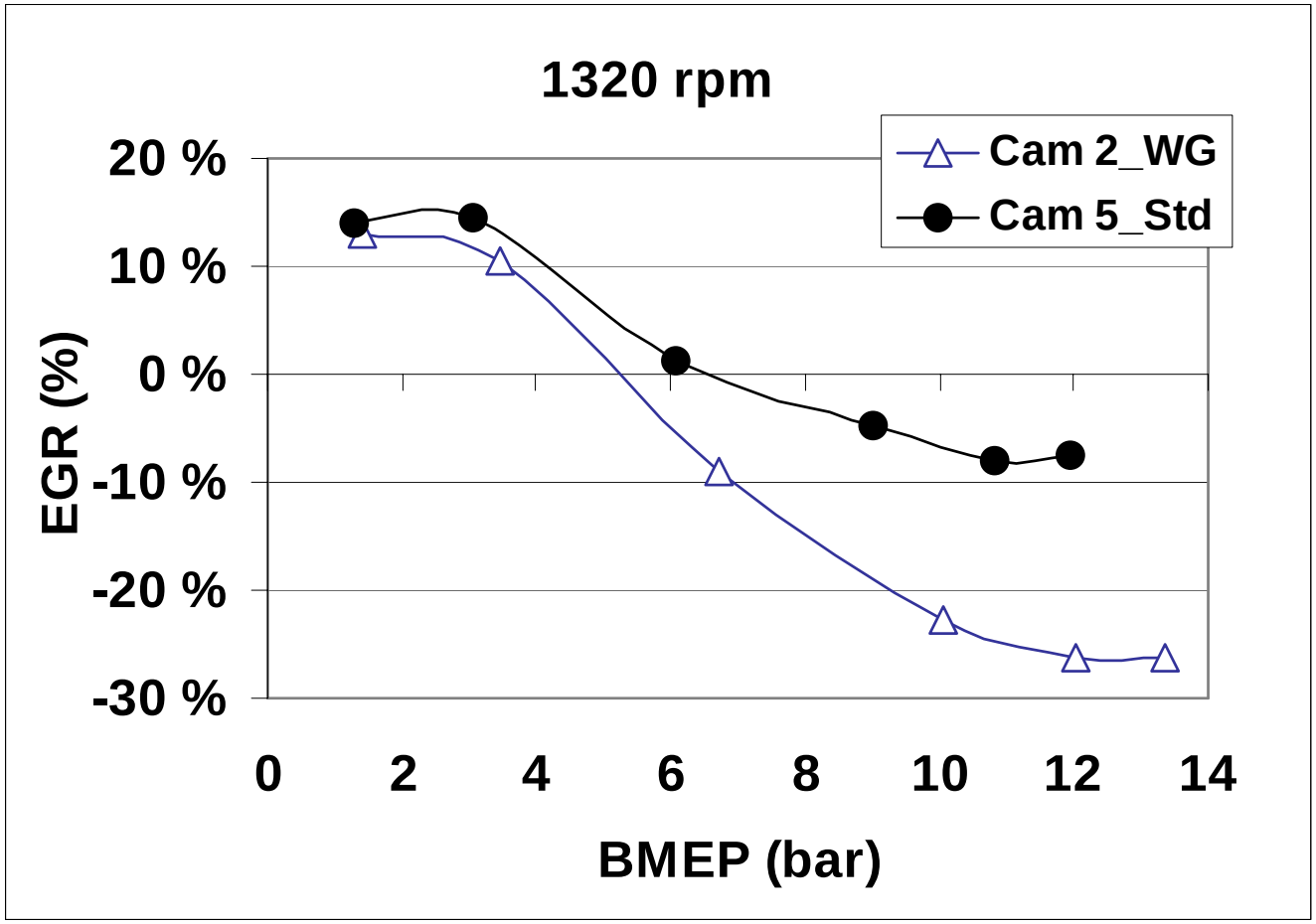

$NMHC+NO_x$ and NO_x

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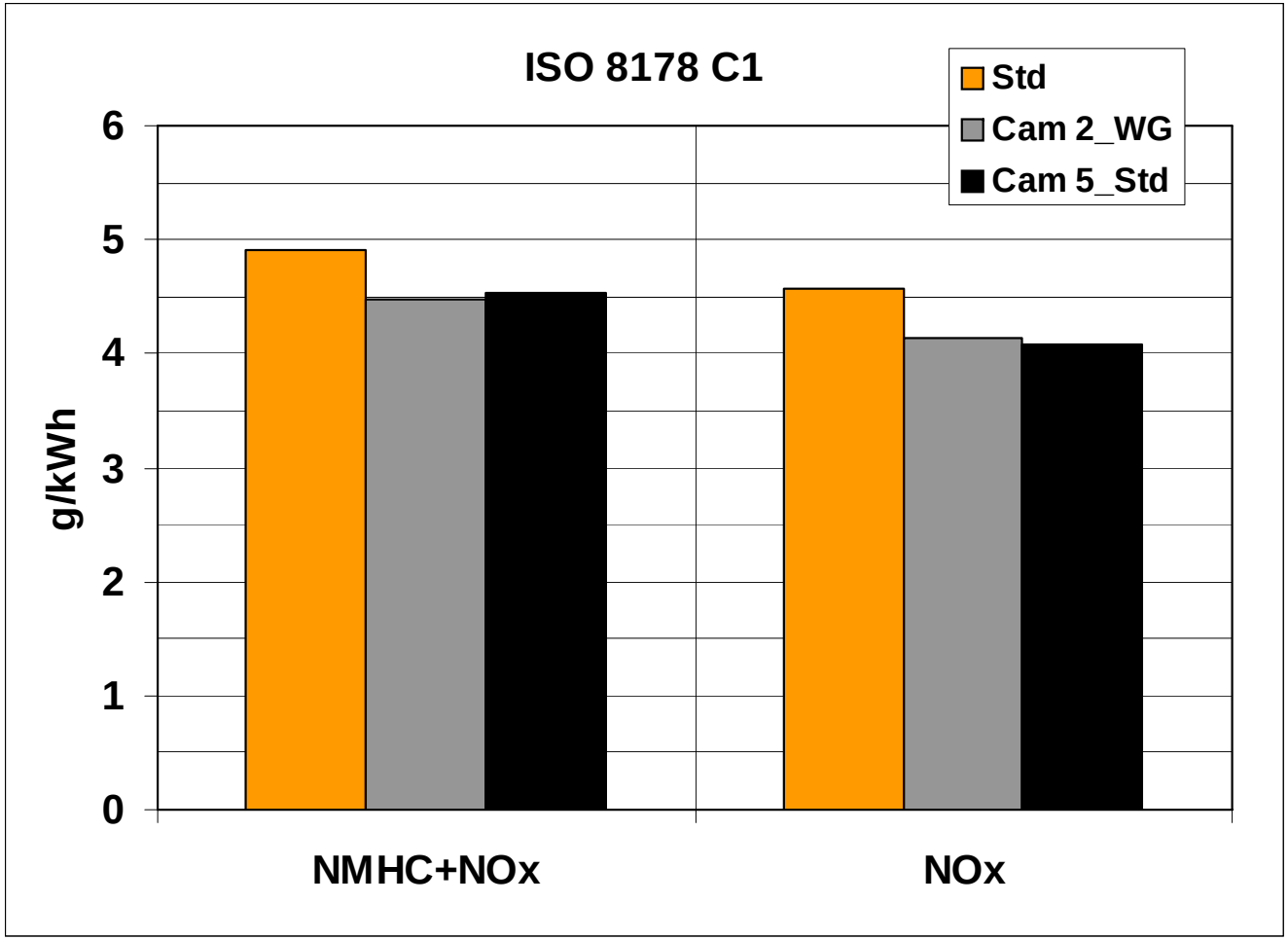

HC and CO

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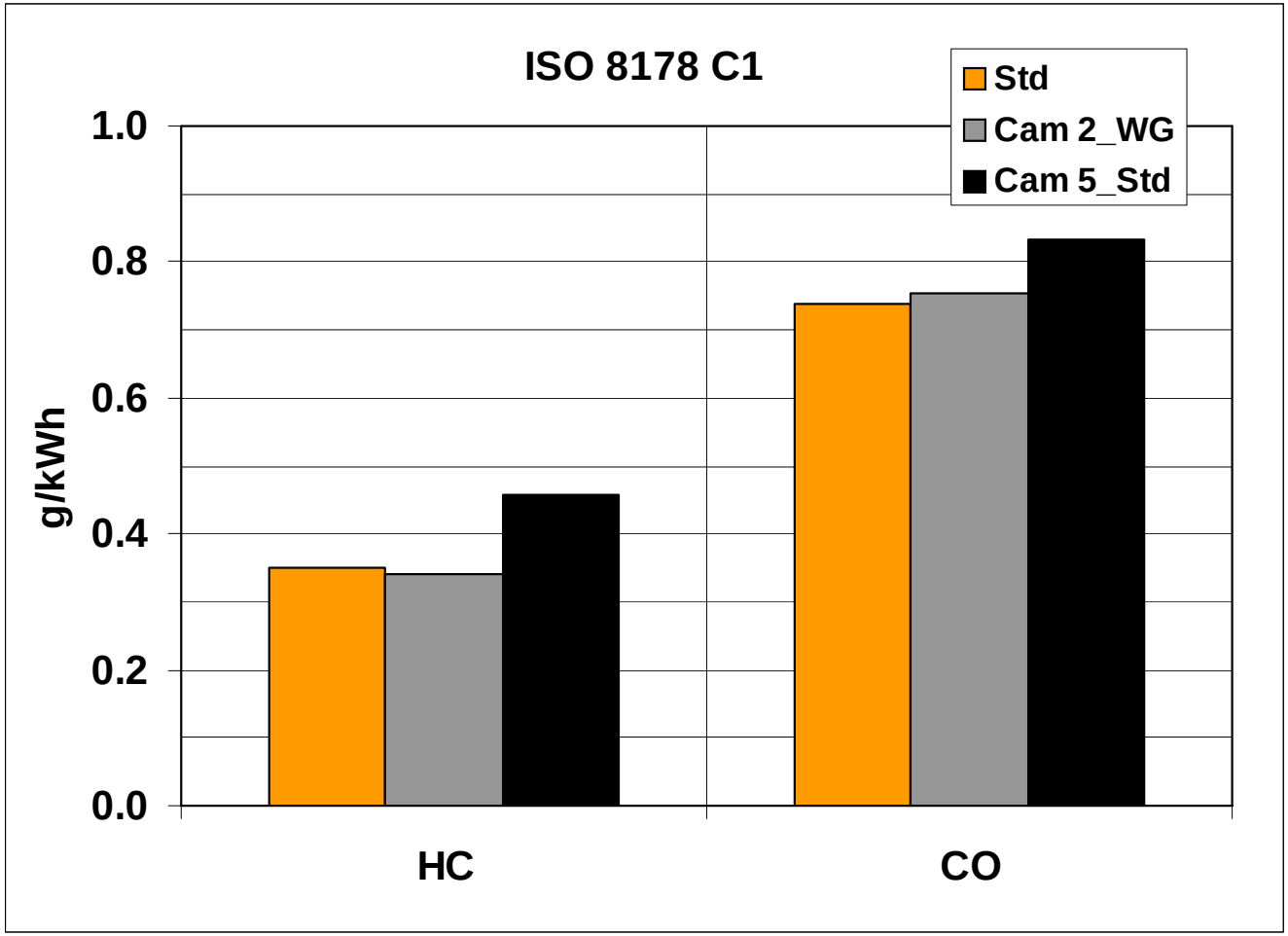

PM and specific fuel consumption (SFC)

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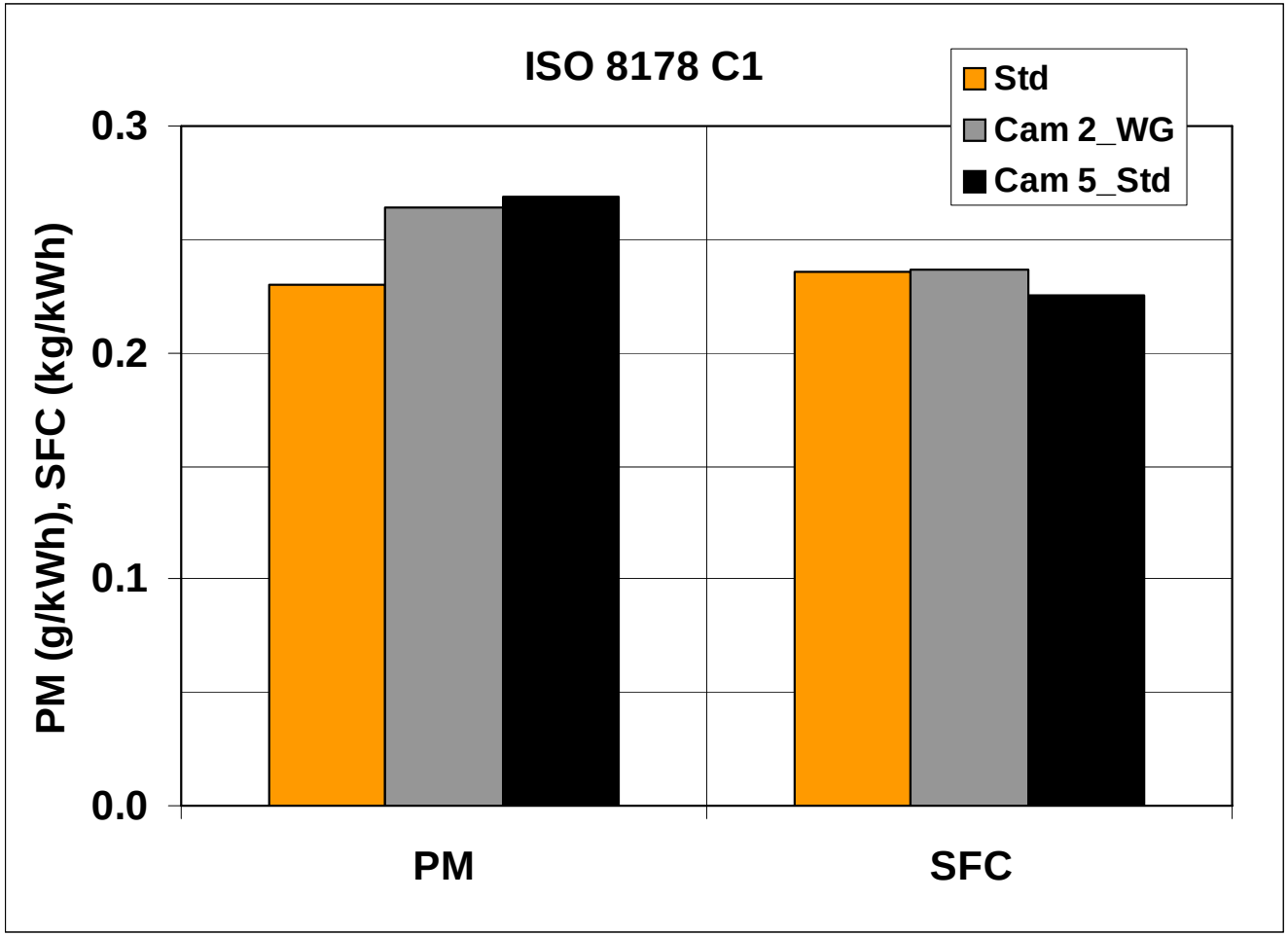

Particle number at full output

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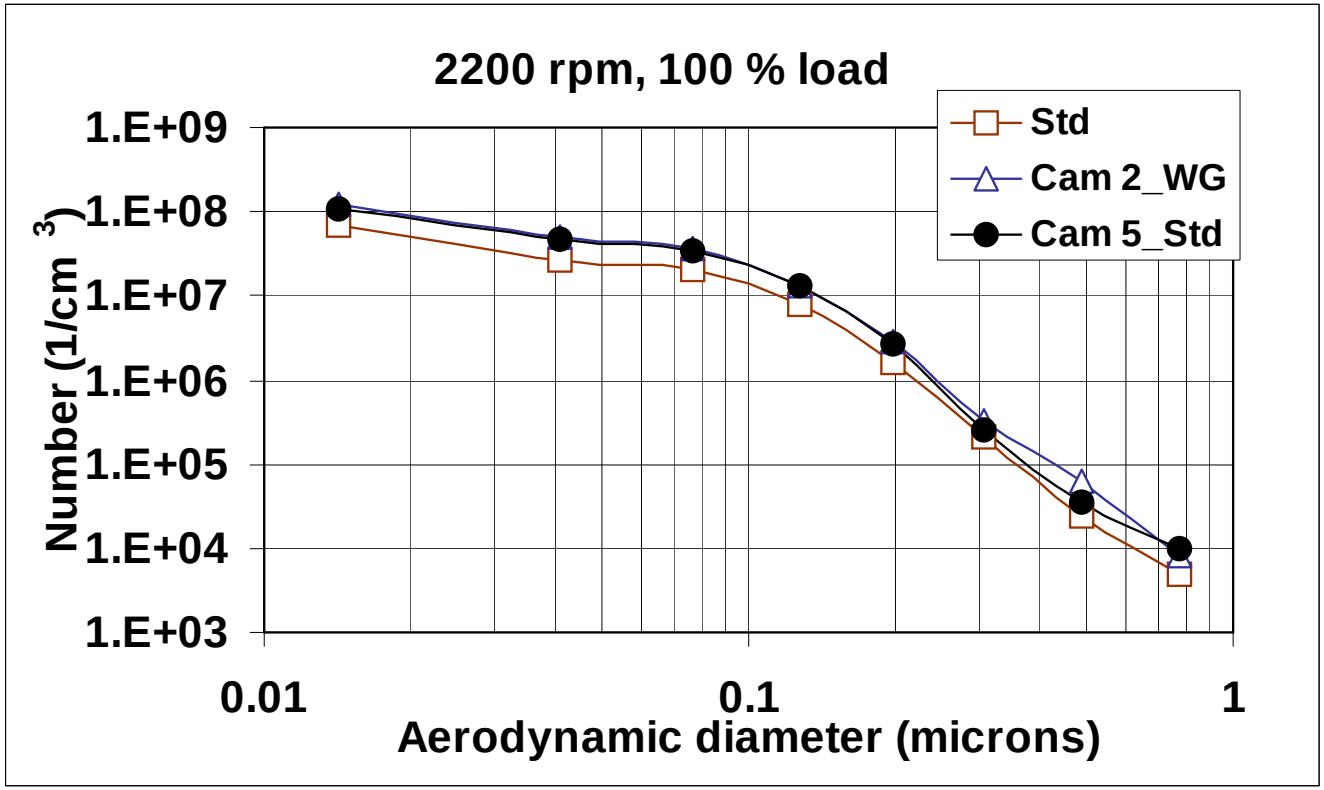

Particle number at half load at rated speed

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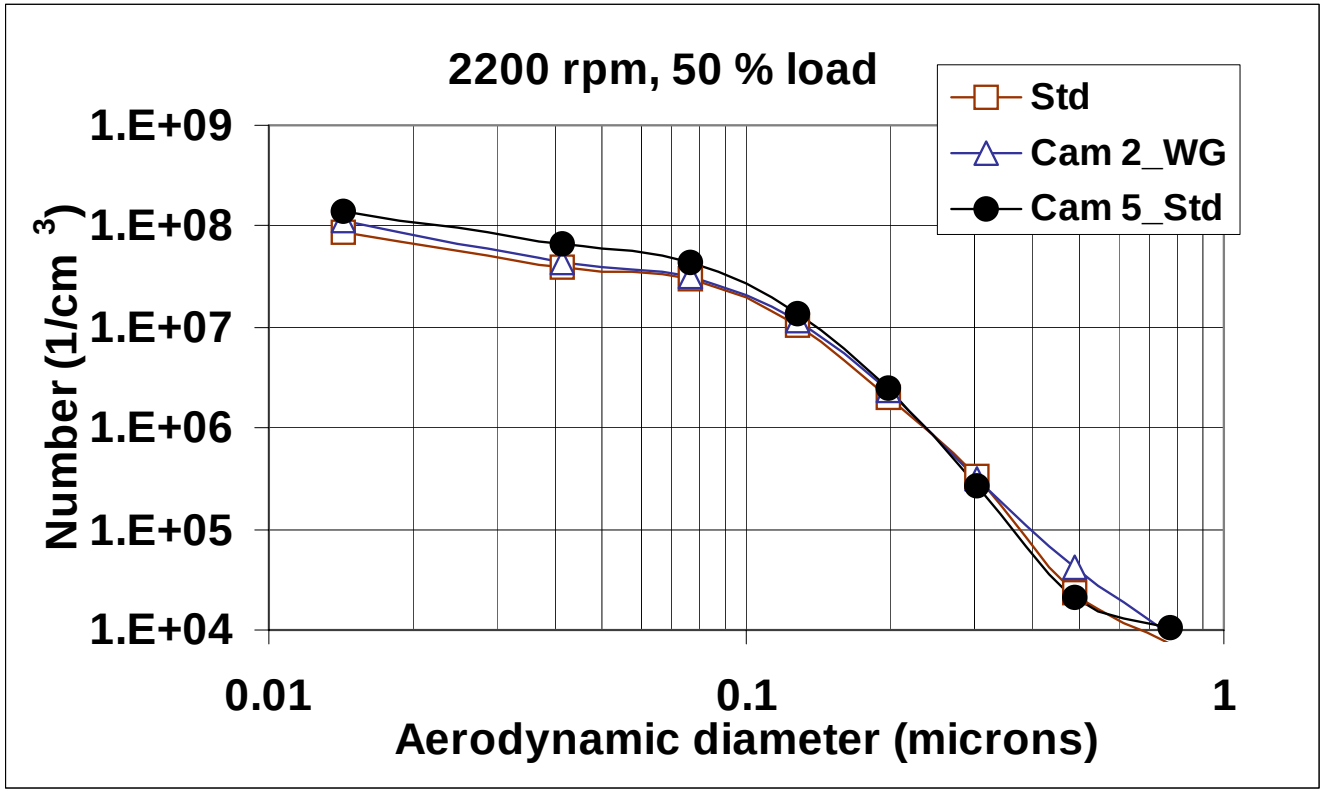

Particle number at full load at intermediate speed

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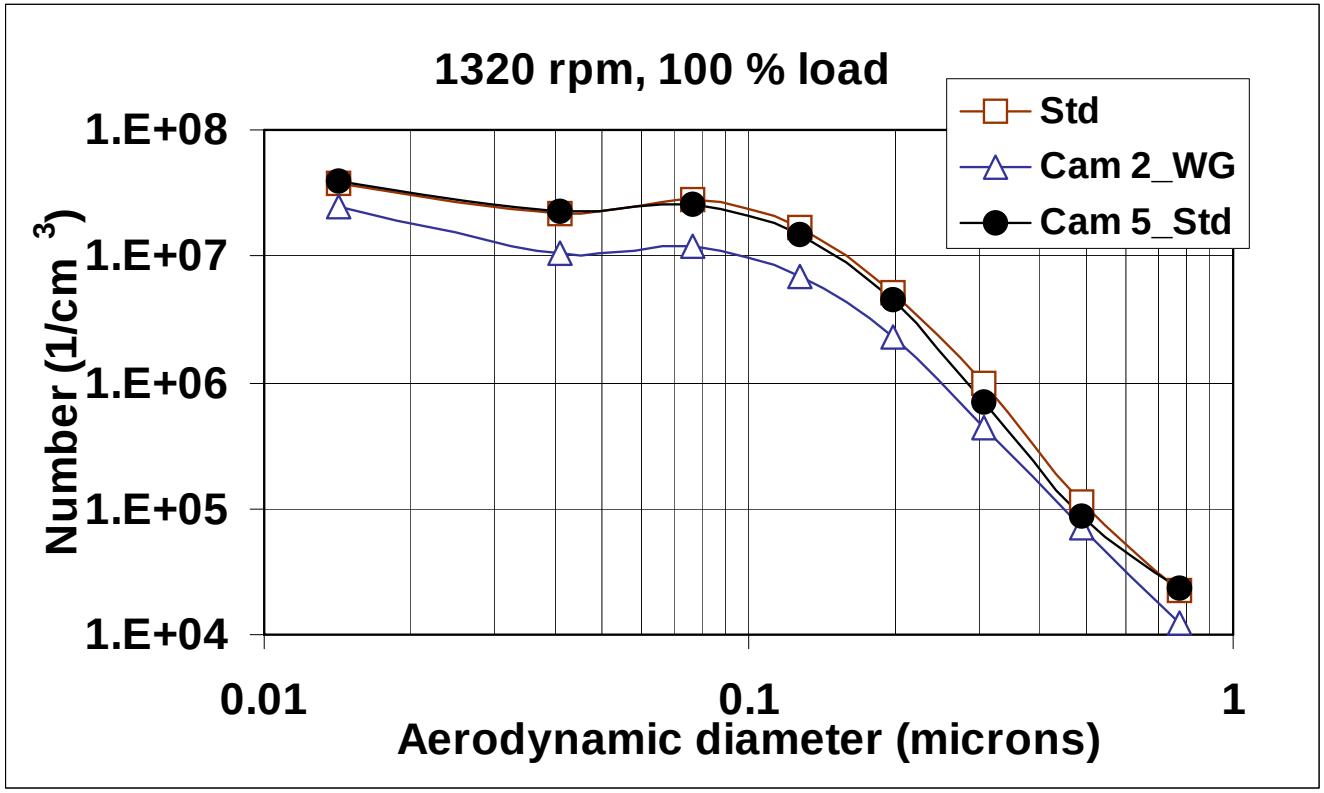

Particle number at half load at intermediate speed

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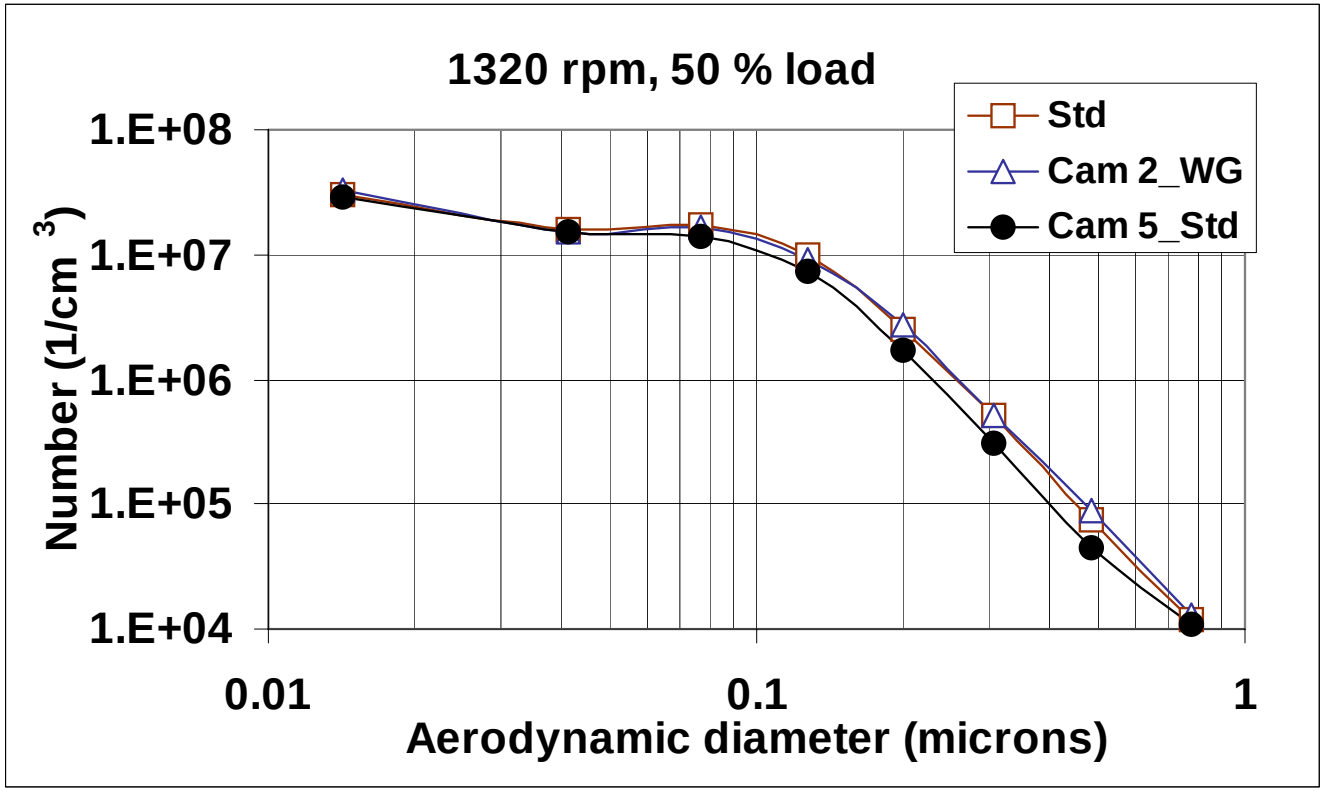

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Conclusions

Conclusions 1

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- The off-road test engine complied with the US Tier 3 emissions legislation by adopting
  - internal EGR
  - appropriate turbocharging
  - proper injection timing

Conclusions 2

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- Along with total emissions reduction, the particle number
  - slightly increased at full output
  - remained almost unchanged at 50 % loads at rated and intermediate speeds
  - slightly decreased at full load at intermediate speed
- No essential deterioration was detected in particle behaviour due to internal EGR with adjustments

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Thank you for your kind attention!