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SUMMARY

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Effects of injection nozzles, waste-gate turbocharger and oxidation catalyst on the exhaust particle number and size distributions of an off-road diesel engine

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Exhaust emissions of all kind of diesel engines are to be drastically reduced in the near future both in the EU, Japan, and the US. Of the pollutants, the oxides of nitrogen (NO_x) and particulate matter (PM) form the main challenge for the diesel engine development. Thanks to the new strict legislation, new engine models will emit considerably less exhaust pollutants than the older engines.

Nevertheless, a great number of older engine models will remain, e.g., in off-road use and the operators will be continuously exposed to very high levels of exhaust particles and other pollutants unless improvements are implemented for those engines.

In the present study, a turbocharged, inter-cooled direct-injection off-road diesel engine of type Euro 1 was developed with the aim to particularly reduce exhaust particle number at different engine loads. The main aim of the development work was to make the engine less vulnerable for the operators working in the immediate vicinity of the engine. The swept volume of the engine was 4.4 dm^3. The engine had a traditional mechanical in-line injection pump. European low-sulphur diesel fuel oil was used as fuel in the study. The engine was operated at a rated speed of 2400 rpm, at an intermediate speed of 1500 rpm, and at idle.

As a first means to reach the goal, injection nozzles were optimised. Second, the effects of a waste-gate turbocharger (WG TC) were studied. Finally, an oxidation catalyst was incorporated into the exhaust system to further reduce the exhaust particle number. All of these measures were selected with the aim not to increase modification or retrofitting costs too much.

Three different injector tips were studied. The standard tips had five orifices with a bore of 0.275 mm. The six-hole test nozzles had an orifice diameter of 0.255 mm and the seven-hole tips 0.235 mm. The flow rate of the both test tips was approximately 6% lower than that of the standard nozzles. Consequently, the injection period was slightly lengthened with test nozzles relative to standard tips.

The increase in the injection nozzle holes reduced the exhaust particle number best at medium loads at 1500 rpm. Very often, the number of the smallest particles tended, however, to increase with six- and seven-hole injector tips. At high loads, this was perhaps due to the lengthened injection period. This increase was, however, also apparent at low engine power. At idle and to some extent even at 1500 rpm, the seven-hole tips were competitive with the six-hole ones, but at rated speed the seven-hole injector tips were clearly worse than standard or six-hole nozzles.

Regarding NO_x, the six-hole injector tips generated the highest concentrations at medium and high loads at both speeds, whereas the lowest NO_x contents were generally recorded with seven-hole nozzles. At almost all loads, the brake specific fuel consumption (BSFC) was the lowest with six-hole tips at both speeds while the use of seven-hole nozzles often resulted in the highest fuel consumption.

As a whole, it seems that the injector tip geometry must be optimised based on the loading profile of the off-road machine. No combination of the injector and combustion chamber geometry was found that would have proved optimal within the entire speed-load envelope.

The use of a waste-gate turbocharger also had an advantageous effect on the particle number of the engine exhaust under some loading conditions. At high loads at 1500 rpm, the total particle concentration decreased and no increase was detected in any particle size category. At low loads, however, particles generally slightly increased. At rated speed, some particle sizes increased, some decreased. At high loads, close to rated power, an increase was evident in the vicinity of 100 nm particles and no clear reductions were observed. At other loads, larger particles were usually reduced, but smaller increased. At 25% load, an overall favourable result was, however, achieved.

The use of the waste-gate turbocharger did not increase brake specific NO_x ($BSNO_x$) emissions at 1500 rpm, but NO_x reductions were detected at low loads. At rated speed, the $BSNO_x$ was similar or slightly lower with a WG TC than with a standard one. With the WG TC, the brake thermal efficiency (BTE) increased at 1500 rpm, but decreased at low loads at rated speed.

The prototype particle oxidation catalyst (POC) proved to be very efficient at idle and at low loads. At idle, the particle concentration clearly decreased within the whole particle size range. At higher loads, the POC generally reduced small particles of below 200 nm.

The use of the prototype POC also slightly reduced oxides of nitrogen at high loads at the intermediate speed and at almost all loads at rated speed. Of the oxides of nitrogen, nitrogen dioxide (NO_2), however, increased particularly at medium loads when the POC was used. The BTE of the engine was almost equal independent of whether the POC was used or not.

Based on the results, it can be concluded that particle emissions of an older off-road diesel engine can be reduced by optimising the injector tips, by replacing the standard turbocharger by a waste-gate one, and by incorporating a cost-effective particle catalyst into the exhaust system. Nevertheless, the loading profile of the engine or machine in question must be taken into account when selecting methods for particle reduction. The reason is that in-expensive retrofitting methods seldom affect the emissions performance beneficially within the entire load-speed range of the engine.

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Outline

- Objectives
- Test engine and catalyst specifications
- Test fuel
- Effects of injector tips
- Effects of a waste-gate turbocharger
- Effects of a particle oxidation catalyst
- Conclusions

Objectives

- To reduce particle emissions of a Euro 1 off-road diesel engine by means of
  - Modified injector tips
  - Waste-gate turbo-charging
  - A particle oxidation catalyst (prototype unit)

Test engine specification

Type	Valmet 420 DSJ
Bore	108 mm
Stroke	120 mm
Swept volume	4.4 litres
Compression ratio	16.5
Injection pump	Bosch PES 4A 95D 320 RS 2807 /D
Injector tips	Five holes, bore 0.275 mm Six holes, bore 0.255 mm Seven holes, bore 0.235 mm
Turbochargers	Schwitzer S1B and S1BG
Inter-cooler	Air-to-water, Valmet
Rated speed	2400 rpm
Intermediate speed	1500 rpm

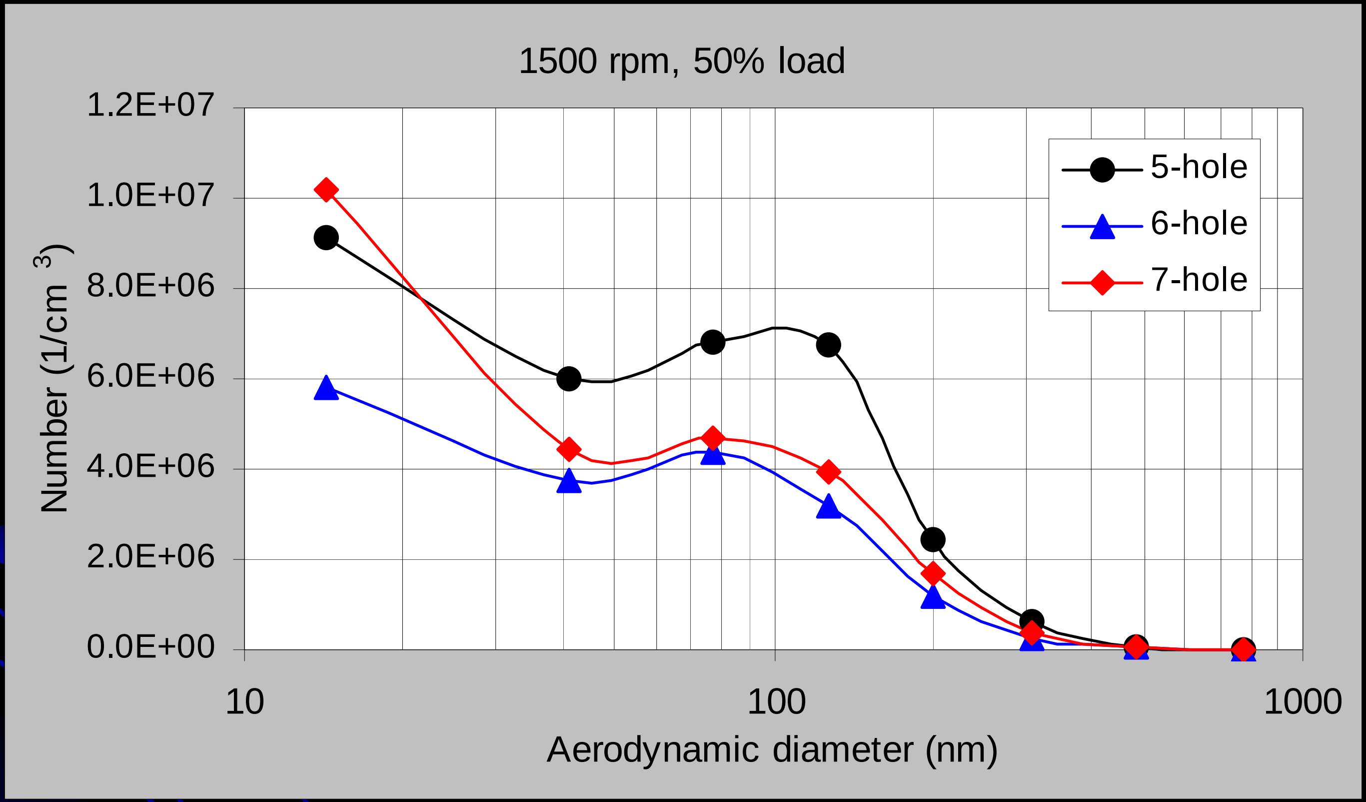
Catalyst specification

Diameter	mm	**211**
Length	mm	**152**
Volume	dm^3	**10.7**
Cross section	cm^2	**350**
Cells/in^2		**350**
Precious metals	g/dm^3	**1.41**
Precious metals, totally	g	**15.0**
Pt:Pd:Rh		**1:0:0**

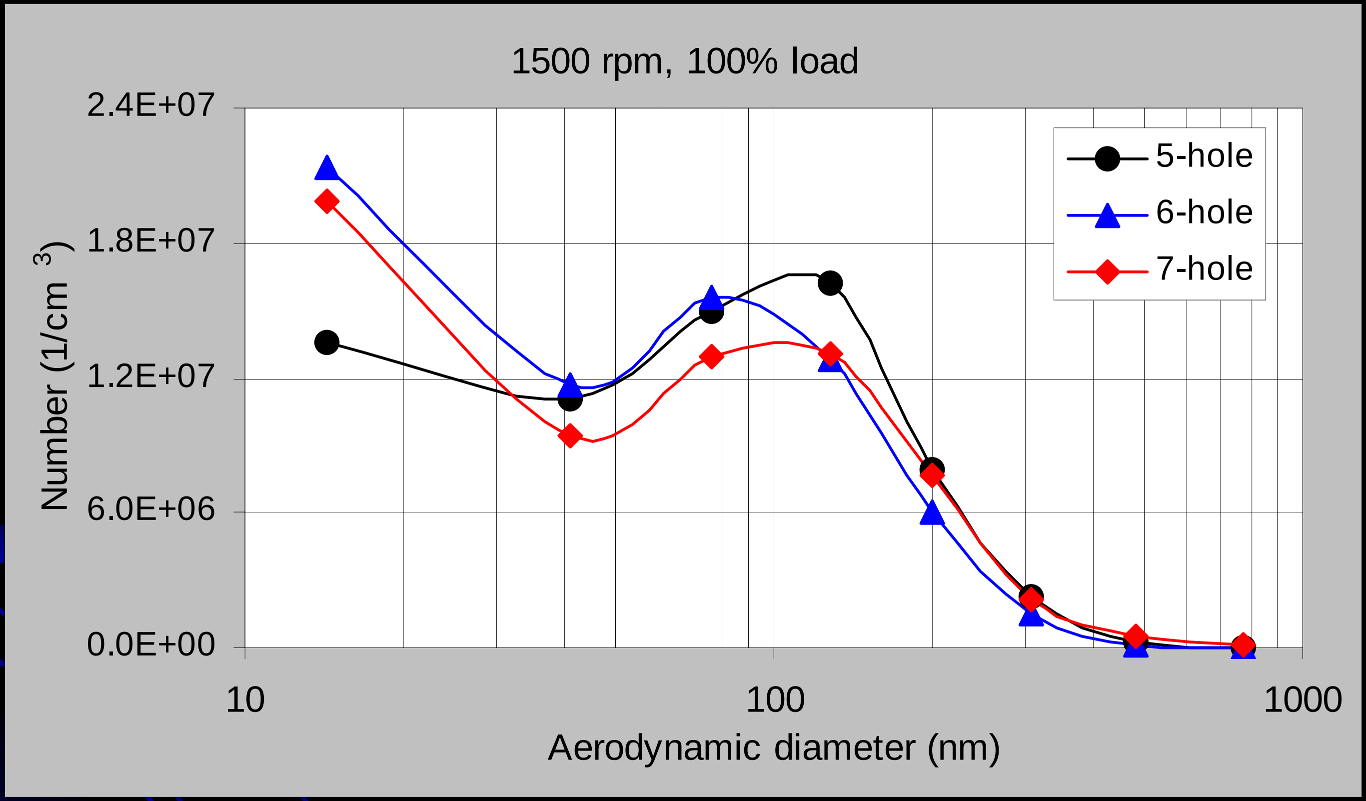
Test fuel

			Method
C	mass-%	**85.7**	ASTM D 5291
H_2	mass-%	**13.8**	ASTM D 5291
N_2	mg/kg	**28**	ASTM D 4629
S	mg/kg	**55**	XRF-Oil Guant
Ash	mass-%	**0.003**	ASTM D 5291
Monoaromatics	mass-%	**19.9**	IP 391
Di-aromatics	mass-%	**2.7**	IP 391
Tri+ aromatics	mass-%	**0.3**	IP 391
Polyaromatics (Di+, Tri+)	mass-%	**3**	IP 391
Total aromatics	mass-%	**22.9**	IP 391
Lubricity	mm	**380**	HFRR
Cetane number		**54.5**	

Effects of injector tips



Effects of injector tips



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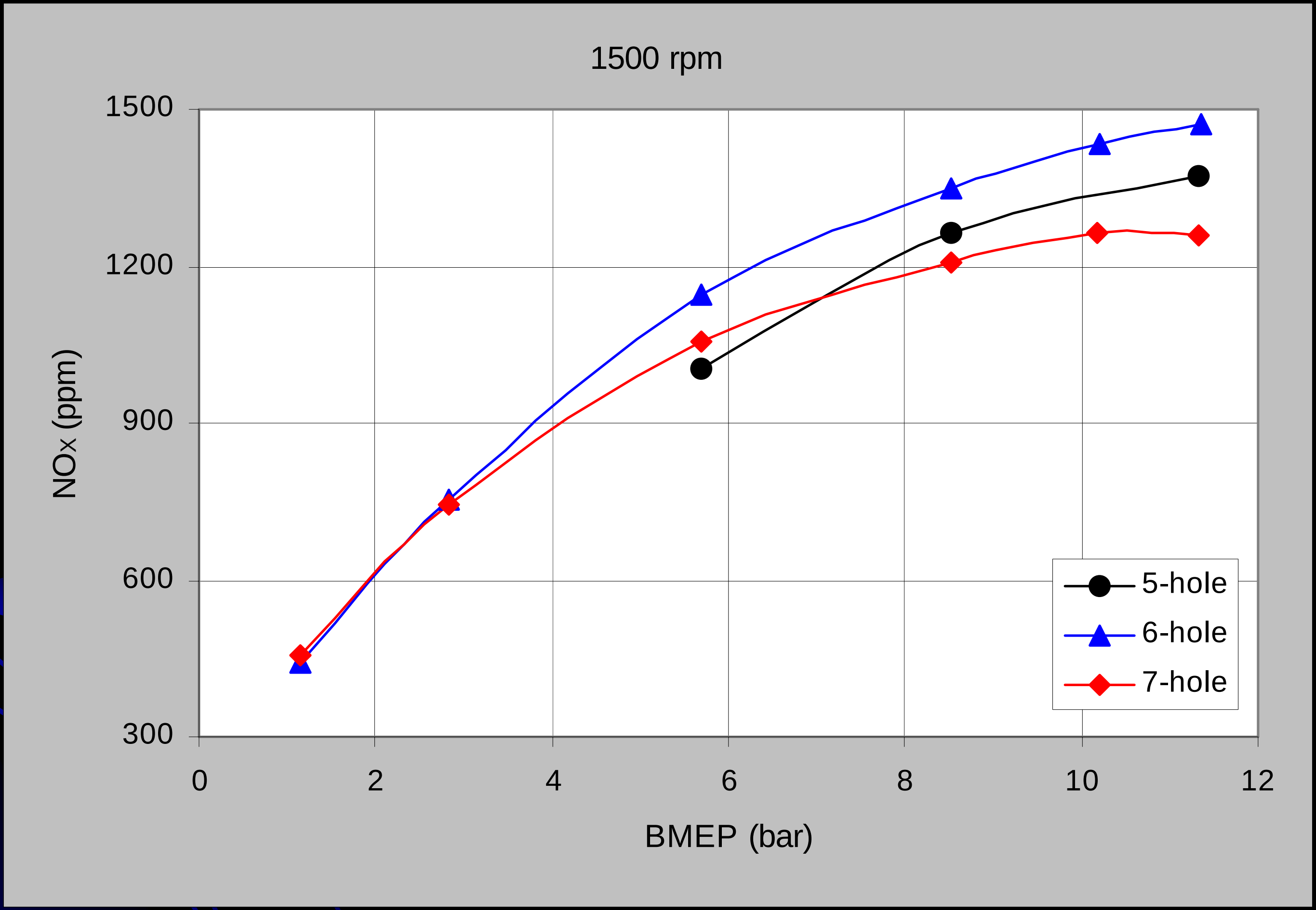
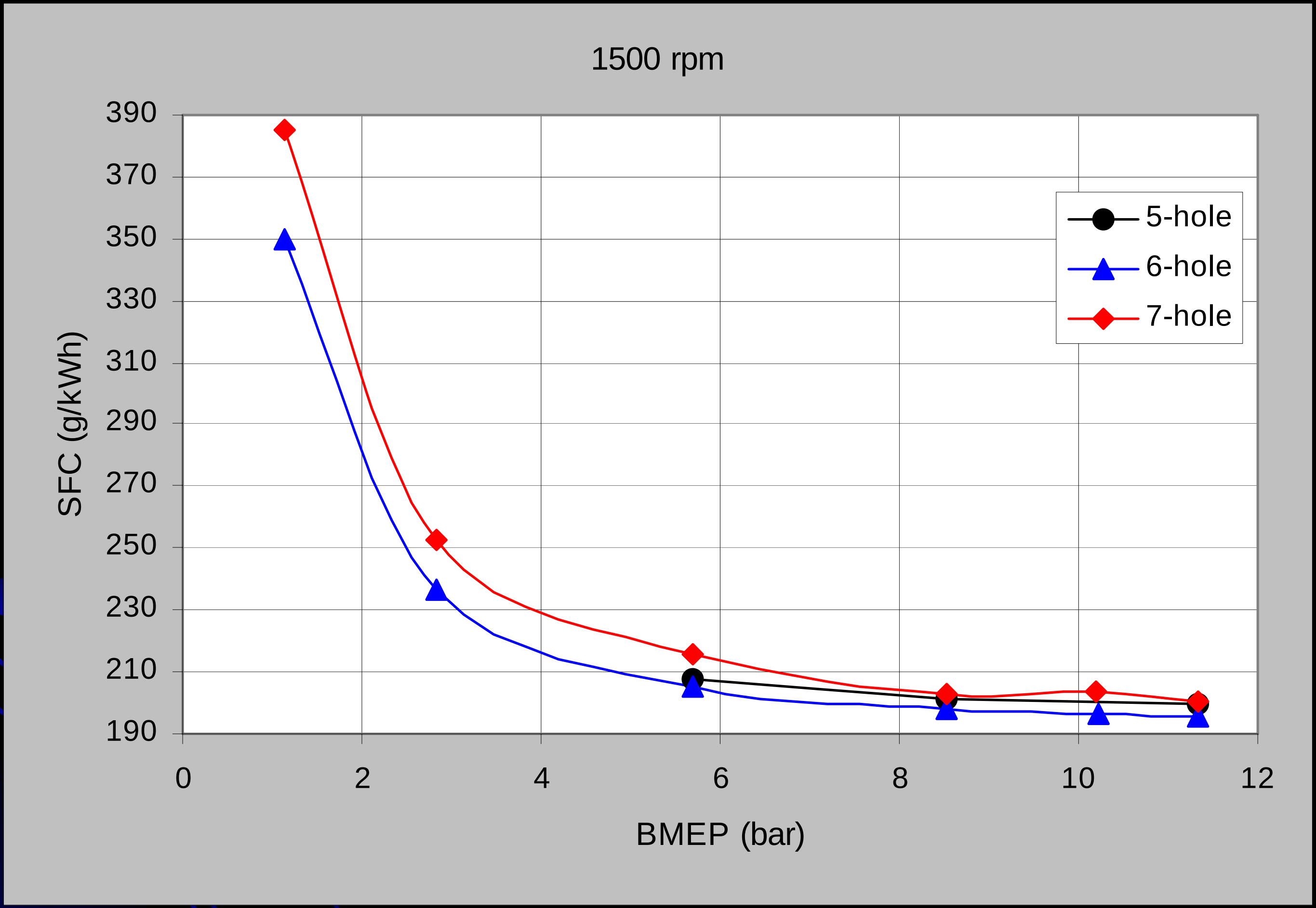
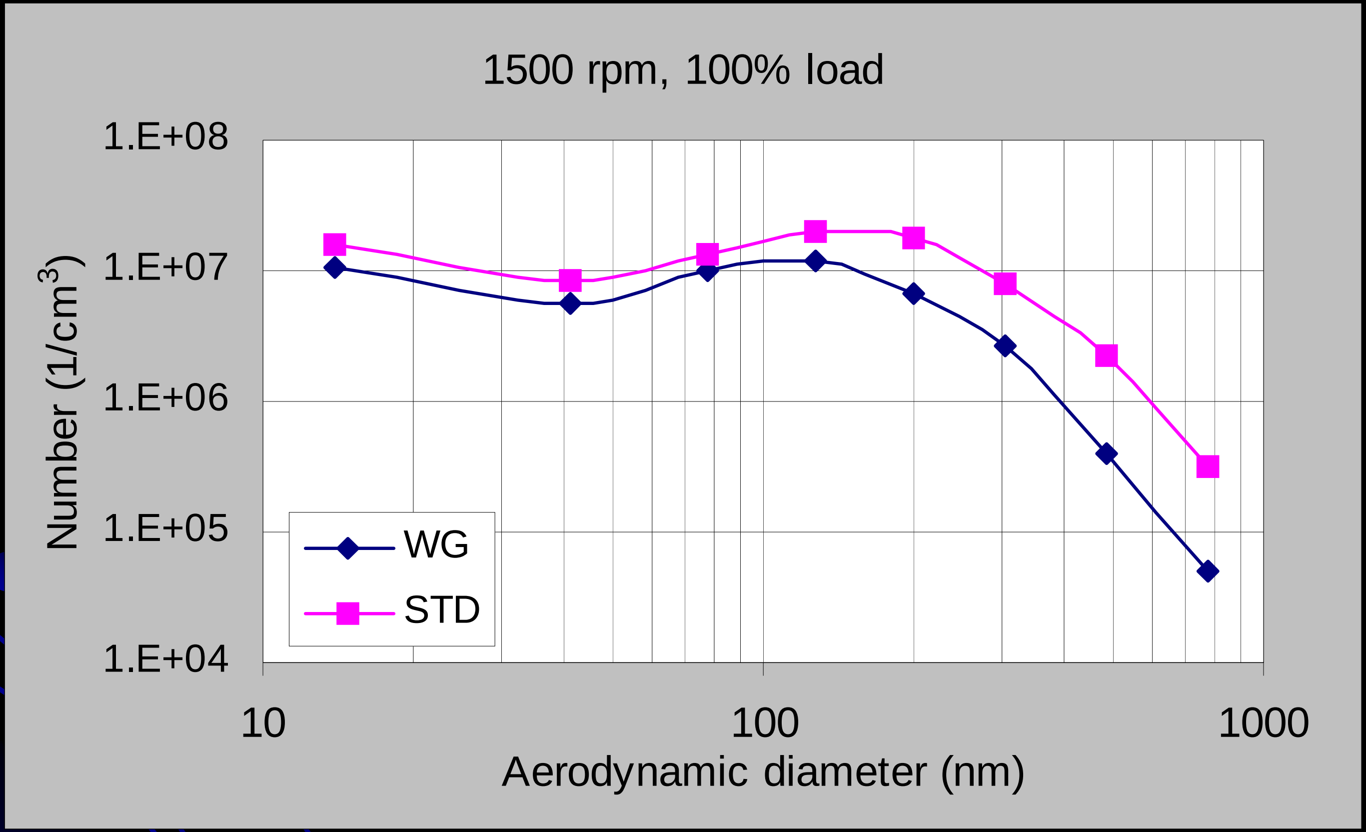


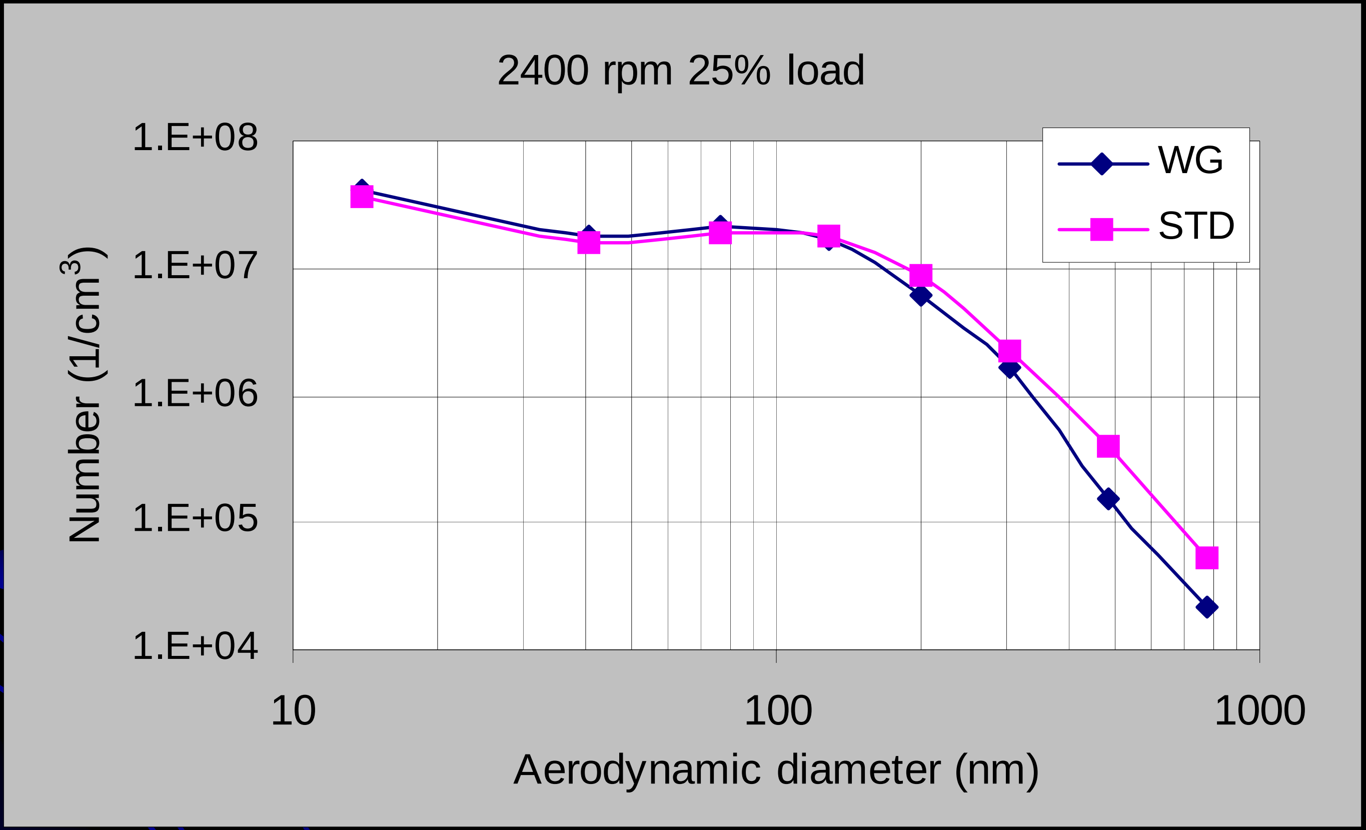
Effects of injector tips



Effects of turbochargers



Effects of turbochargers



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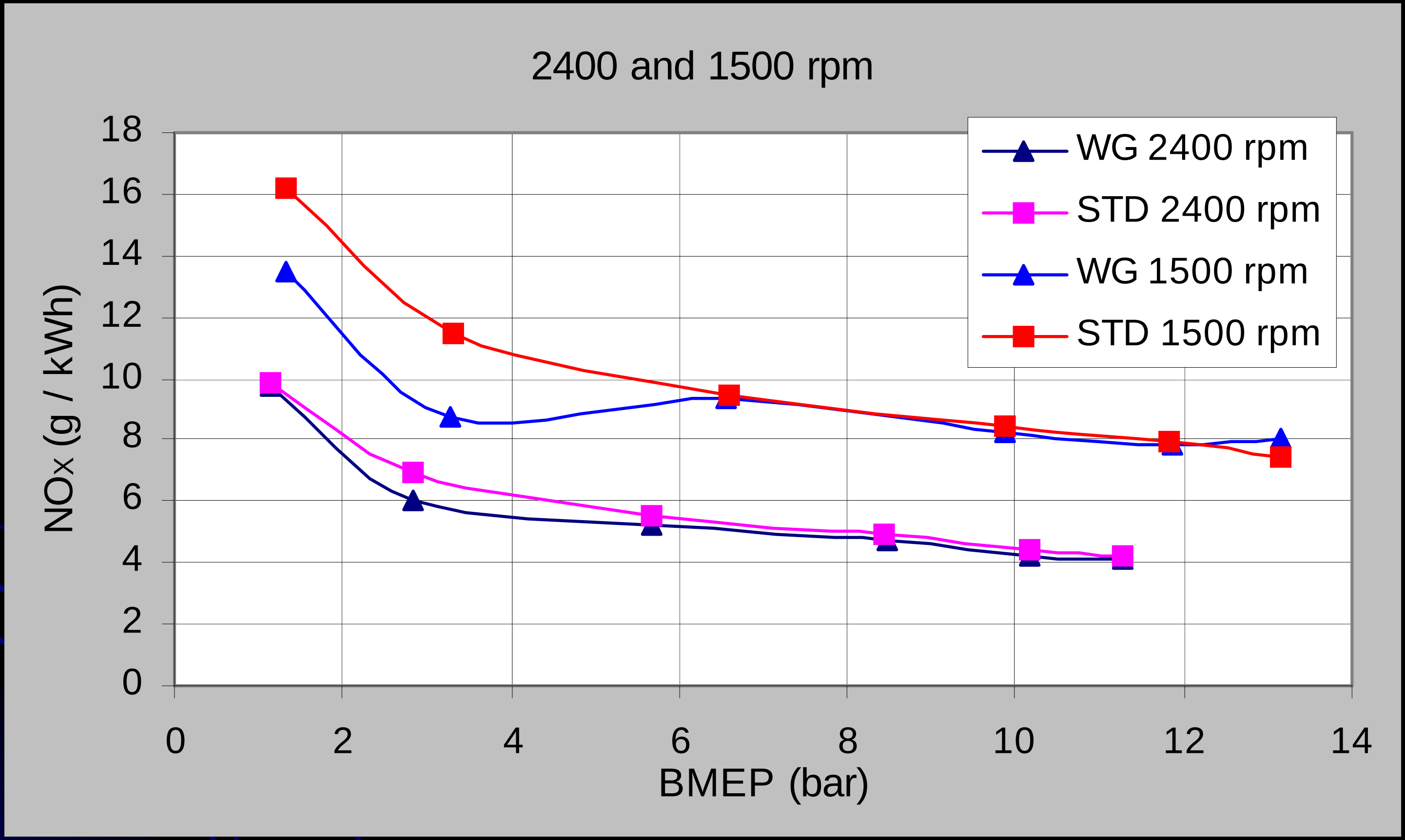

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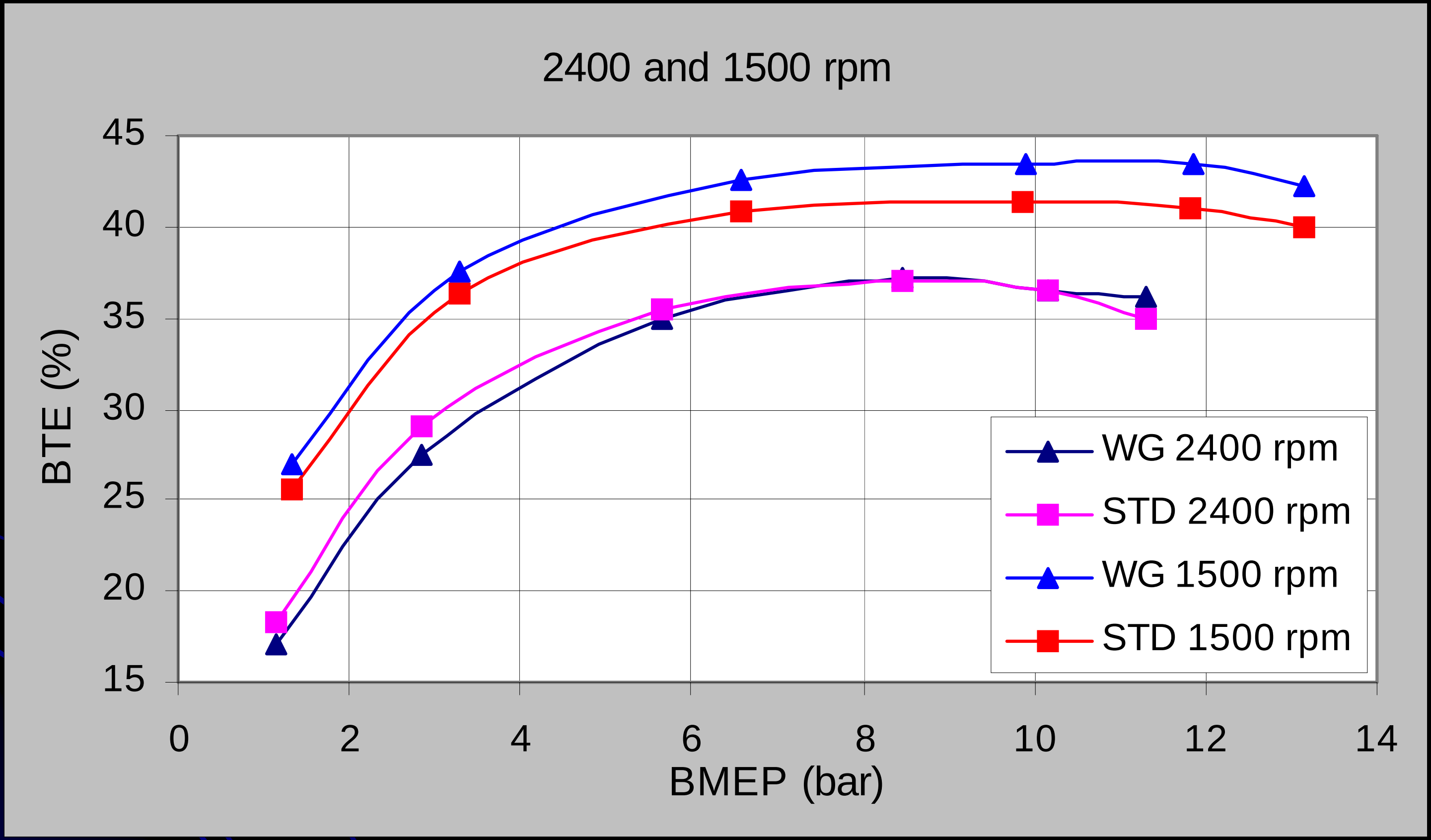
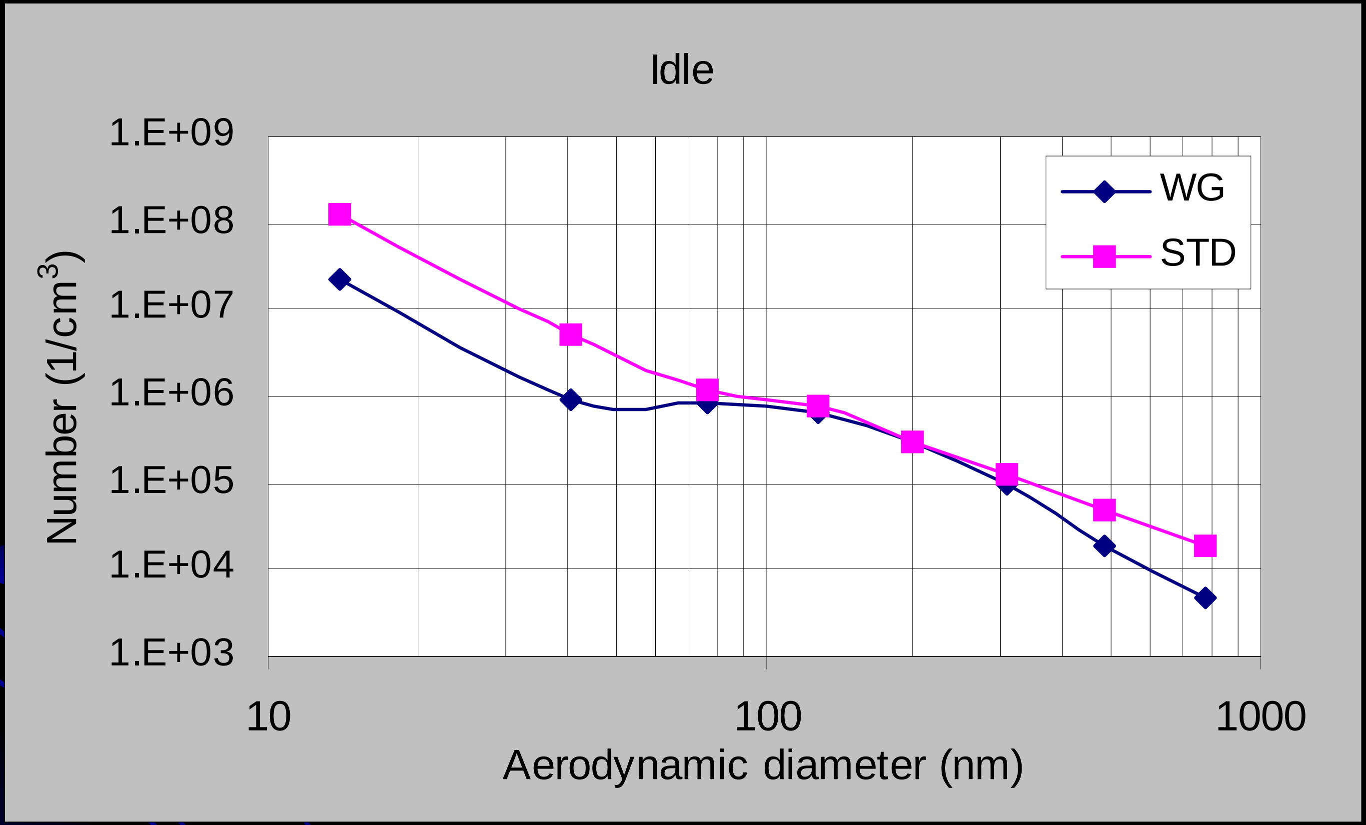
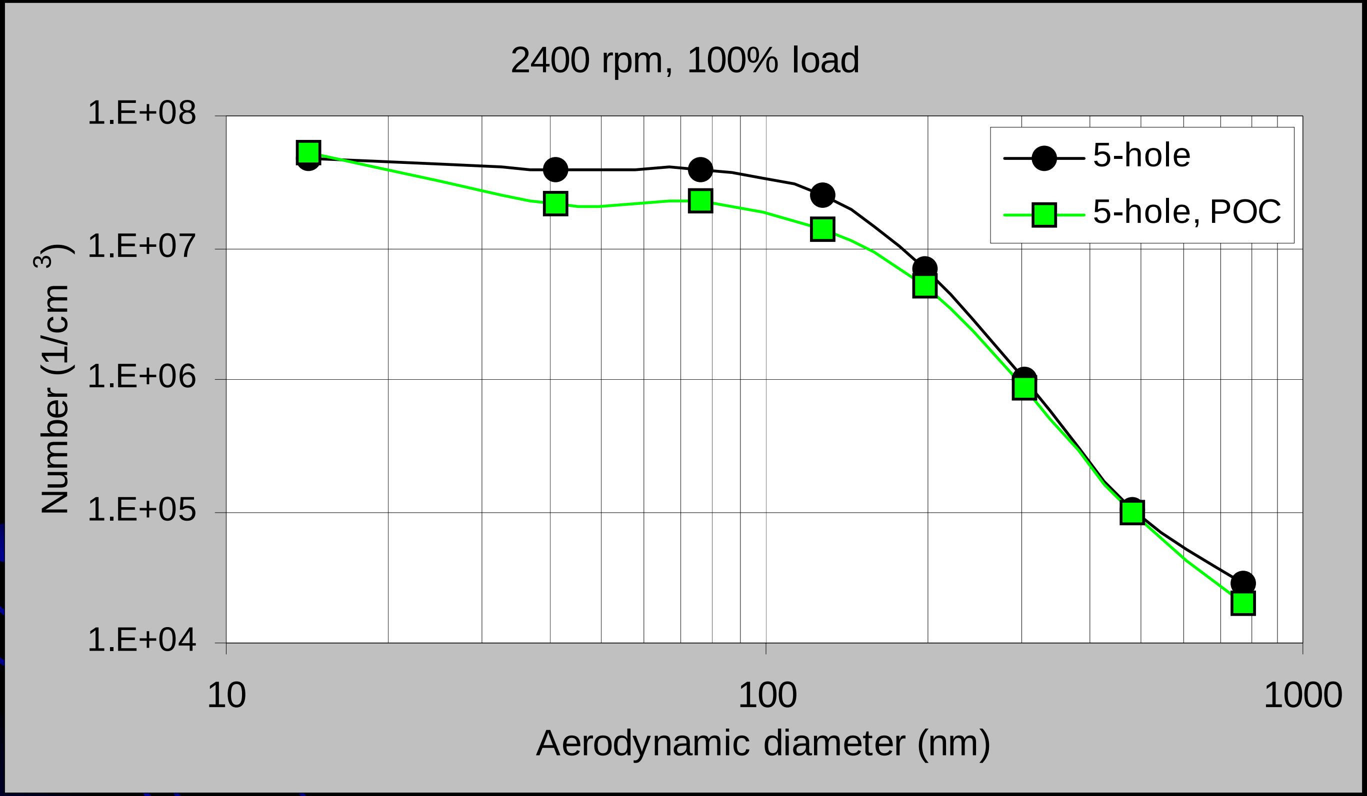


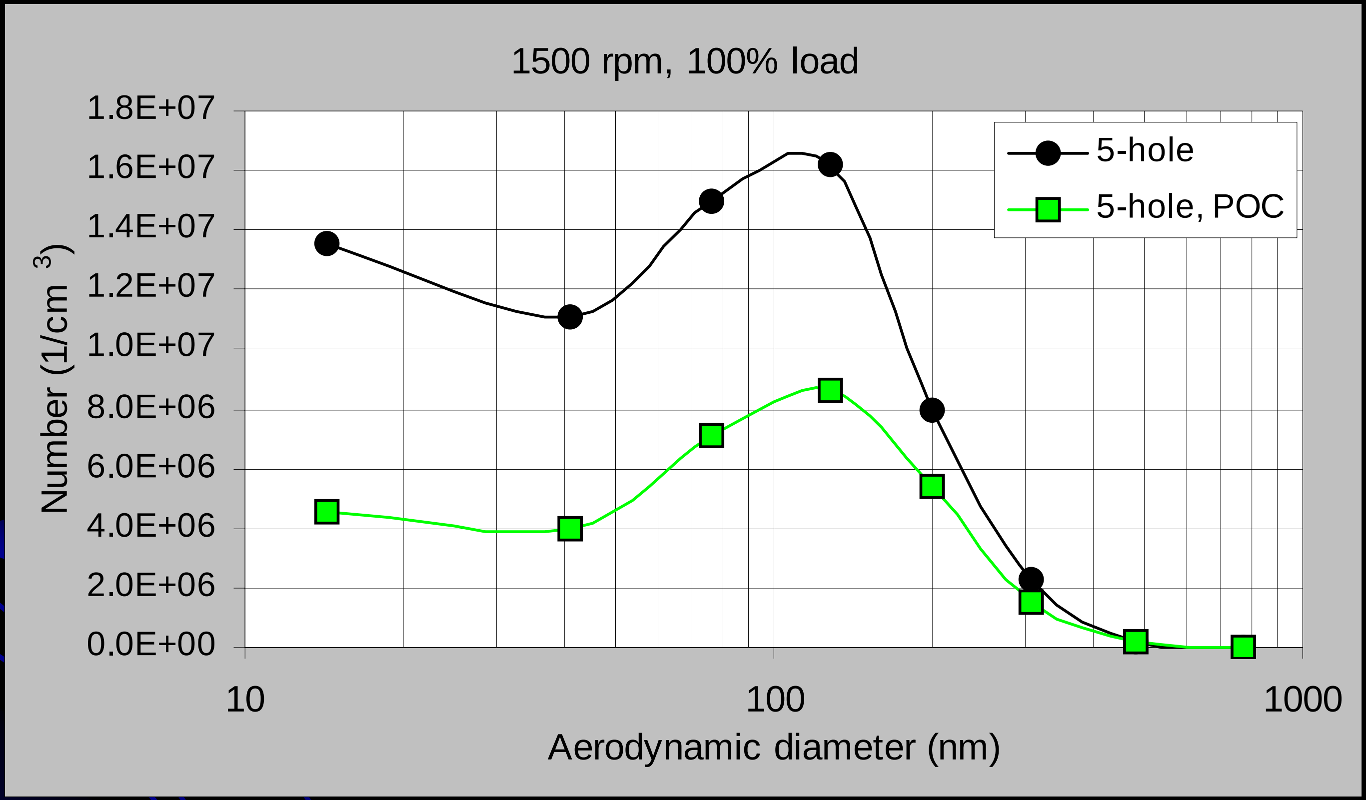
Effects of turbochargers



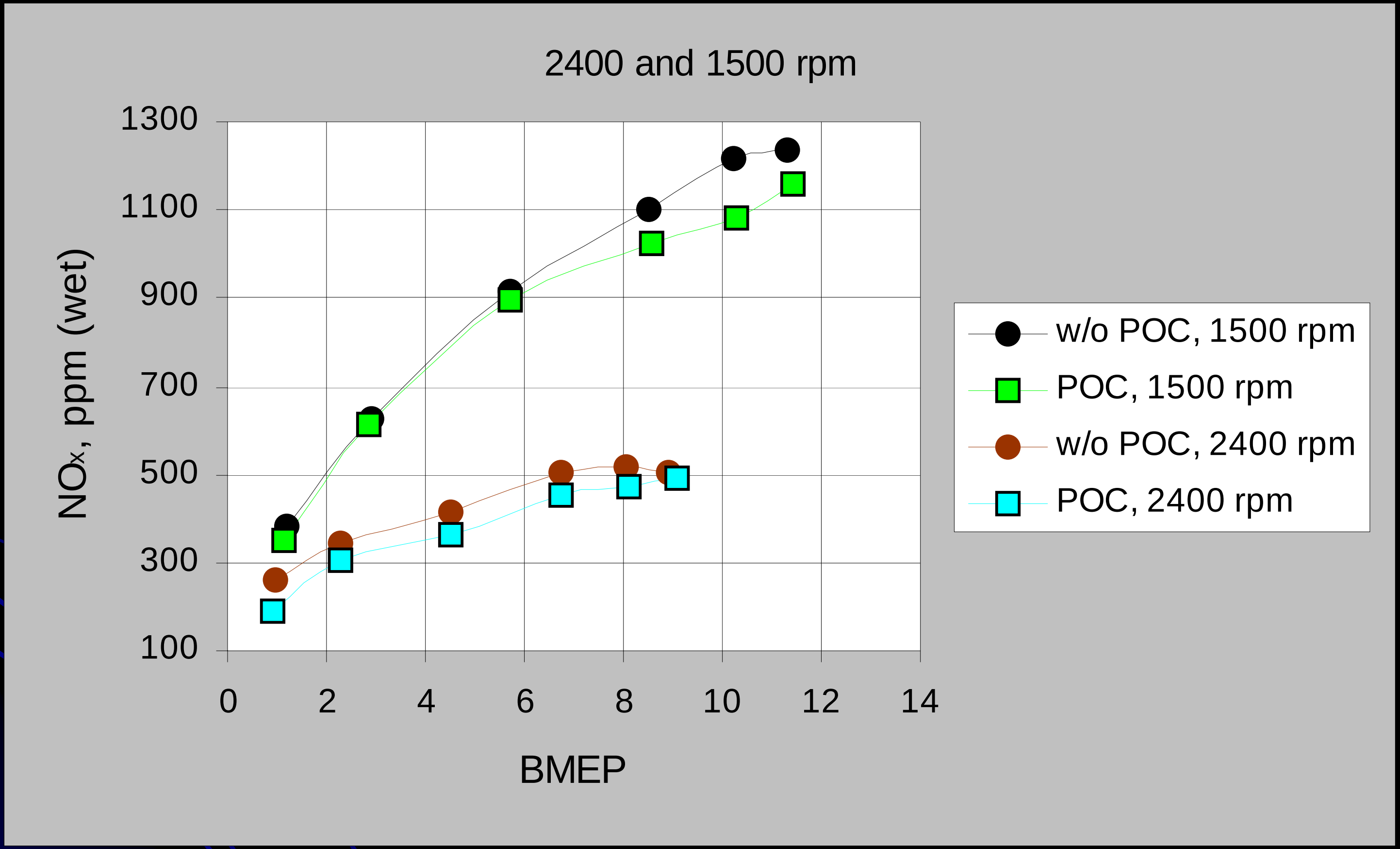
Effects of catalyst



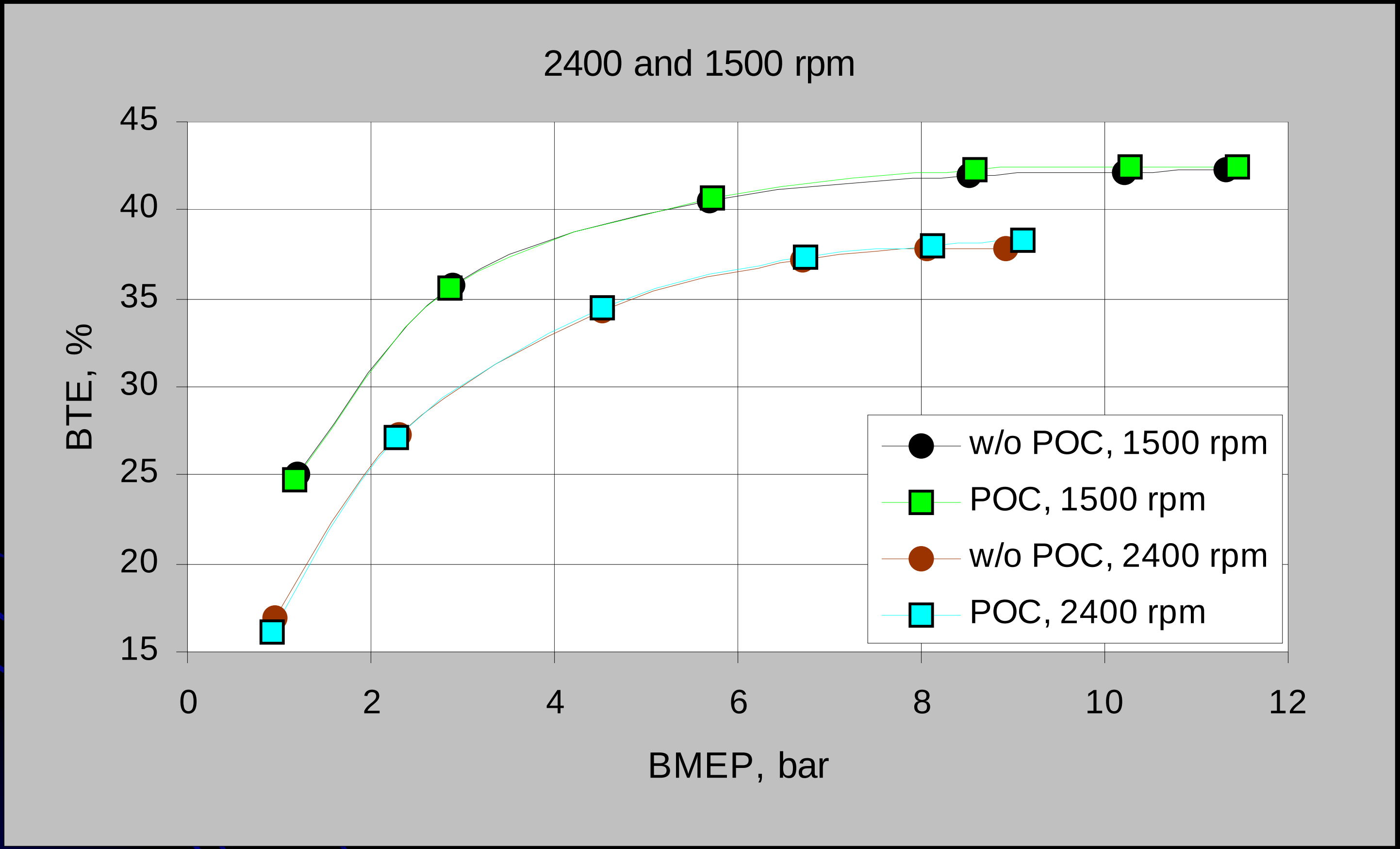
Effects of catalyst



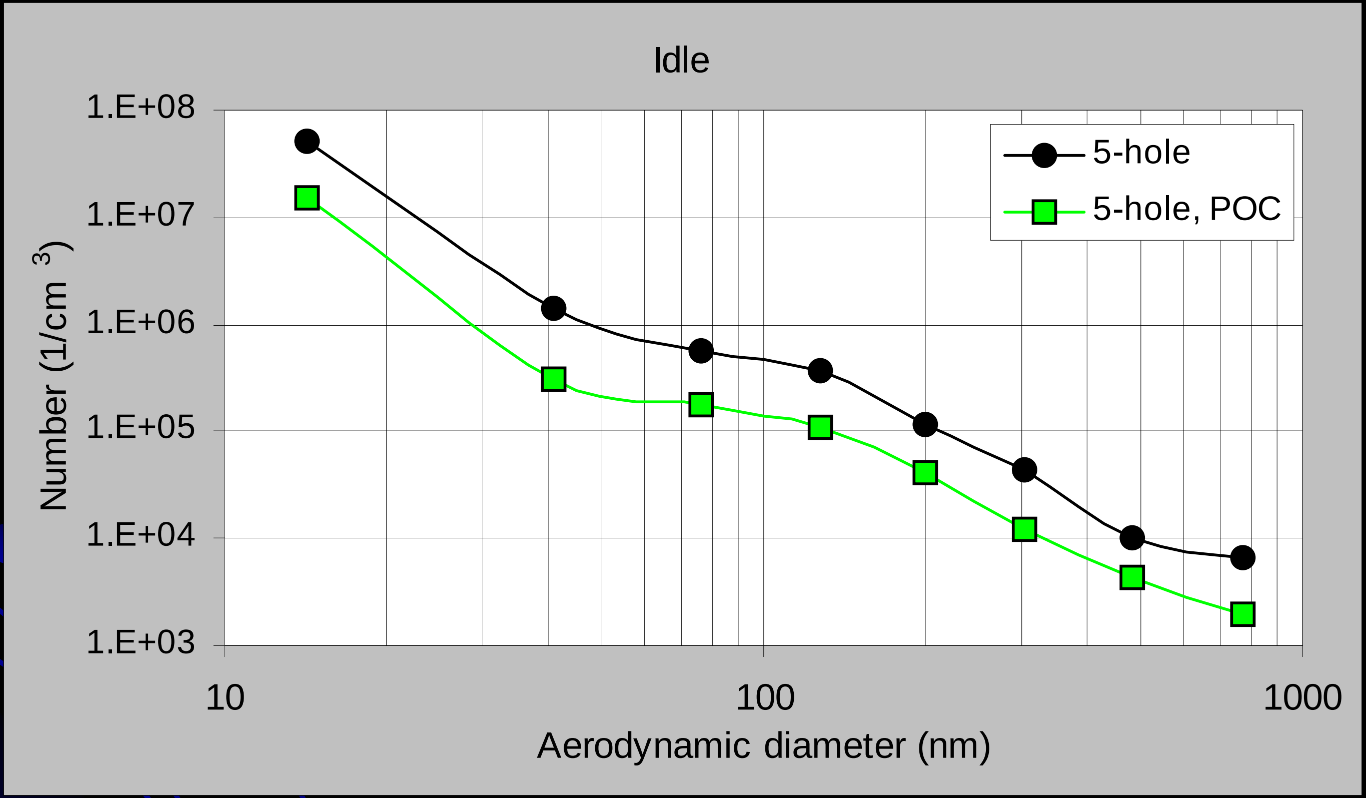
Effects of catalyst



Effects of catalyst



Effects of catalyst



Conclusions 1

- In an older off-road diesel engine, the exhaust particle number was reduced by
  - An increase in injector tip orifices at medium power
    - At several loads, the smallest particles increased, however

Conclusions 2

- In an older off-road diesel engine, the exhaust particle number was reduced by
  - A waste-gate turbocharger at loads surrounding the peak torque and at idle
    - At rated speed, the effects varied

Conclusions 3

- In an older off-road diesel engine, the exhaust particle number was reduced by
  - A particle oxidation catalyst at almost all loads
- Regarding NO_x and SFC, the particle reducing methods gave benefits rather than drawbacks

Conclusions 4

- The combination of methods should be selected based on the engine loading profile

Thank you for your kind attention!