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SUMMARY

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EFFECTS OF INJECTOR TIPS ON THE EXHAUST PARTICLE SIZE DISTRIBUTION OF A COMMON-RAIL NON-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 generally emit considerably less exhaust pollutants than the older engines.

Nevertheless, the modern engines may produce nuclei-mode and ultra-fine particles abundantly, even though the particle mass emissions would be low. Therefore, one also must pay attention to particle size distributions when developing new low-emission diesel engines. Fuel consumption forms another issue. New low-polluting engines may be less economical than their predecessors.

In the present study, a turbocharged, inter-cooled direct-injection non-road diesel engine was investigated. The engine utilised a common-rail injection system enabling a multi-stage injection strategy (CR engine). The main aim was to optimise the injection strategy in order to make the engine comply with future emissions legislation. Different injector tips were also studied. As one task of the project, the effects of different factors on the exhaust particle size distributions were also investigated.

This poster paper presents the results of the injector tip optimisation and illustrates how the different injection nozzles affected the particle size distribution. For comparison, the paper also includes particle number figures recorded in a mechanically almost identical non-road engine, though using an electronically-controlled distributor-type injection pump (VP engine). The swept volume of the engines was 6.6 dm^3.

In addition to the standard five-hole injector tips, six-, seven- and eight-hole injection nozzles were studied in the CR engine. The nominal fuel flow rates were identical. In the VP engine, five-hole tips were used. The flow rate was here app. 48% higher than that of the CR nozzles resulting, thus, in a shorter injection period and larger fuel droplet size.

As fuel, commercial low-sulphur diesel fuel oils (DFOs) were used in the experiments. The fuels were very similar, most probably not causing noticeable differences in particle emissions. The content of aromatic compounds was, however, higher for the fuel batch used for engine operation with seven- and eight-hole tips (28% against 22 to 23% for the others). The ash content of the fuel for the VP engine was also higher relative to those for the CR engine, but still low.

On the whole, no big differences in particle numbers were detected at rated speed within the ultra-fine particle range when running the CR engine with different injector tips. Within larger particles, however, the six-hole nozzles proved to be the best ones, since the brake specific particle number (BSPM) decreased almost by an order of magnitude at the largest particle category compared with the standard five-hole tips.

At intermediate speed, the differences were smaller than at rated speed. The six-hole tips were still advantageous within larger particles. The difference in fuel aromaticity must be borne in mind, however, when assessing the results obtained with different injector tips.

The particle size distributions of the CR engine were also compared with those of the VP engine that utilised a different injection system. Of the CR engine, the results of the six-hole tips were taken into comparison, since these tips proved to be the best compromise for the engine.

At 50% load at intermediate speed, the CR engine emitted less particles within the almost entire particle size range than the VP. One reason might be the smaller injector orifices, even though the injection period was simultaneously longer, leaving less time for particle oxidation. The engines to be compared also had different EGR systems. An external, long-route EGR system had been incorporated into the VP engine, whereas internal EGR was exploited in the CR engine.

According to ISO 8178 cycle C_1, both the VP and the CR engines complied with US EPA Tier 3, but the PM emissions of the VP were just at the limit. The margin in NMHC + NO_x was also smaller than in the CR. Nevertheless, the VP consumed clearly less fuel than the CR.

Based on the conducted studies, the following conclusions could be drawn:

- By optimising injector tips, some benefits were achieved within larger than ultra-fine particles
- With common-rail technology, particle number emissions decreased at a certain level of gaseous emissions
- Fuel consumption forms a great challenge for engine development. While reducing nanoparticles and toxic gaseous emissions, any increase in CO_2 should be carefully avoided.

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INTRODUCTION

In the present study, a turbocharged, inter-cooled direct-injection non-road diesel engine was investigated. The engine utilised a common-rail injection system enabling a multi-stage injection strategy (CR engine).

The main aim was to optimise the injection strategy in order to make the engine comply with future emissions legislation. Different injector tips were also studied. As one task of the project, the effects of different factors on the exhaust particle size distributions were also studied.

This paper presents the results of the injector tip optimisation and illustrates how the different injection nozzles affected the particle size distribution. For comparison, the paper also includes particle number figures recorded in a mechanically almost identical non-road engine, though using an electronically-controlled distributor-type injection pump (VP engine). The swept volume of the engines was 6.6 dm^3.

INJECTORS AND FUELS

In addition to the standard five-hole injector tips, six-, seven- and eight-hole injection nozzles were studied in the CR engine. The nominal fuel flow rates were identical. In the VP engine, five-hole tips were used. The flow rate was here app. 48% higher than that of the CR nozzles resulting, thus, in a shorter injection period and larger fuel droplet size.

As fuel, commercial low-sulphur diesel fuel oils (DFOs) were used in the experiments, Table 1. The fuels were very similar, most probably not causing noticeable differences in particle emissions. The content of aromatic compounds was, however, higher for the fuel batch used for engine operation with seven- and eight-hole tips (28% against 22 to 23% for the others). The ash content of the fuel for the VP engine was also higher relative to those for the CR engine, but still low.

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Table 1. Fuel specifications

		CR	CR	VP
		5- & 6-hole	**7- & 8-hole**	
C	%	86.4	86.4	85.7
H_2	%	13.3	13.3	13.8
N_2	mg/kg	46	46	
S	mg/kg	48	52	55
Ash	%	< 0.001	< 0.001	0.003
Mono-aromatics	%	20.1	24.4	
Di-aromatics	%	1.7	3.3	
Tri-aromatics	%	0.1	0.4	
Poly-aromatics	%	1.8	3.7	
Total aromatics	%	21.9	28.1	22.9
Cetane number		53.6	53.9	54.5

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Test runs and measurements: ICE Laboratory, Turku University of Applied Sciences, Finland

RESULTS

Rated speed

On the whole, no big differences in particle numbers were detected at rated speed within the ultra-fine particle range when running the CR engine with different injector tips, as shown in Fig. 1.

Within larger particles, however, the six-hole nozzles proved to be the best ones, since the brake specific particle number (BSPM) decreased almost by an order of magnitude at the largest particle category compared with the standard five-hole tips.

Intermediate speed

At intermediate speed, the differences were smaller than at rated speed, as shown in Fig. 2 for the 75% load. The six-hole tips were still advantageous within larger particles.

The difference in fuel aromaticity must be borne in mind, however, when assessing the results obtained with different injector tips (Table 1).

Comparison of different engines

Figure 3 illustrates how the particle size distributions differed at 50% load at intermediate speed in six-cylinder engines using different injection systems. Of the CR engine, the results of the six-hole tips were taken into comparison, since these tips proved to be the best compromise for the engine.

The CR engine emitted less particles within the almost entire particle size range than the VP. One reason might be the smaller injector orifices, even though the injection period was simultaneously longer, leaving less time for particle oxidation.

The engines to be compared also had different EGR systems. An external, long-route EGR system had been incorporated into the VP engine, whereas internal EGR was exploited in the CR engine.

According to ISO 8178 cycle C_1, both the VP and the CR engines complied with US EPA Tier 3, but the PM emissions of the VP were just at the limit, Table 2. The margin in NMHC + NO_x was also smaller than in the CR. Nevertheless, the VP consumed clearly less fuel than the CR.

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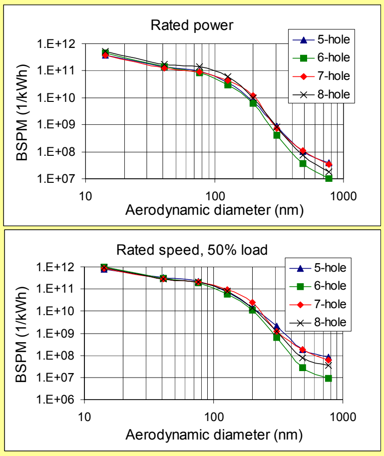

Figure 1. Effects of injection nozzles on brake specific particle number at two loads at rated speed

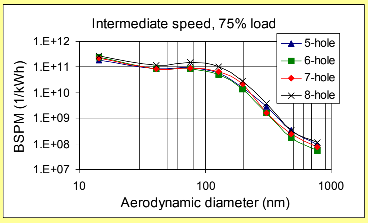

Figure 2. Effects of injection nozzles on particle size distributions at 75% load at intermediate speed

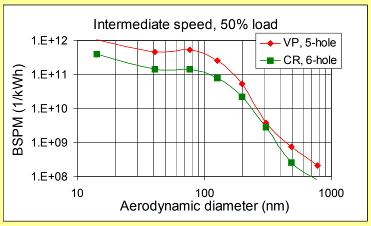

Figure 3. Brake specific particle emissions of different engine versions at half load at intermediate speed

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Conclusions

1. With common-rail technology, particle number emissions clearly decreased at a certain level of gaseous emissions.

2. By optimising injector tips, some benefits could be achieved within larger than ultra-fine particles.

3. Fuel consumption forms a great challenge for engine development. While reducing nano-particles and toxic gaseous emissions, any increase in CO_2 should be carefully avoided.

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Table 2. ISO cycle emissions of the two engines

		CR	VP
NMHC+NO_x	g/kWh	3.7	3.9
NO_x	g/kWh	3.6	3.7
HC	g/kWh	0.16	0.20
CO	g/kWh	0.51	0.77
PM	g/kWh	0.12	0.20
SFC	g/kWh	234	222

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Sisu Diesel Inc. is greatly appreciated for the permission to publish this paper.