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Dependence of particle size distribution on injection pressure

Summary

The influence of the injection pressure on the particle size distribution has been measured with a SMPS and a one stage ejector dilution unit. Measurement were carried out on a stationary test bench with a 3 l, 6 cyl., common rail direct injection engine from a passenger car, by varying the pressure in the rail. The sulphur content of the diesel fuel was < 10 ppm, and the sampling point was the tailpipe or the outlet of a transfer line.

First of all, the size distribution had been measured with the standard engine setting. In a second step, only the torque had been set to the value of the original operating point (the one with the original rail pressure, etc.) after changing the pressure. This had been done by adapting the end of injection. In a third step, the engine had also been set to the emission level of the original application by varying the EGR rate to set the soot emission (Bosch Smoke Number), and the start of injection for the NOx level. Finally, the size distribution had been measured in this configuration, but with the sampling point at the outlet of a transfer line.

When the original injection pressure of 550 bar is varied in a range of 250...1600 bar and only the engine torque is kept at 82 Nm, a slight decrease in the count median diameter (CMD) with increasing rail pressure can be found; on the other hand, the total number concentration (N) is reduced quite significantly. In the step three configuration (same emission as original application) both particle size and concentration are almost constant with changing injection pressure. When the residence time of the aerosol prior to dilution is increased by employing a transfer line, a smaller number of slightly larger particles can be measured.

With the test procedure and measurement conditions used in this investigation, no negative effect of high injection pressure on the particle size distribution could be found.

Introduction

The development of new diesel injection systems and components in the last decade has lead to a steep decline in soot emission levels. Most of this success is due to the introduction of direct injection systems, and the steady increase of the injection pressure. Since only the soot mass emission is relevant for legislation, whereas recent publications indicate a correlation between the number concentration and the carcinogenic effect, a discussion on the size distribution of aerosols from diesel engines arose.

This section is a report on the measurement of the particle size distribution with different levels of the injection pressure.

Measurement setup

All measurements were performed with a scanning mobility particle sizer (SMPS) in a dual path configuration. Both paths have an identical arrangement with a DMA and a CPC, only that in one path the aerosol is heated upstream of the DMA. The heating section is not a thermodenuder, because there is no vapour adsorbing agent in it.

Dilution was achieved with a one stage (1:10) ejector system close to the sampling point, which could not be heated. For the calculation of the particle concentration, the measured dilution ratio was used (CO_2 balance). There are further dilution stages within the SMPS. The aerosol was taken from the tailpipe, or from the outlet of a transfer line (5 m length, 70 mm in diameter).

Test engine

A standard passenger car engine on a stationary test bench was employed for the measurements. Only the electronic control unit was a modified Bosch EDC 16 device, that allowed for tuning the engine parameters. Besides that, the EDC software was standard.

Some engine specifications:

? 3 l, 6 cylinder, direct injection, 150 kW

? Common-rail injection system (Bosch), with a CP 3 pump and a maximum rail pressure of 1600 bar

? Turbo charger with variable nozzle turbine (VNT)

? Cooled charge air and exhaust gas recirculation (EGR)

? Euro 3 emission standard

The engine was operated with low sulphur diesel fuel (< 10 ppm), which is probably the reason for the absence of a nucleation mode in all of the measured distributions.

Procedure

When the injection pressure is modified, a number of parameters like torque, NOx emission, soot emission and fuel consumption will also change. One can take this phenomenon as given, or one can try to tune the engine to get these parameters as close as possible to their original value. There are pros and cons to both approaches, so both were realised in the experiments. The measurement procedure was:

1. Setting the engine operating point and waiting for stationary conditions. The operating point was chosen to match a vehicle speed of 100 km/h: n = 2000 1/min; M = 82 Nm; q_air = 100 m3/h; p_rail = 550 bar.
   – Measuring the particle size distribution.

2. Changing the pressure in the rail. The adaptation of the torque is done automatically by the EDC 16 by changing some parameters, especially the end of injection.
   - Measuring the particle size distribution.

3. Changing the EGR rate, until the Bosch Smoke Number (SN) equals the value of the standard setting.
   Changing the start of injection to set the NOx level to the standard value.
   - Measuring the particle size distribution.

4. Switching from the sampling probe in the tailpipe position to the one behind the transfer line.
   – Measuring the particle size distribution.

Results

All of the measured size distributions have a log-normal shape without a nucleation mode. The difference between the curves from the heated and the cold path is quite small, which is probably due to the low sulphur fuel and to the low HC emission level of the engine. Therefore, the results can be discussed in terms of the count median diameter (CMD) and the total number concentration (N).

Measurements of CMD and N for a range of the injection(rail-) pressure are shown in **Fig. 1**. When only the torque is kept at the original value, there is a decrease in particle size with increasing injection pressure. On the other hand, the number of particles is reduced quite significantly. The change in the combustion process induced by the variation of pressure

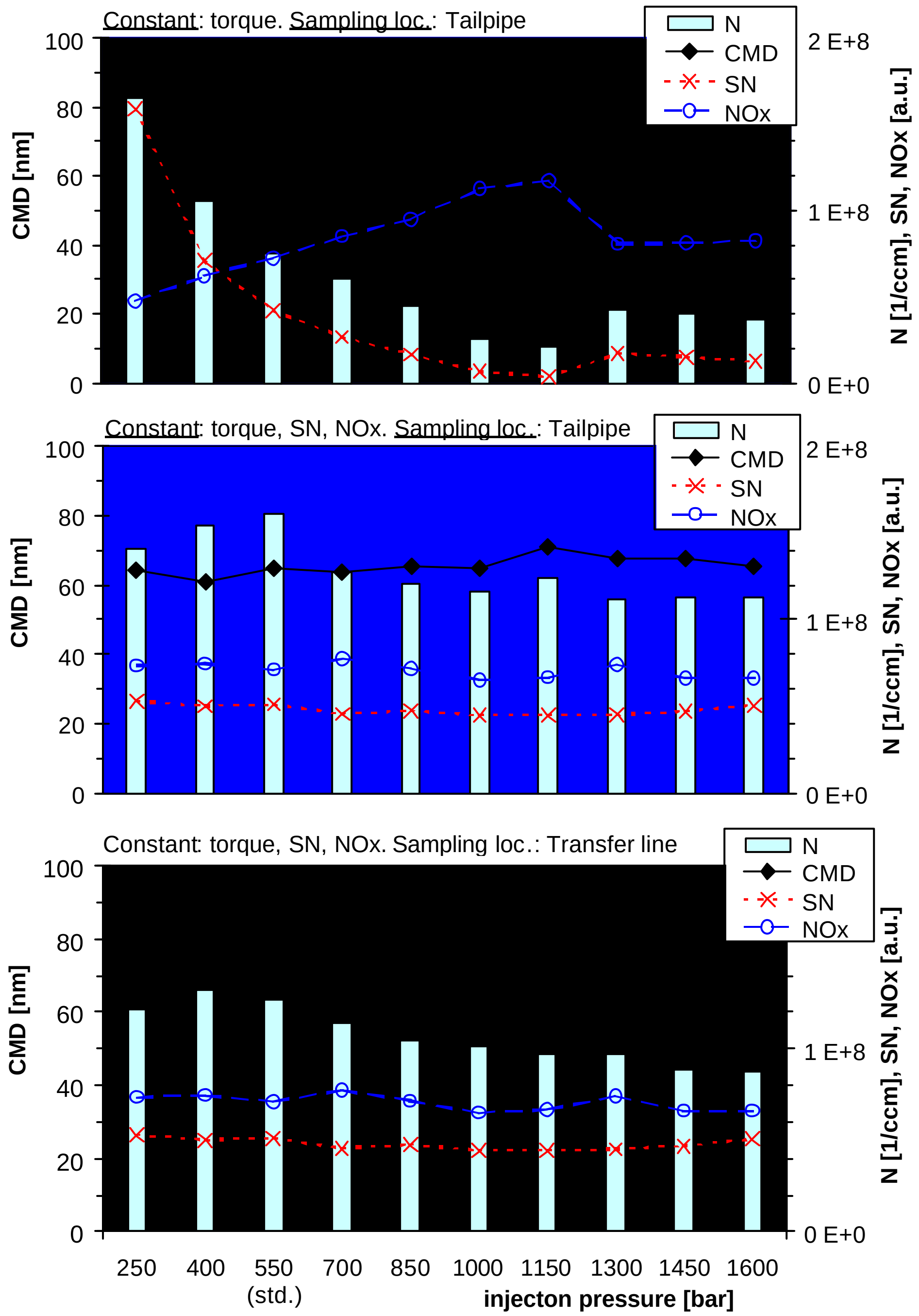

Fig. 1: Particle size (CMD), number concentration (N), smoke number (SN) and NOx level versus injection pressure; n = 2000 1/min, Torque = 82 Nm (v = 100 km/h). The standard injection pressure is 550 bar for this engine speed and load.

<u>Top</u>: Torque set to standard value.
<u>Middle</u>: Torque, Smoke and NOx set to standard value.
<u>Bottom</u>: Like middle, but sampling behind transfer line.

and injection timing leads to a remarkable modification of the emission behaviour of the engine. This is also shown in the figure. The rise in particle emission from 1300 bar on is caused by the electronic control unit, which automatically increases the exhaust gas recirculation rate. It should be pointed out here that neither the injection system, nor the software in the EDC are designed for an injection pressure in this range at this engine operation point. For example, the standard design sets a rail pressure of 1300 bar at n = 2500 1/min, mep = 15 bar, and 1600 bar at n = 4000 1/min, mep = 12 bar.

When the NOx and smoke levels are set to their standard values as described above, no clear correlation between particle size and number concentration and the injection pressure can be observed. With the same measurement procedure, but the sampling probe at the outlet of a transfer line, a smaller number of slightly larger particles can be measured.

The smoke number (SN) measures the amount of soot in a specified volume; it does not contain any information on the exhaust gas flow rate. Therefore, the volume related number concentration is shown in the figure. The course of the distance related number concentration N [1/km] differs from it, because the EDC reduces the intake air flow with rising injection pressure. This leads to a clear decrease of N [1/km] with increasing injection pressure, especially in the measurements with constant smoke number and NOx level.

In the process of applying an injection system and an electronic control unit to an engine, the parameters like EGR, injection timing, and so on are set in order to reach a certain trade-off concerning smoke emission, NOx emission and fuel consumption. Therefore, it seems useful and necessary to set the engine to the original emission levels after changing the injection pressure – the same would be done in an application process.

The transfer line is only a very rough approximation to the agglomeration processes, that occur in the atmosphere behind the tailpipe. Nevertheless, the measurements with the transfer line indicate that the influence of the injection pressure on the atmospheric aerosol is even lower, than the tailpipe measurements show.

In summary it may be said, that with the test procedure and measurement conditions used in this investigation, no negative effect of high injection pressure on the particle size distribution could be found.