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Comparative Measurements of Particle Size Distribution: Influences of Motor Parameters and Fuels

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1. Introduction

Besides its predominant position at the commercial-vehicle sector, its low fuel consumption and economical reasons have lead to the high popularity of diesel engines also for passenger cars. But not only its high thermal efficiency but also its low HC- and CO-emissions are advantages of modern diesel engines. Nevertheless the trade-off between particulate emission and NO_x-emission causes the main difficulties to meet future emission regulations.

Additional to the mass related particulate emission recent health studies direct the interests more and more on other characteristics like particle size, surface and number distribution. Although there is no concrete knowledge about possible health risks caused by diesel particles, detailed investigations on measurements of particle size and number distribution and their connection to mass related emissions are of high importance to answer this question.

Therefore the institute for internal combustion engines at the university of Vienna works on this topic in cooperation with partners in industry and medicine.

2. Comparison Between DI And IDI Engines

To investigate the difference behaviour of DI and IDI diesel engines several measurements have been carried out. To eliminate influences caused by operating cars on chassis dynamometers and for getting a closer look at the influences of certain engine parameters on particle size distribution, the measurements have been done mainly on engine test beds.

For measuring the size and number distribution both a Scanning Mobility Particle Sizer (SMPS) from TSI and a Low Pressure Impactor (LPI) have been used.

Figure 1 shows the particle number distribution for a naturally aspirated IDI passenger car diesel engine. The particle diameter is traced on a logarithmic scale. The engine load has been varied between p_{me}= 2 bar and p_{me}= 8 bar in increments of 2 bar. With increasing load the number concentration increases clearly. Additional the distribution moves to larger diameters, especially at p_{me}=8bar, which means full load.

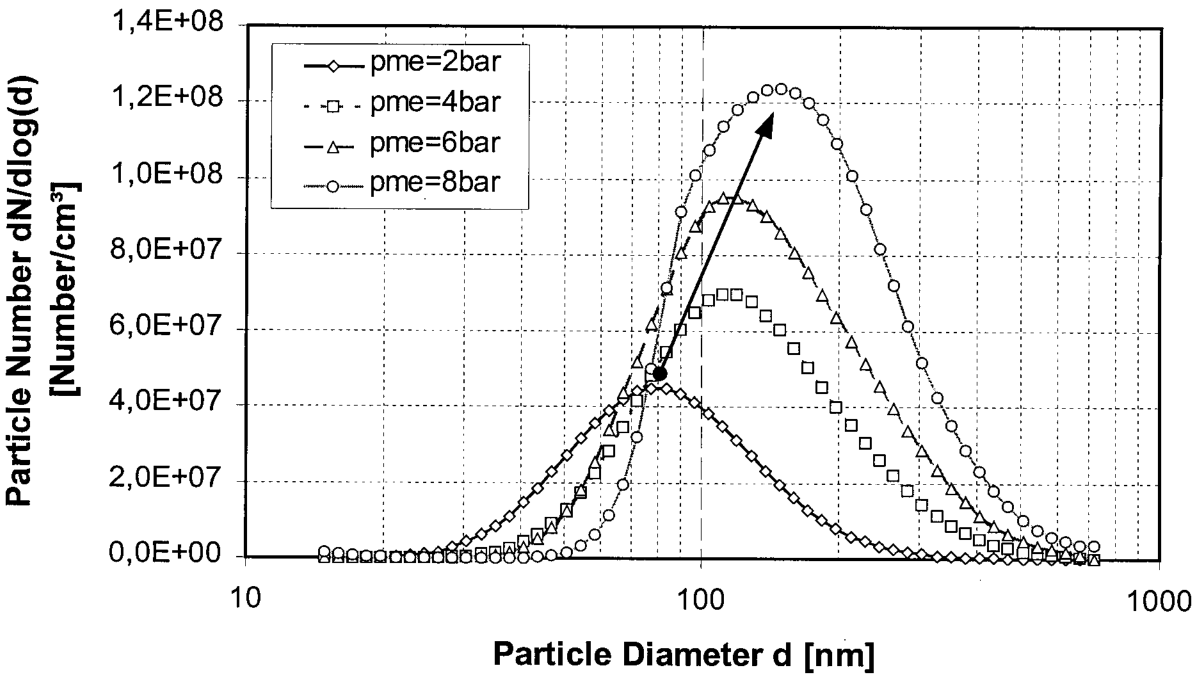

Figure 1: Influence of engine load on particle diameter and number IDI-engine; engine load: n=2000m^{-1} / p_{me}=2/4/6/8 bar - SMPS

However, the cause for this shift is not only the influence of the engine load itself but also the EGR-rate. Because the EGR-rate is not adjusted by the motor management it is not reduced at higher loads.

The behaviour of the particle size distribution on a turbo charged DI engine can be seen in figure 2. It shows a variation of the EGR-rate at a constant engine load of n=2000 min^{-1} and p_{me}= 2 bar. The EGR-rate is varied between 0% and 50%. Similar to figure 1 with increasing EGR-rate the particle number distribution moves to higher numbers and larger diameters. The shift however is not so strong, which might be caused by a better injection system and mixture formation.

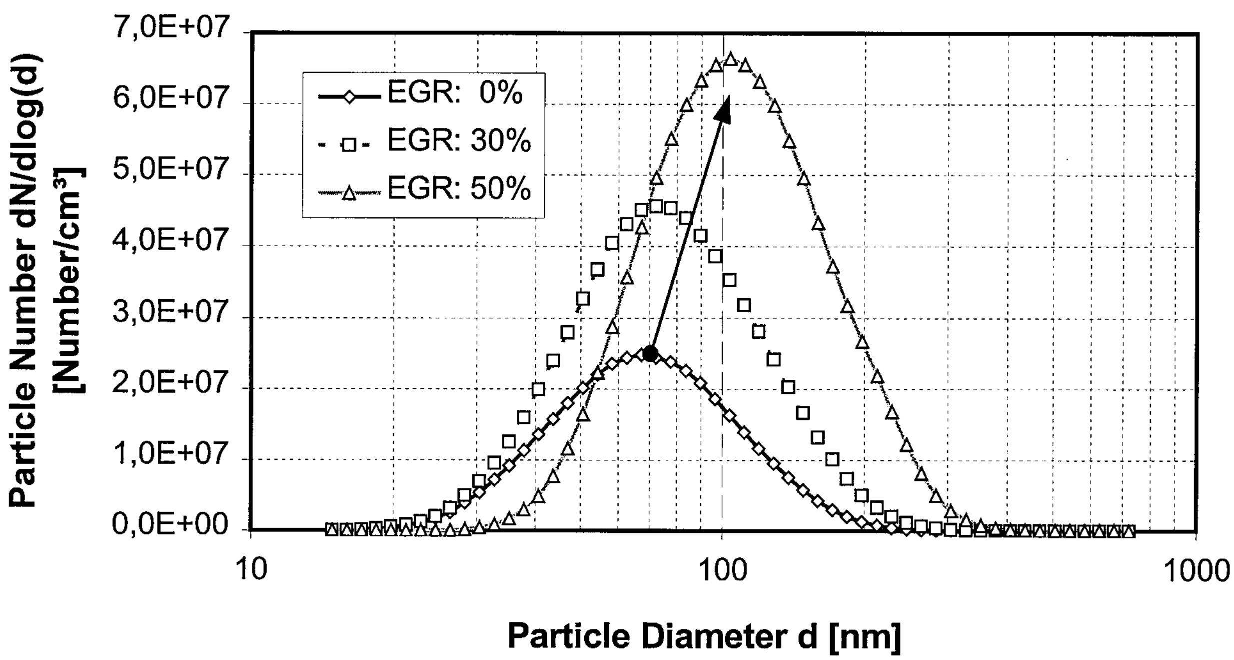

Figure 2: Influence of EGR-rate on particle diameter and particle number DI-engine; engine-load: n=2000m^{-1} / p_{me}= 2 bar - SMPS

3. Influence of Engine Parameters on Particle Size Distribution

Figure 3 gives a more detailed look at the influence of EGR on particulate size distribution. The measurements have been performed at the same turbo charged DI engine as mentioned above. Instead of the distribution traces only the maximum number concentration and the mean particle diameter are depicted. The diagram below shows the corresponding smoke numbers.

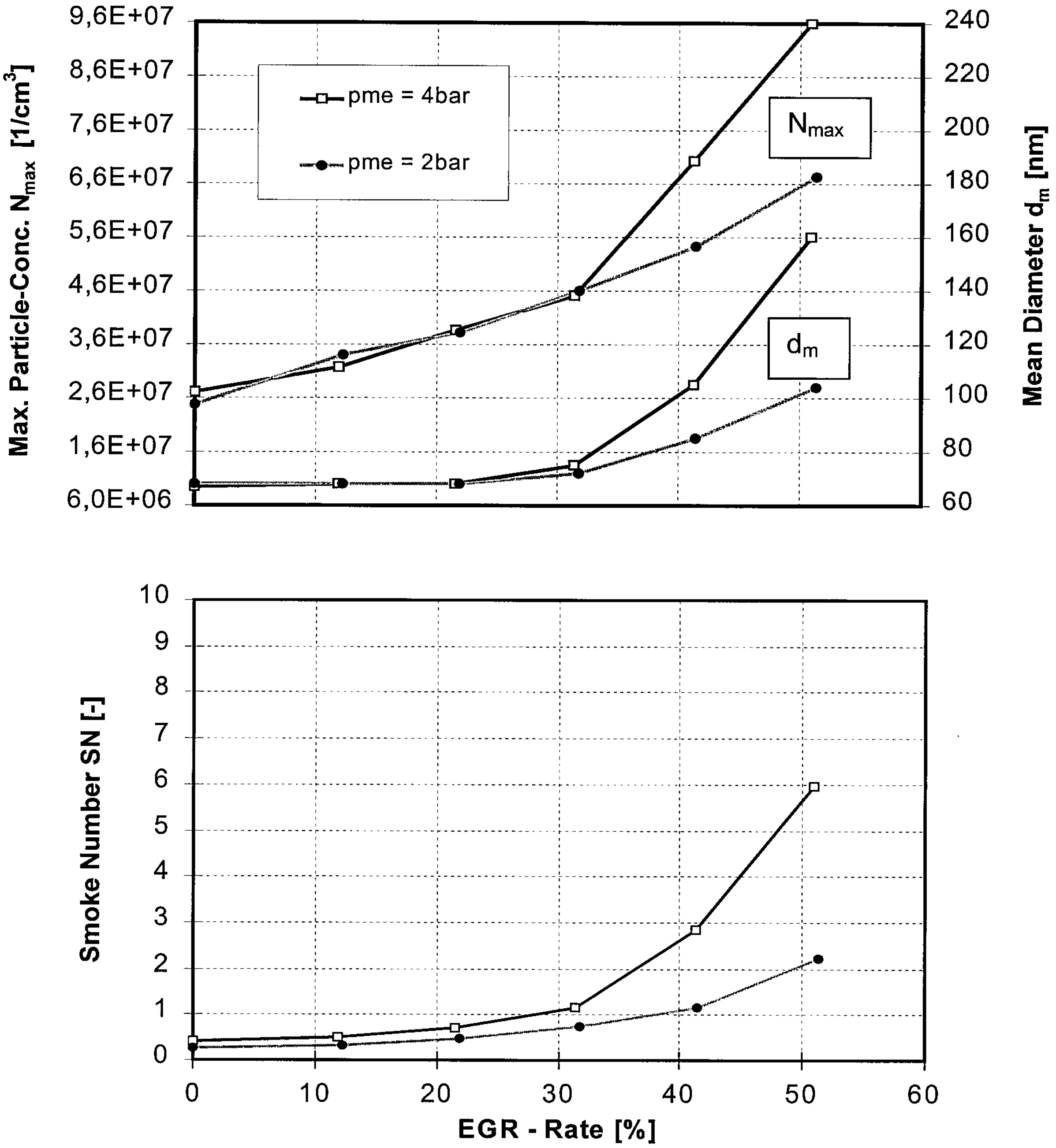

Figure 3: Influence of EGR-rate on max. particle concentration, mean diameter and smoke number - SMPS

DI-engine; engine load: $n=2000 m^{-1}$ / $p_{me}= 2$ / 4 bar

Up to 30% EGR the traces for $p_{me}= 2$ bar and $p_{me}= 4$ bar run parallel, above that value both particle concentration and mean diameter of the particles increase more at

p_{me}= 4 bar. The same applies for the smoke number. Therefore a good correlation between maximum particle concentration, mean particle diameter and smoke number could be detected.

A variation of injection timing is shown in figure 4. The injection timing has been varied between –4° BTDC and 10° BTDC while the EGR-rate was set to 0%.

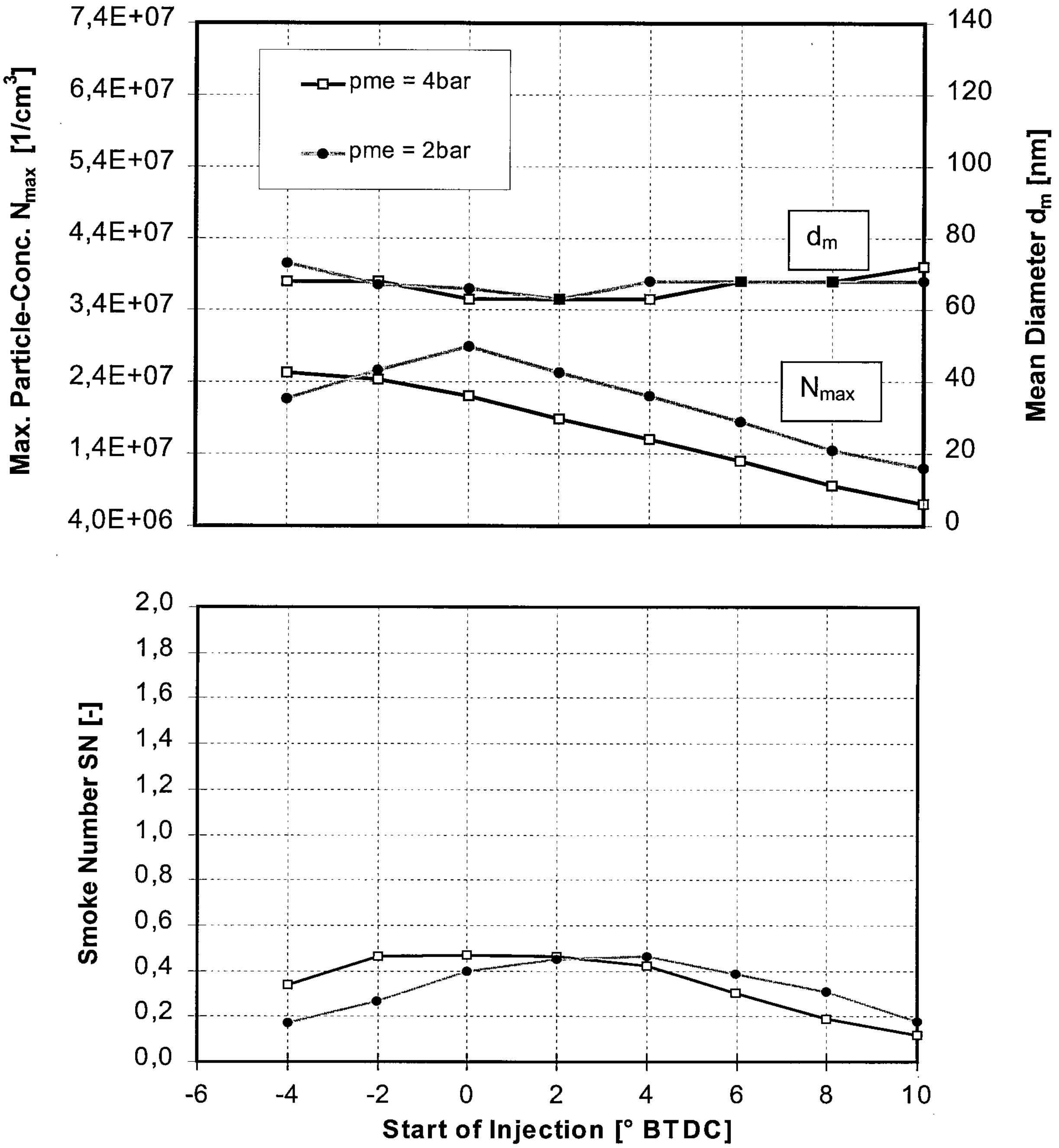

Figure 4: Influence of start of injection on max. particle concentration, mean diameter and smoke number - SMPS
DI-engine; engine load: $n=2000m^{-1}$ / p_{me}= 2 / 4 bar

In contrast to EGR-rate there is nearly no effect of injection timing on the mean diameter of the particles at the shown load levels. The maximum number concentration is slightly changing and shows the same behaviour as the smoke number.

4. Influence of Fuels on Particle Size Distribution

Besides engine parameters also fuel properties influence particulate characteristics. In contrast to the measurements discussed before the following have been performed with a low pressure impactor (LPI). Using two different kinds of measuring methods should make it possible to compare a number based particulate distribution to a mass based one and to verify the conversion from one to the other.

Figure 5 shows the influence of a fuel additive on particulate mass concentration. Seeding CEC-diesel with a fuel additive leads to a reduction of particulate mass concentration. The reduction increases with bigger diameters, therefore the mean diameter of the particles is slightly shifted to smaller values. Due to the restricted lower measuring range of the LPI a shift of the trace at very small particles could not be detected.

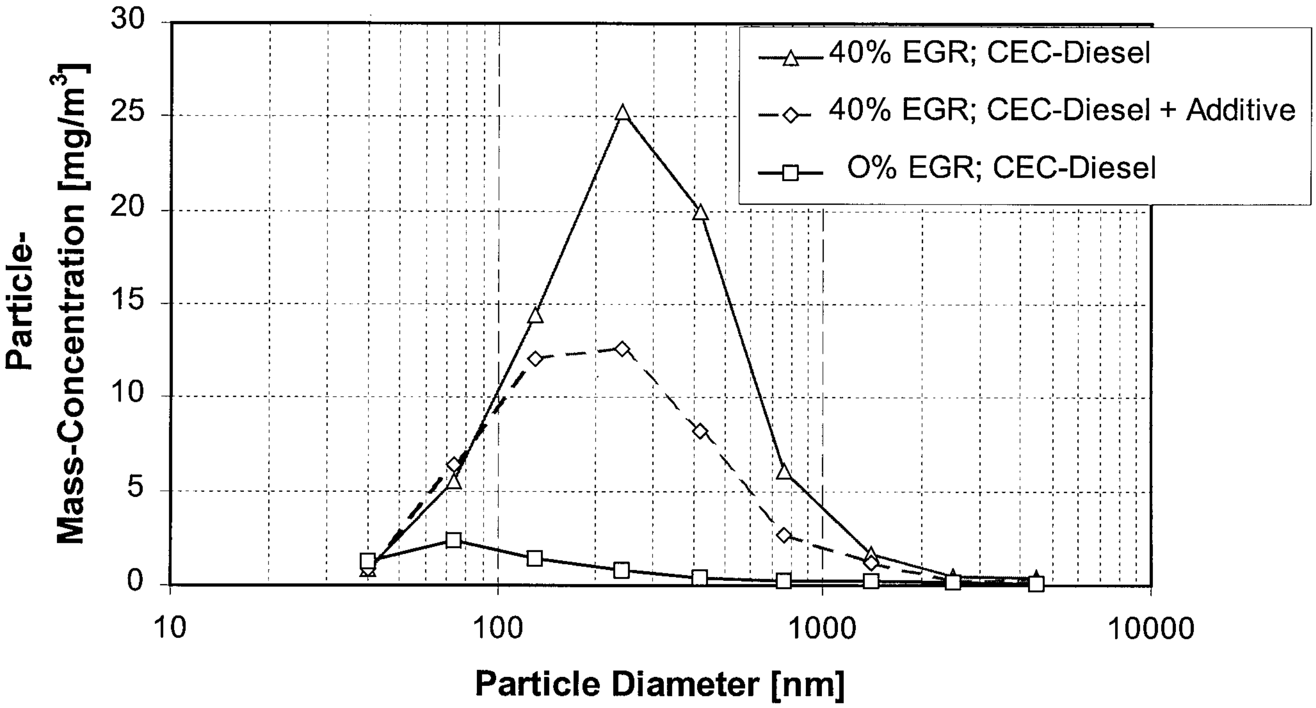

Figure 5: Influence of fuel additive on particle size distribution - LPI
DI-engine; engine load: n=2000m^{-1}; p_{me}= 4 bar

The effect of sulfur content in diesel fuel on particulate size can be seen in figure 6. Compared to CEC-diesel the mass concentration decreases significantly at larger diameters but increases at small diameters. Nearly the same distribution can be found using RME. However the level of the maximum mass concentration is again much lower.

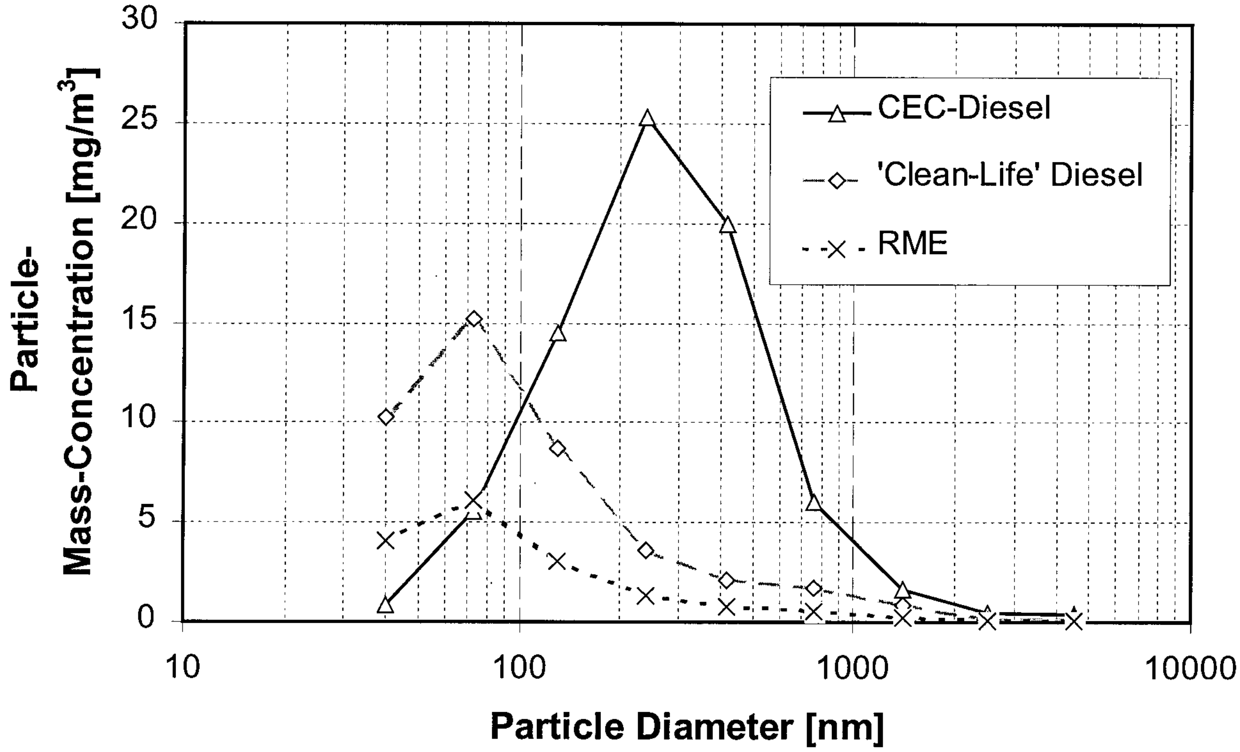

Figure 6: Influence of different fuels on particle size distribution - LPI
DI-engine; engine load: $n=2000m^{-1}$; p_{me}= 4 bar / EGR=40%

According to latest measurements using a SMPS equipment this measuring method indicates less influence of fuel properties on particle size distribution than the LPI.

Using both measuring methods should make it possible to verify the respective results and to investigate possible variations of particle density and structure.

5. Summary

Particulate size, number and mass distributions have been investigated with both a Scanning Mobility Particle Sizer (SMPS) and a Low Pressure Impactor (LPI) on IDI and DI diesel engines. The presented results can be summarised as follows:

Particle number and mean diameter raise with increasing EGR-rate. On modern DI diesel engines this shift might be not so significant as on IDI engines.

The correlation between particle concentration and smoke number is very good.

The oxidising effect of fuel additives decrease particle mass concentration. Because of the measuring range of the LPI a shift at very small particles could not be detected.

Based on measurements with LPI, using fuels with low sulfur content particulate mass concentration decreases significantly at larger diameters but increases at small diameters. RME causes a similar mass distribution as diesel with low sulfur content, due to the relatively high content of oxigen it effects a much higher decrease of the mass concentration.

A comparison of the results from different measuring methods is very difficult, therefore detailed investigations of measuring methods for particulate size and mass distribution, such as SMPS and LPI and verification of the correlation among them and with smoke number and filter methods have to be carried out to verify them.