

Particle Number Measurement in the Periodic Technical Inspection (PTI) of Gasoline Vehicles

Introduction

It is widely known that fine particulate matter has negative effects on human health [1]. Nanoparticles with a particle diameter smaller than 100 nm play the largest role for health, as they can penetrate deepest into the body [2]. The transport sector is responsible for a substantial portion of nanoparticle emissions. Numerous studies have shown that a small share of the vehicle fleet – so-called “high emitters” – is responsible for the majority (up to 90%) of total particle emissions from vehicles [3,4,5,6]. A targeted approach to identify these high emitters is particle number (PN) measurement during the periodic technical inspection (PTI).

PN measurement for diesel vehicles has already been successfully introduced in Germany, Belgium, the Netherlands, and Switzerland. Diesel vehicles with defective diesel particulate filters (DPF) are identified and removed from circulation through this measurement [3]. Consequently, the introduction of PN measurement significantly contributes to improving air quality [3].

Data from the first two years of implementation show that high-emitter vehicles can be effectively detected with this method, and that an OBD check cannot fulfill this purpose. In 2024, 132,611 diesel vehicles in Germany failed the emissions test—a failure rate of 2.95%. Only 0.29% of these failures were indicated by the OBD system. More than two-thirds of high emitters would have passed an OBD-only inspection despite having a demonstrably defective DPF [7]. In Belgium, where EURO 5 vehicles are also measured, as many as **97% of high emitters would have passed with an OBD-only test**. This clearly shows that **tailpipe particle number measurement is the only valid method to detect a defective DPF and cannot be replaced by OBD functionality checks** [8,9].

As with diesel particulate filter checks, it is equally sensible to verify the gasoline particulate filter (GPF/OPF) functionality in gasoline vehicles. New gasoline direct-injection (GDI) vehicles show particle emission behavior similar to diesels, which is why the same particle number limits apply for their type approval since 2017. These limits can only be met with a functioning GPF, making GPF functionality verification necessary within PTI as well.

Recent studies indicate that a good–bad discrimination can also be achieved for gasoline vehicles through an idle PN measurement [10]. However, several gasoline-specific aspects must be considered when introducing such a measurement.

Aspects of Measuring Gasoline Vehicles

1) Particle Size Distribution

Gasoline vehicles generally exhibit smaller particle sizes in the tailpipe than diesel vehicles [11–14]. The size distribution can also be bimodal, meaning that in addition to soot particles in the accumulation mode, smaller particles below 23 nm (sub-23 nm

particles) may appear in high concentrations, either volatile (nucleation mode) or solid (core mode) [15].

A crucial aspect: sub-23 nm particles do not appear in significant quantities when the GPF is intact, as they would otherwise be effectively removed by the filter [14].

2) Measurement Procedure and Limit Value

For diesel vehicles, good vs. bad DPFs can be distinguished reliably by low-idle PN measurement: intact DPFs show values far below $50,000 \text{ cm}^{-3}$, while defective systems can exceed $1,000,000 \text{ cm}^{-3}$. Intermediate values may appear in pre-damaged filters.

For gasoline vehicles, PN concentrations strongly depend on engine load and may vary significantly even during idle. The correlation between idle PN emissions and homologation emissions is weaker for gasoline than for diesel vehicles [16].

3) Volatile Particles

Volatile particles appear in both diesel and gasoline exhaust but are highly non-reproducible and depend on many parameters. When a nucleation mode occurs, particle sizes typically fall below 23 nm, and particle numbers dominate over the soot-based accumulation mode.

These volatile particles contain harmful substances (e.g., polycyclic aromatic hydrocarbons, PAHs). However, they are strongly diluted upon exiting the exhaust pipe and tend to re-evaporate, meaning they usually do not deposit in the respiratory system. Only when they adsorb onto soot particles they can penetrate the respiratory tract and become harmful. Without soot, volatile particles are harmless – meaning the removal of soot via particulate filters is essential.

By the way: An intact particulate filter actually increases the likelihood of nucleation mode formation downstream of the filter, since the absence of soot prevents condensation onto particles and leads instead to homogeneous nucleation. The resulting droplets evaporate upon dilution when getting released in ambient air.

4) Humidity

Gasoline exhaust shows higher moisture content and slightly higher dew points than diesel exhaust. This can lead to condensation and cause measurement errors or even device damage. Particularly during cold starts, condensation can increase significantly [17], which is why PN measurements should only be performed on warmed-up vehicles.

5) Operation of Gasoline Particulate Filters

Although the fundamental filtration mechanisms (diffusion for small particles, interception and impaction for larger particles) are the same in GPFs and DPFs, their operating behavior differs considerably.

Due to higher exhaust temperatures in gasoline engines, GPFs often reach the thermal levels required for passive regeneration. These regeneration events occur during deceleration phases, when oxygen concentrations and temperatures are high. Because GDI engines produce lower overall soot mass, the soot layer formed in the GPF is thin and unstable – it may accumulate or be removed through passive regeneration, depending on the temperature [18].

10 nm vs. 23 nm: Why is it reasonable not to measure particles below 23 nm?

- **Sub-23 nm particles are removed more effectively**

Filtration efficiency increases as particle size decreases (due to diffusion). Thus, 10 nm particles are filtered more efficiently than 23 nm particles. Sub-23 nm emissions from vehicles with particulate filters are therefore negligible. As noted above, sub-23 nm particles appear in significant quantities only when the OPF is defective [14]. This remains true even in the presence of small filter cracks. A 23 nm cutoff is therefore entirely sufficient for PTI devices.

By the way: Soot particles in gasoline and diesel exhaust typically measure around 100 nm (20–200 nm). Particles in this size range have the lowest probability of being lost by either diffusion or impaction – making them the most dangerous for human health.

- **Sub-23 nm particles reduce measurement reproducibility**

Homogeneous nucleation becomes more likely downstream of a functioning particulate filter, producing <23 nm volatile particles. Removing these particles requires complex and expensive technology (e.g., catalytic stripper with sulfur trap). Without it, PTI devices may show artifacts or become significantly more expensive.

- **Sub-23 nm requirements enhance the complexity of instrument type approval**

PTI PN counters must undergo counting efficiency tests during type approval, using monodisperse particles at specific diameters. Current devices with a 23 nm cutoff must be tested at 23, 30, 50, 70, 100, and 200 nm. Meeting the required efficiency range (20–60%) at 23 nm already requires high particle concentrations ($\sim 25,000 \text{ cm}^{-3}$), as the counters must have a detection limit of $5,000 \text{ cm}^{-3}$. Monodisperse soot particles at this high concentrations are very difficult to generate reliably.

For 10 nm testing, this becomes even more challenging. The required efficiency between 10% and 50% at the lower cutoff requires to generate monodisperse 10 nm soot particles at a concentration of $50,000 \text{ cm}^{-3}$, which is nearly impossible. As a consequence, either PTI counters would require a $10\times$ lower detection limit ($<500 \text{ cm}^{-3}$) and/or a new traceable metrological standard must be developed by metrological institutes. Such a development typically takes years and would significantly delay the enforcement of PN measurements for gasoline vehicles.

- **Core-Mode artifacts below 23 nm**

Even with effective volatile particle removal, cold-start gasoline exhaust may contain solid sub-23 nm core-mode particles [15]. These particles already cause significant device-to-device variability with 23 nm counters, and the effect would be more severe for 10 nm counters.

- **High diffusional losses increase the measurement uncertainty**

Sub-23 nm particles are heavily lost in sampling lines. Only $\sim 10\%$ of 10 nm particles reach the sensor in PTI devices, increasing the measurement uncertainty drastically.

AVL DiTEST Position

Measuring PN emissions from gasoline vehicles is environmentally meaningful and should be implemented broadly in PTI. Existing diesel PN counters can, in principle, be used. Additional research is needed to validate measurement procedures, but this challenge appears solvable.

However, including sub-23 nm particles poses major obstacles in metrological approval that could jeopardize the introduction of gasoline PN measurement altogether.

This does not mean the technology is impossible – AVL's DC-based PN sensor can meet 10 nm efficiency requirements proposed in EURO 7 – but including sub-23 nm will complicate and delay implementation.

Therefore, the focus should be on the actual purpose: verifying particulate filter functionality.

Q&A

Why does PN measurement for gasoline vehicles make sense?

The share of gasoline vehicles continues to rise, driven by hybridization and strong market demand. Modern gasoline vehicles emit harmful nanoparticles similar to diesels. With the widespread introduction of DPFs, gasoline vehicles will represent an increasing share of ultrafine particle emissions [19,20].

Euro 6c (and Euro 7 for all gasoline vehicles) introduced diesel-equivalent PN limits, requiring particulate filters. As with diesels, emission system functionality must be ensured over the vehicle lifetime, requiring periodic checks.

Can the particulate filter be checked via OBD?

Data from Germany and Belgium clearly show that only PN measurement can reliably detect defective particulate filters. In Germany, 90% of defective DPFs and in Belgium 97% would not have been detected by OBD alone [8,9].

OBD functionality checks are therefore insufficient.

Why is PN measurement more difficult for gasoline vehicles?

Diesels show clear differences between intact and defective DPFs (factor 100). Gasoline emissions depend heavily on engine operating conditions, requiring more detailed research to establish a reliable procedure.

Gasoline exhaust also contains higher humidity and smaller soot particles on average than diesel.

Why is measuring sub-23 nm particles difficult in PTI?

Within the vehicle type approval, complex and expensive particle number measuring systems are used according to the Particle Measurement Programme (PMP). Such systems include multi-stage dilution, complex heating systems, catalytic volatile removal instruments and exhaust flow measurements. They can handle the high losses in the sub-23-nm range along with the increased measurement uncertainty, but are too large, complex, and expensive for PTI. Furthermore, PTI measurement devices may exhibit an increased occurrence of artifacts – such as homogeneous nucleation – when measuring sub 23 nm particles, which could result in a higher number of false detections.

What should gasoline PN measurement look like according to AVL DiTEST?

The priority must be developing a reliable procedure to identify high-emitting vehicles and defective OPFs. Measurement devices must be validated regarding accuracy, humidity effects, and volatile components – analogous to diesel PN verification.

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