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Particulate Filter Testing

Why is the smoke opacity test no longer suitable in the PTI?

What is the alternative?

WCRAQ Online meeting
June 8th, 2021
Gerrit Kadijk

1. Introduction

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- Gerrit Kadijk Bsc (1963), Delft – The Netherlands
- Automotive combustion engine and emission engineer
- Researcher/scientist @ TNO (1988 – 2020)
- Owner of Emission Training Services (2021 - …..)
- Lecturer at Da Vinci College in Dordrecht (2021 - …..)

- Developer of the Particulate Filter Check (2012 – 2020)

Content presentation

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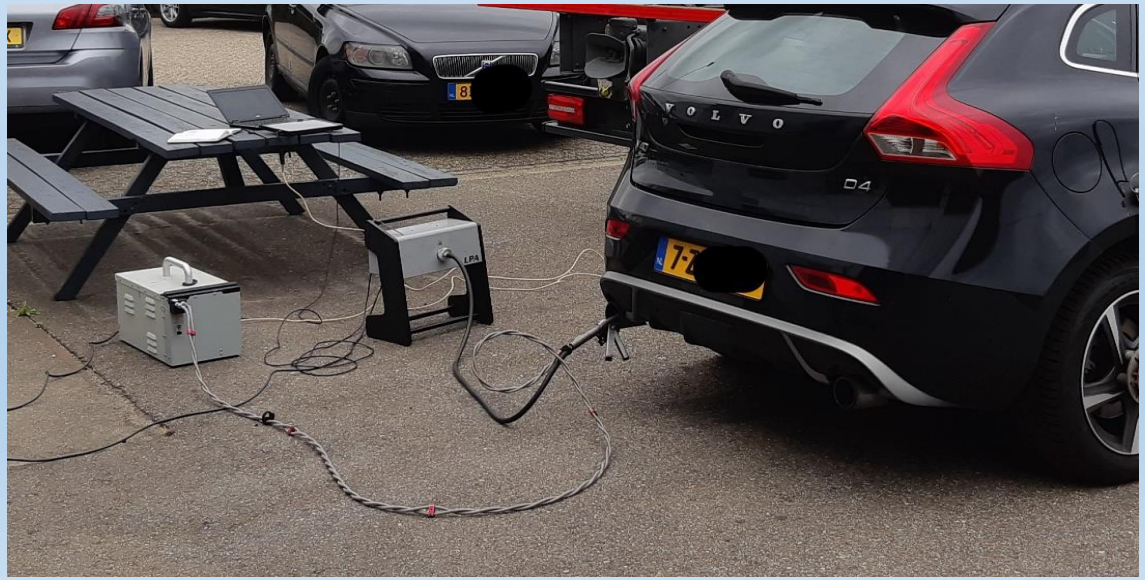

1. Introduction

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Euro 3 without Diesel Particulate Filter (DPF)

Substantial smoke emissions

VW Golf Euro 6b with DPF @ 60.000 km

The tailpipe is not covered with soot!

Observation 1: DPF's are extremely effective for reducing particulate emissions!

2. Particulate emission levels

Passenger vehicles

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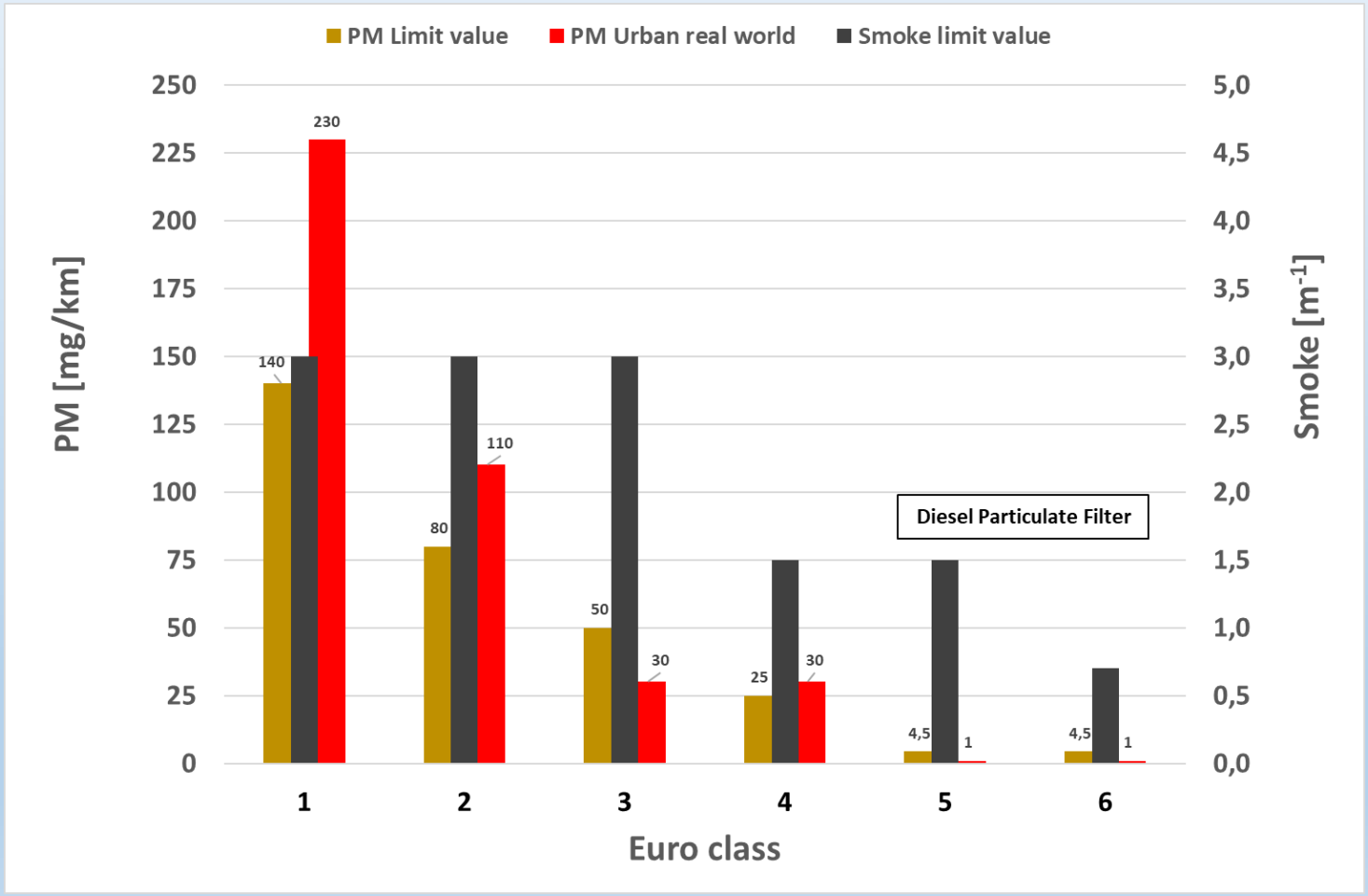

Observation 2:
Particulate mass and smoke emissions of Euro 5 & 6 vehicles are 100-300 times lower than Euro 1 vehicles.

PTI smoke emission limit values reduced only 4 times.

3. PTI Smoke emission test execution

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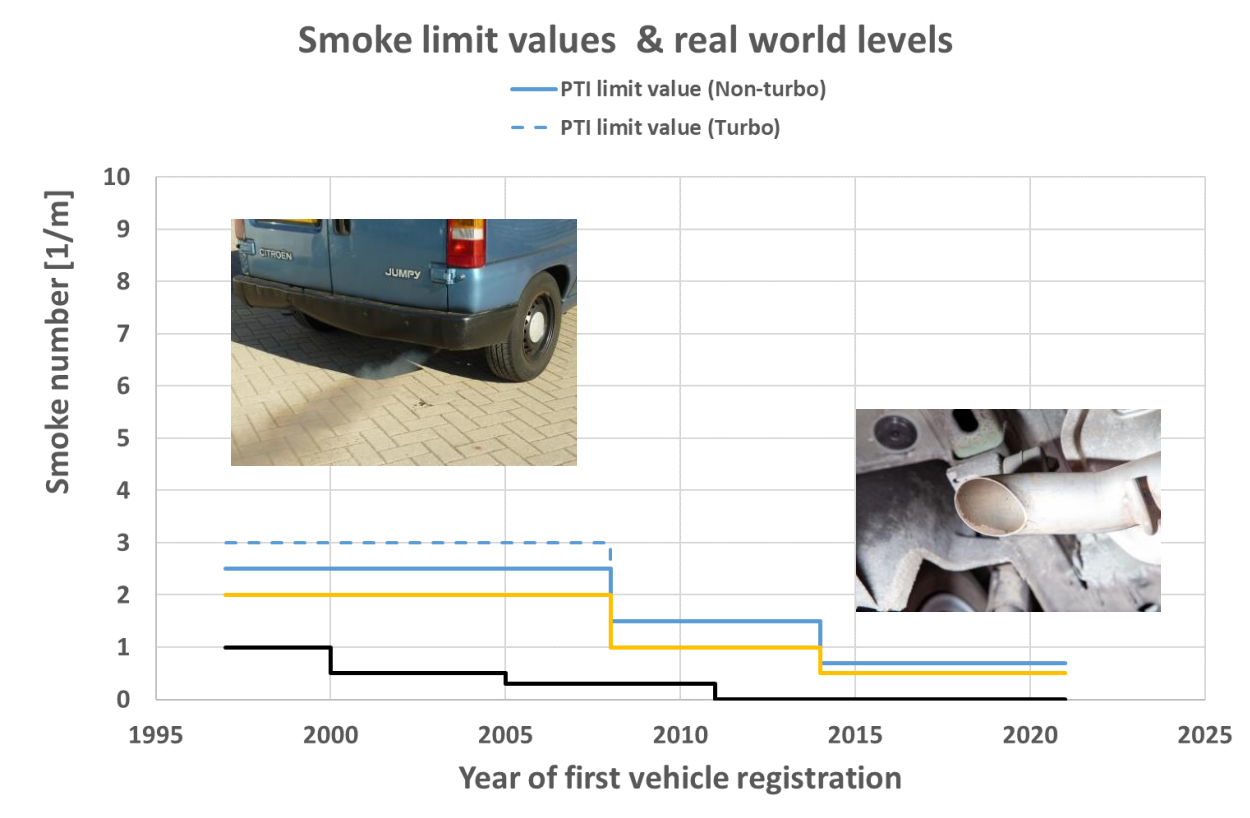

Sixty years ago the smoke emission test was developed for diesel vehicles with high particulate emissions.
Measuring scale is 0 to 10 m^{-1}.
Euro 5 and 6 diesel vehicles have a DPF.

Observation 3:
DPFs have a very high filtration efficiency.
Smoke emission test results are (near) zero!
PTI smoke value post DPF = 0.00 m^{-1}.

https://www.youtube.com/watch?v=V_64Q5-SOcw

3. PTI Smoke emission levels

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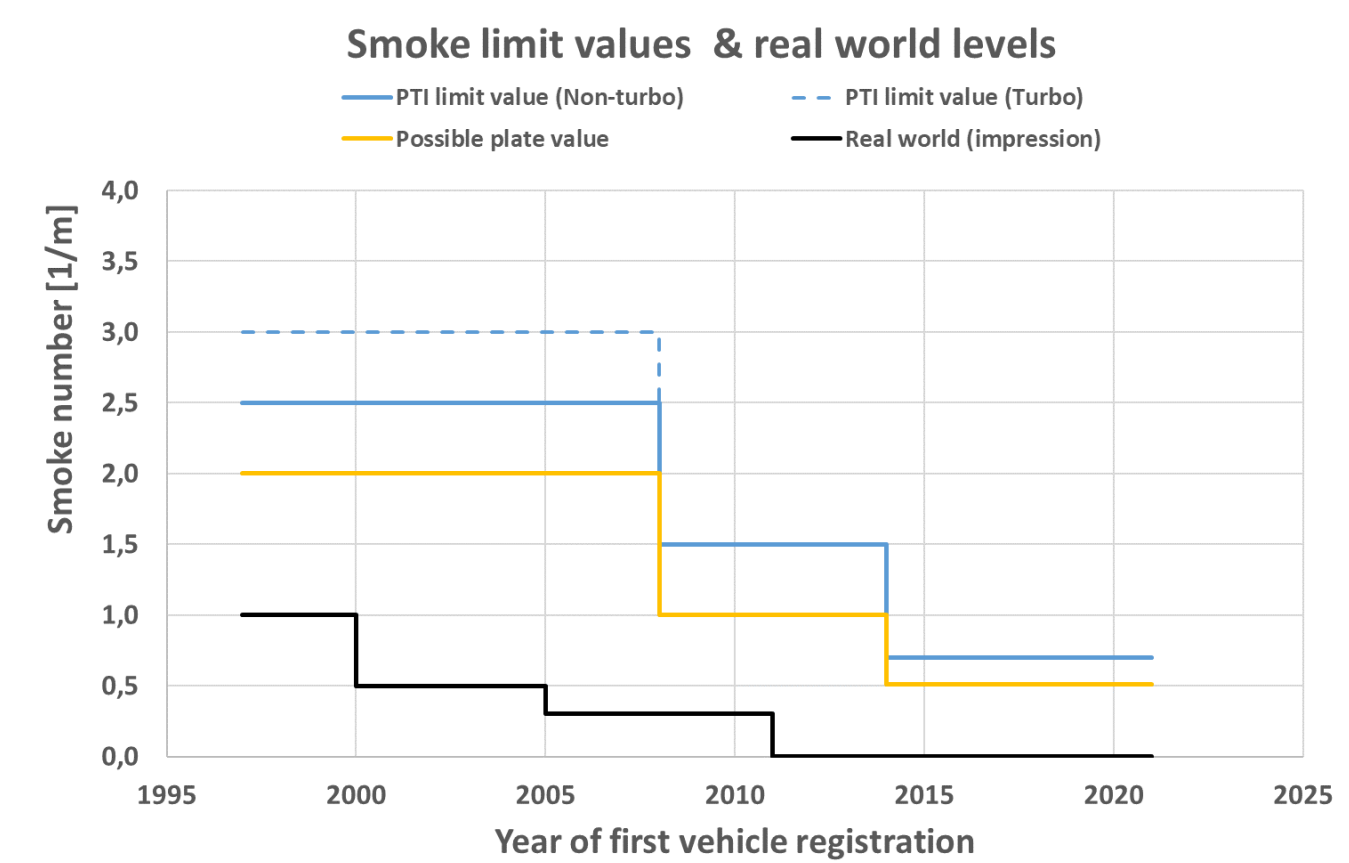

For most measuring devices a reasonable accuracy is possible between 5 and 100% of the measuring range.

Current smoke limit values cannot be further lowered because the range of the measuring scale is 0 to 10 m^{-1} and the detection limit value is 0,5 m^{-1}.

Observation 4:
Smoke emissions below 0.5 m^{-1} cannot be measured accurately.

3. PTI Smoke emission test execution

(Euro 3 or 4 without DPF)

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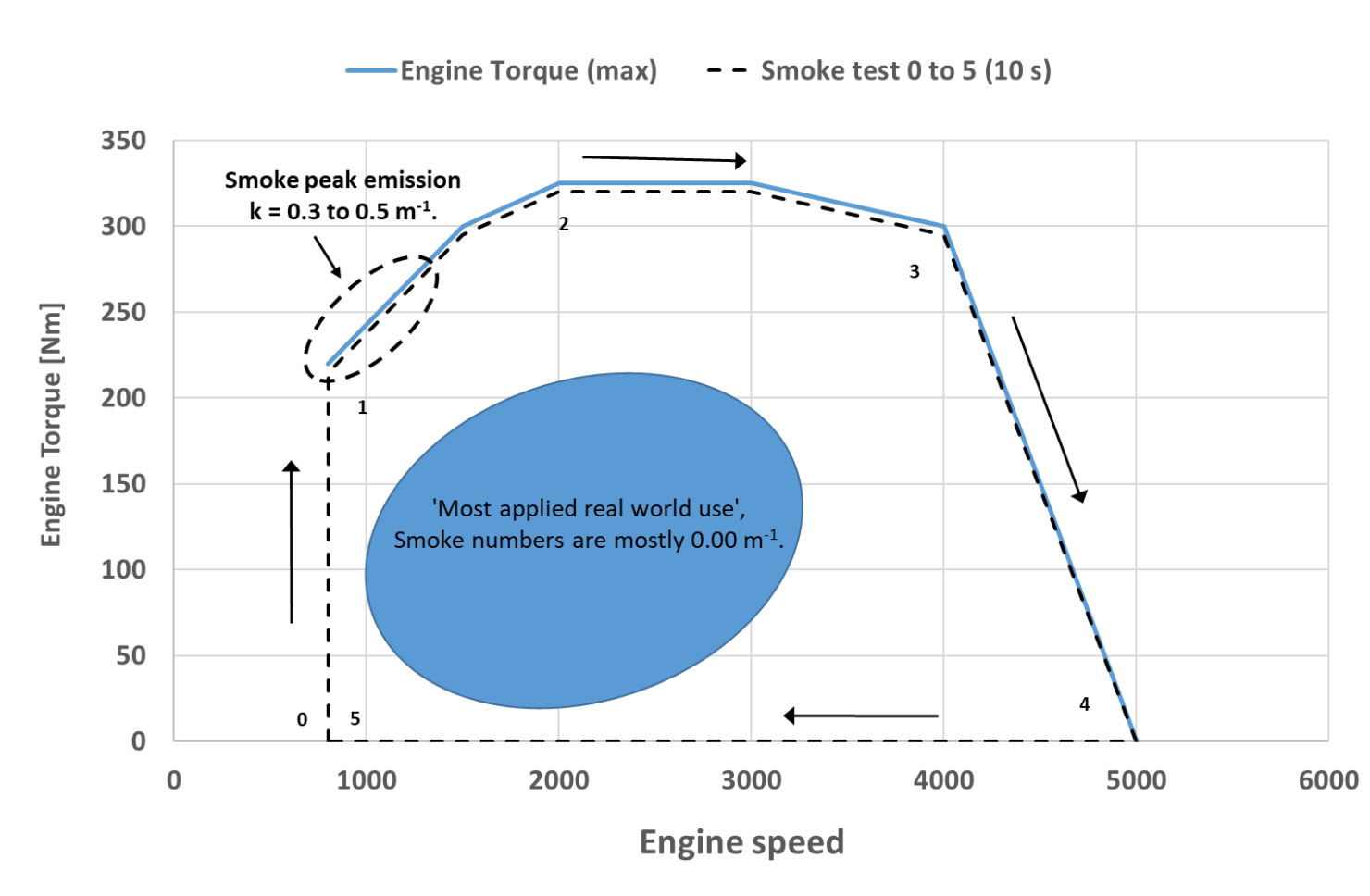

Free acceleration test is a quick dynamic full load test and required to produce some measurable smoke emissions. At low engine speeds @ full load engines produce smoke.

At constant speeds at part load operation and at idle speeds smoke numbers of vehicles without DPF are 0.00 m^{-1}.

Observation 5:
PTI smoke emissions are only detectable at full load conditions.

3. Smoke emission test elements

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- Warm Engine
- Smoke meter or opacimeter (light absorption)
- Free acceleration test (i.e. from low idle to high idle speed)
- Determination of the smoke peak value

- **Observation 6:** The smoke peak is the maximum engine smoke emission value and deviates strongly from average real world smoke emissions. Smoke emission test results (only full load) are not representative for real world operation (mainly part load).

3. Smoke emission values

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- Smoke meter measuring range 0 - 10 m^{-1}
- Accuracy +/- 0.3 m^{-1} (+/- 3%)
- Detection limit value 0.3 m^{-1}
- **Observation 7:** No accurate smoke emission test results below 0.3 m^{-1}.

- Euro 3 or Euro 4 vehicle <u>without DPF</u>
- Realistic smoke value 0.3 - 0.5 m^{-1}
- **Observation 8:** Even Euro 3 and 4 vehicles without DPF can pass the Euro 6 smoke limit value of 0.7 m^{-1}.

3. PTI Smoke emission test results

(Euro 5 with cracked DPF)

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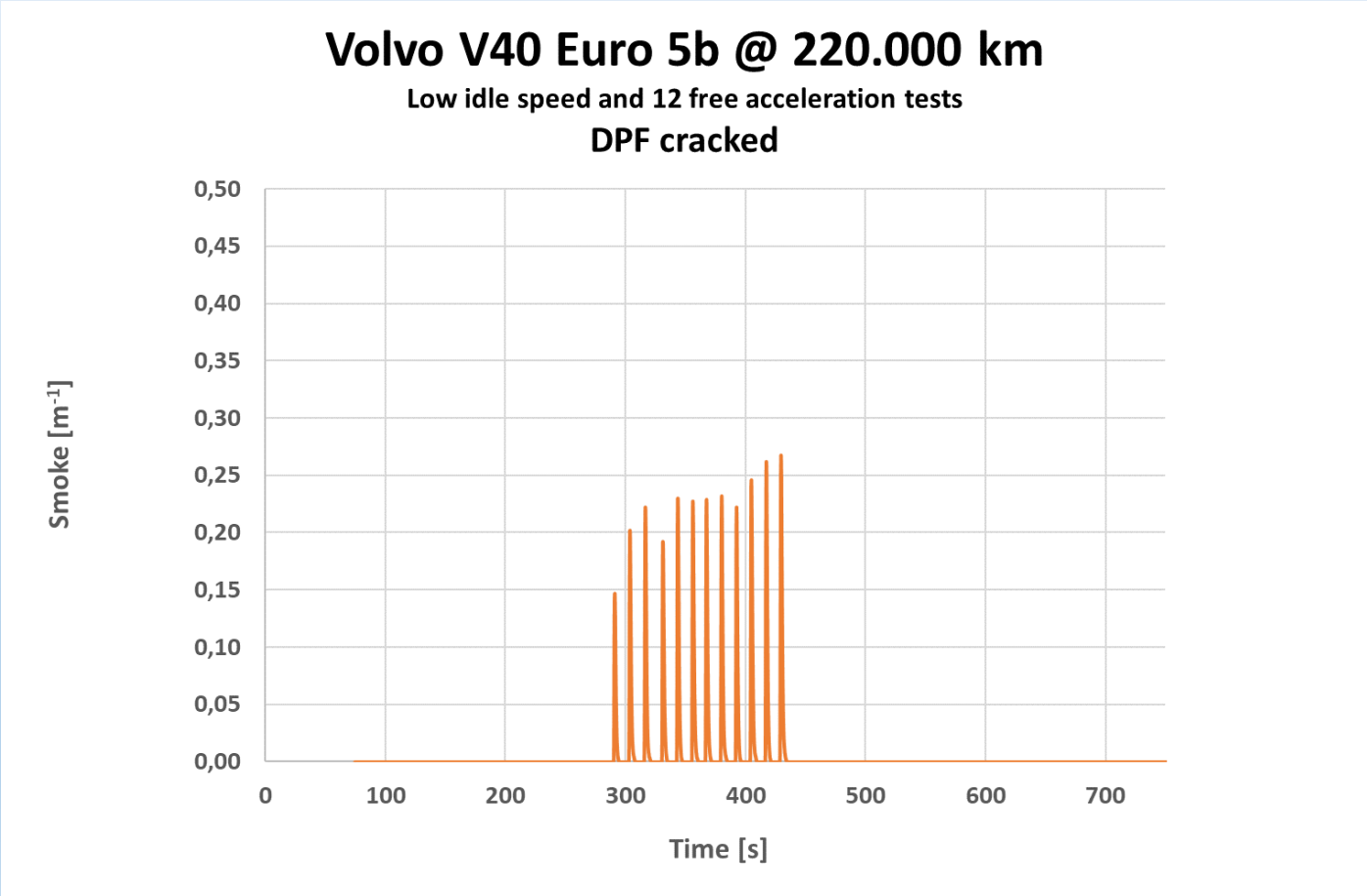

NEDC chassis dyno (fail)

PM = 13.5 mg/km CF = 3.0

PN = 2.9 * 10^{13} #/km CF = 48

PTI-Smoke (pass)

K = 0.25 CF = 0.5

Plate value = 0.51 m^{-1}

Observation 9: PTI smoke test result is not in line with chassis dyno PM and PN emissions.

3. Smoke emission test execution

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- Execution is complicated
  - Warming up takes time (> 10 minutes)
  - Stabilization of engine and emissions take time (30 – 60 seconds)
- Smoke emissions test is not well defined
  - Food pedal must be operated in less than 1 second (0.1 or 1.0 s is crucial)
- Smoke emission test can easily be manipulated/reduced.
  - Fuel composition cannot be checked (GTL/HVO or 10% petrol have major effects)

Observation 10: The concept of the smoke emission test in terms of execution, definition and manipulation is very weak.

3. Smoke emission principle

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- A smoke meter is based on light absorbtion
  - Only big particles absorb light
  - Small particles are not detected or measurable

Recent Developments in the Measurement of Low Particulate Emissions from Mobile Sources:

A Review of Particle Number Legislations. Oliver F. Bischof https://www.springer.com/journal/40825/

Observation 11:

The light absorbtion concept is not suitable for DPF equiped engines.

4. Particulate Filter Check (PFC)

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- PTI emission test at low idle speed, no preconditioning required
- Particle test: measurement of particle number concentration
- Particle concentration is measured with a **low cost particle counter**
- Test time of total test procedure is appr. 90 seconds
- Expected share of vehicles without preconditioning is 90%
- The residual 10% must be tested with a warm engine
- PTI limit value is 250.000 or 1.000.000 #/cm^3

4. Particulate Filter Check (PFC)

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5. Low cost particle counters

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CPC and DC types

10 potential suppliers

3 particle counters are already type approved by the Dutch metrological institute.

Price range: € 4,750 to € 7,000

5. Comparison smoke and PN

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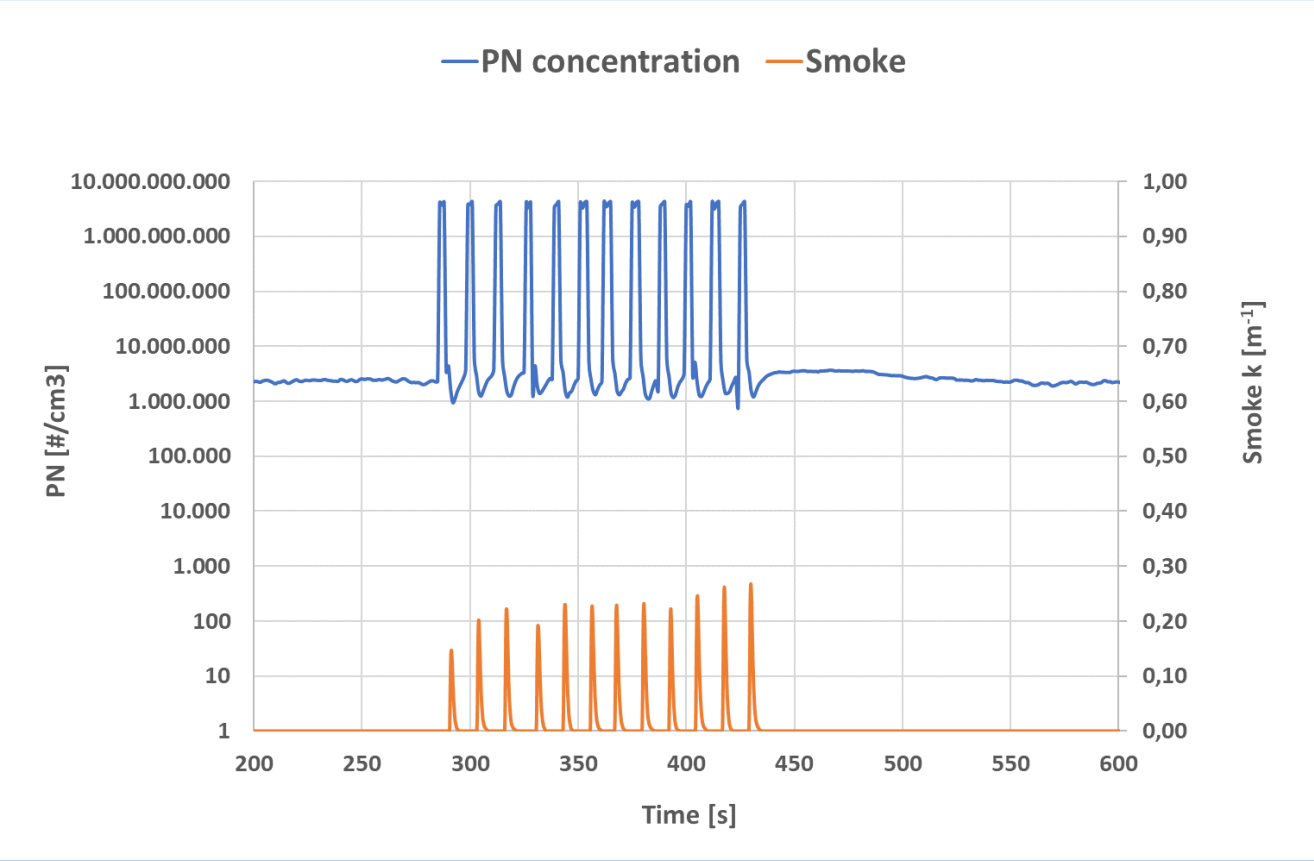

Volvo V40 Euro 5b @ 220,000 km
Free acceleration and low idle speed
DPF cracked

At minimum smoke levels in free acceleration tests the PN counter is running out of scale.

Al low idle speed PN is 2 million #/cm^3 and smoke values are 0.00 m^{-1}.

Observation 12: PN counters have the right sensitivity for PTI testing of DPFs at low idle speed. Smoke opacity meters are not suitable for DPF testing.

5. Overview

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Particulate emission	PM [mg/km]	Euro class	Suitable metric
High	50 – 150	1 and 2	Opacity and PM
Medium	25 – 50	3 and 4	Opacity and PM
Low	0 - 5	5 and 6	PM & PN

Observation 13:
The required PTI measuring technique depends on the particulate emission level of the vehicle.

Note: Measurement of PM-standard for PTI purposes is not fully developed.

References

www.pf-check.com

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6. More information

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Book language Dutch

‘Roet in beeld’ Launch 15-06-2021

Website ETS: www.deeltjestest.nl

7. News

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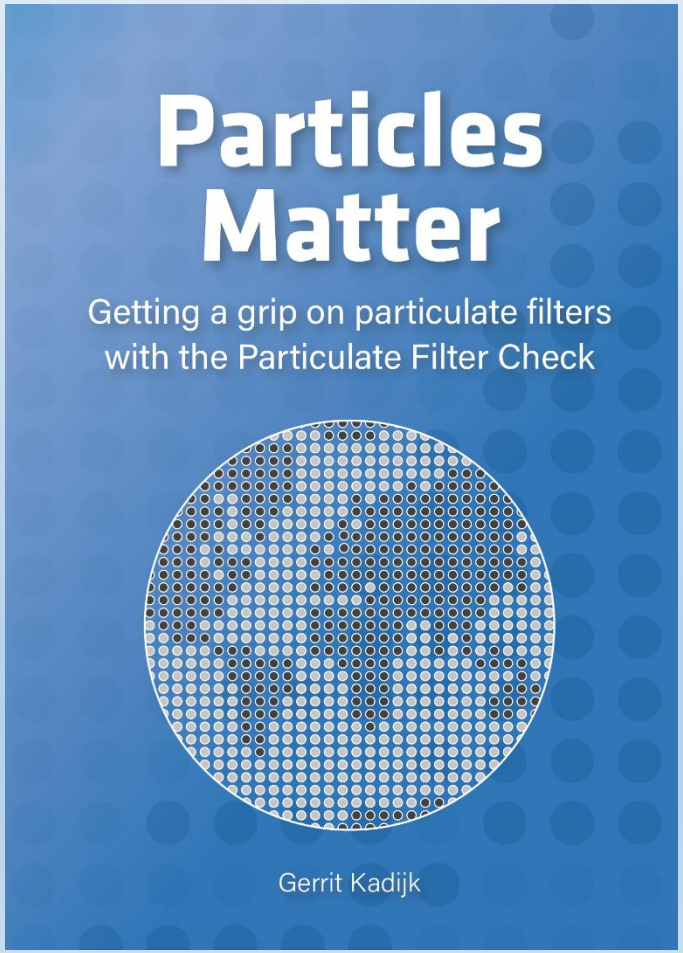
Book language English

‘Particles Matter’

Launch December 2021



7. News

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Thank you very much for your attention

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Diesel vehicles and particulate filters

Passenger vehicles

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Euro class	DPF	PM limit value [mg/km]	Rel. PM emission [%]	PN limit value [# * 10^{11}/km]	Smoke limit value PTI [1/m]	Rel. smoke [%]
1	No	140	100	-	3.0	100
2	No	80	57	-	3.0	100
3	No	50	36	-	3.0	100
4	No	25	18	-	1.5	50
5/6	Yes	4.5	3	6.0	1.5 / 0.7	50 - 23
Real world emissions						
5/6	Yes	**1**	1	0,6	**0.01**	0.3

Conclusion: Particulate mass and smoke emissions of Euro 6 vehicles are 100-300 times lower than Euro 1 vehicles, but PTI smoke emission limit values reduced only 4 times.