WORKSHOP C

SESSION TWO

Presentation 2

Opacity and NOx measurement are reflecting the health and operating status of diesel euro 5/6 engines

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CITA 2013 Session 2 of Workshops

Workshop C: Advances in Test Equipment

Opacity and NOx measurement are reflecting the health and operating status of Diesel euro 5/6 engine

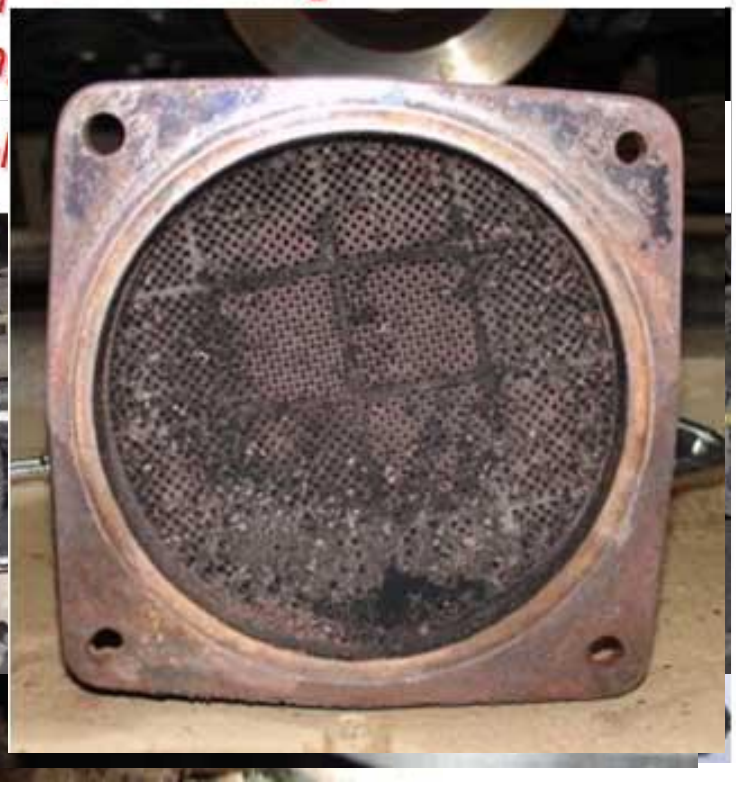
Georges PETELET: CAPELEC, Business Developer

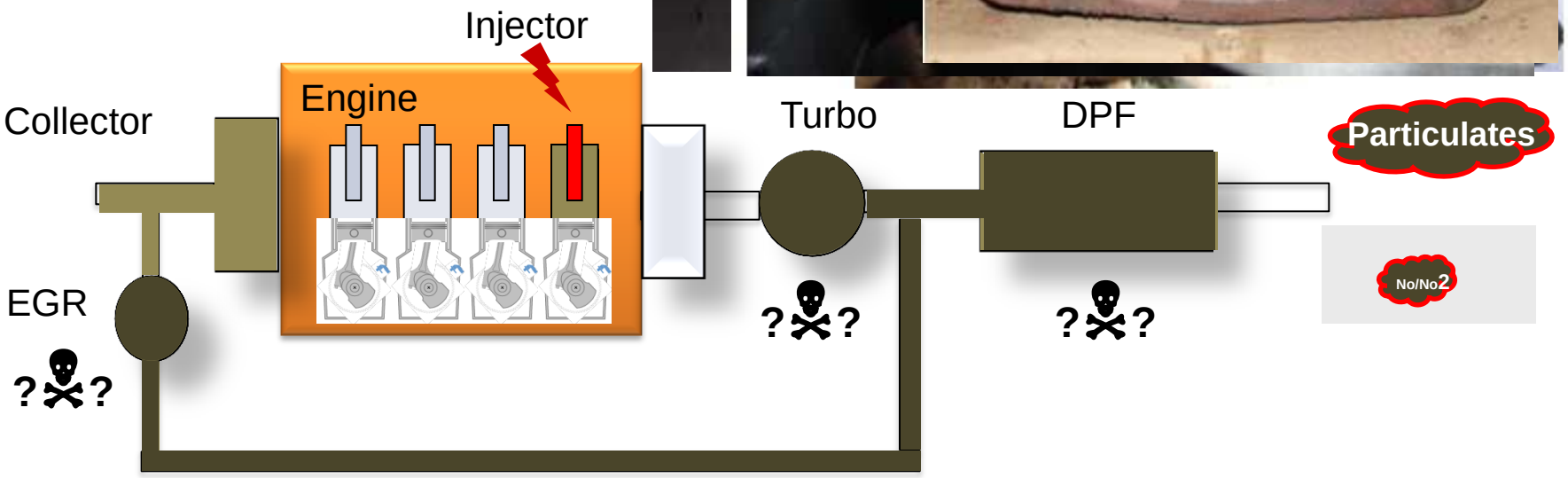
BLACK CARBON / PARTICULATES / NOx
« Production mechanisms »

Euro 5/6 Engine weakness

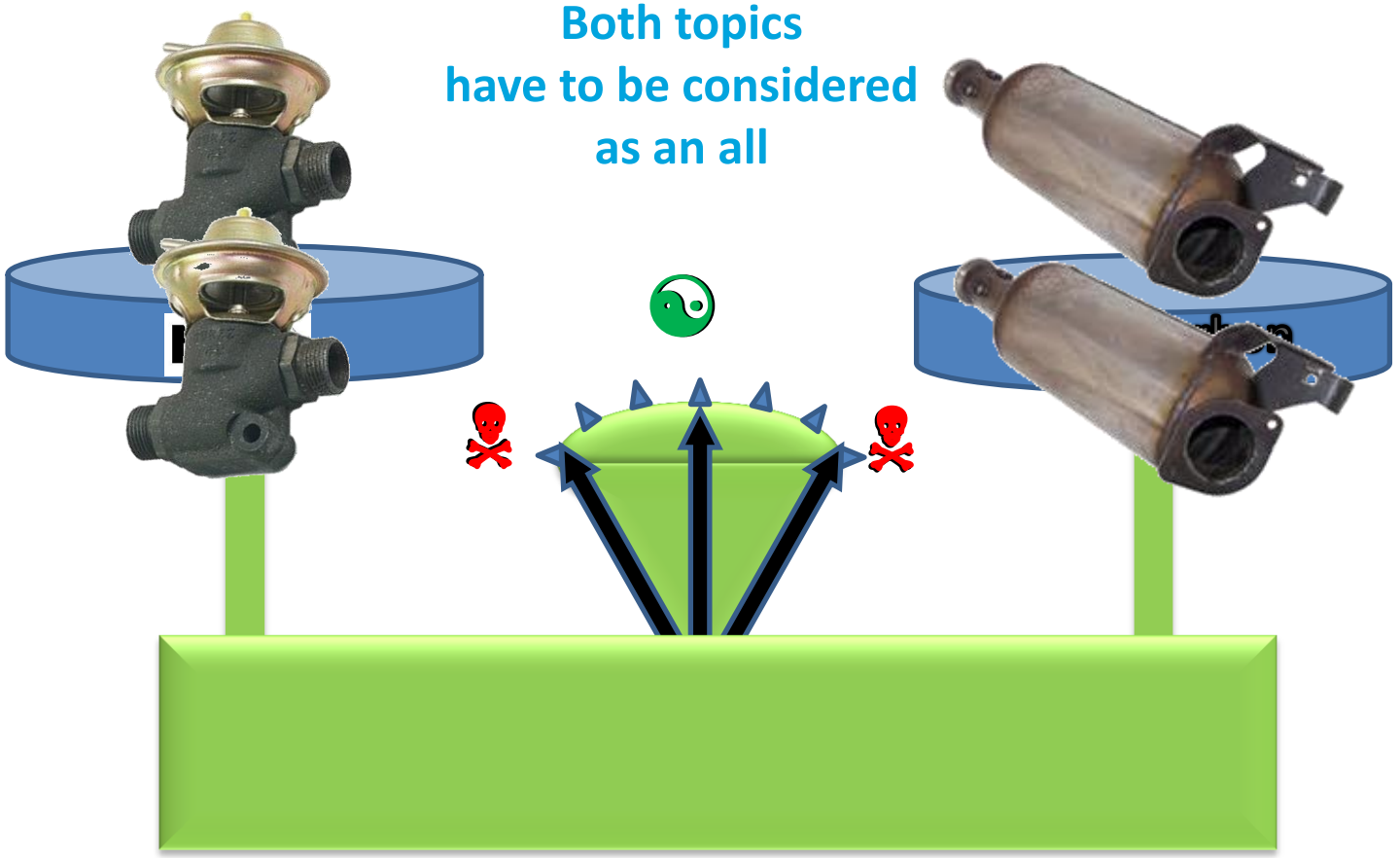
Have to be detected on both sides:

- DPF trouble by better Opacity measurement
- EGR valve trouble by Nox measurement

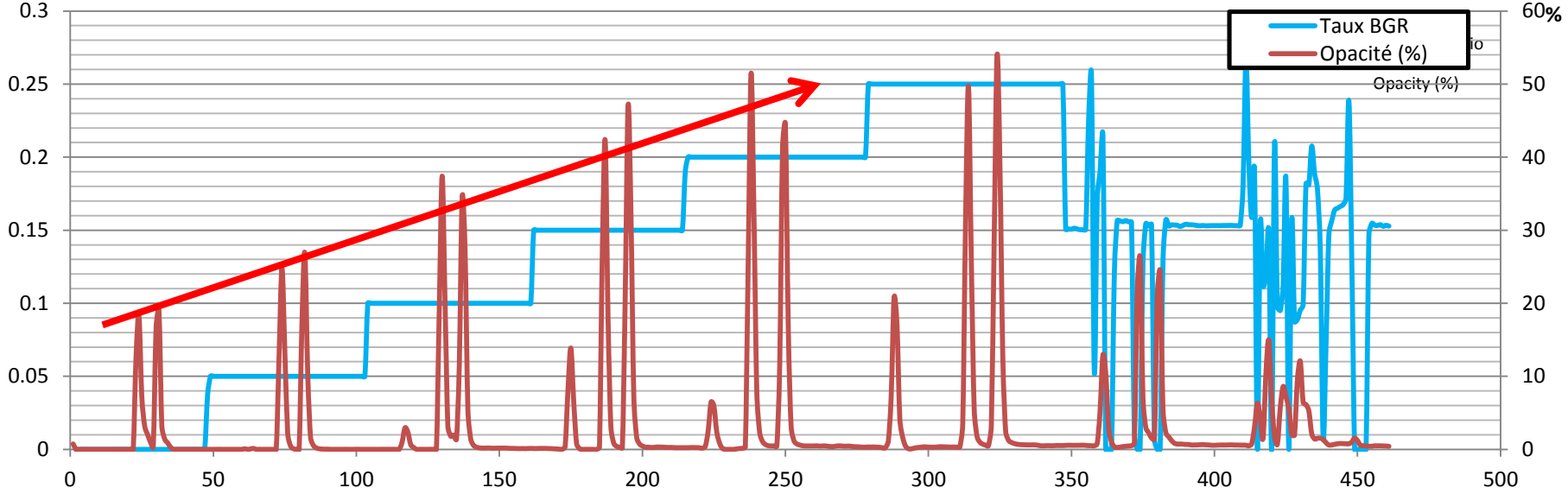




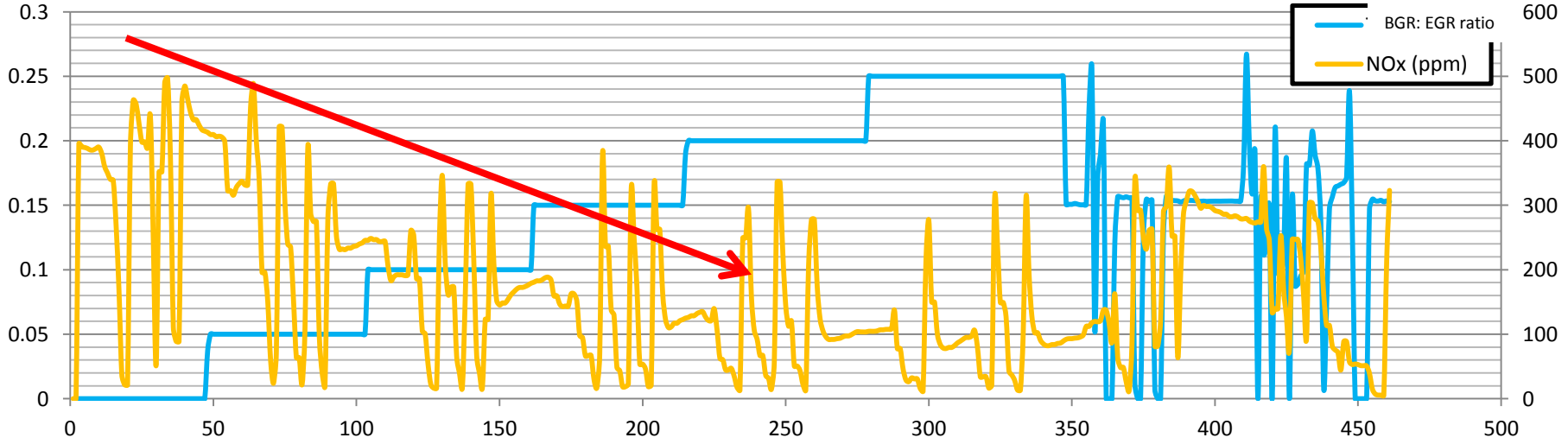
Fight against NOx & black carbon have cross influences

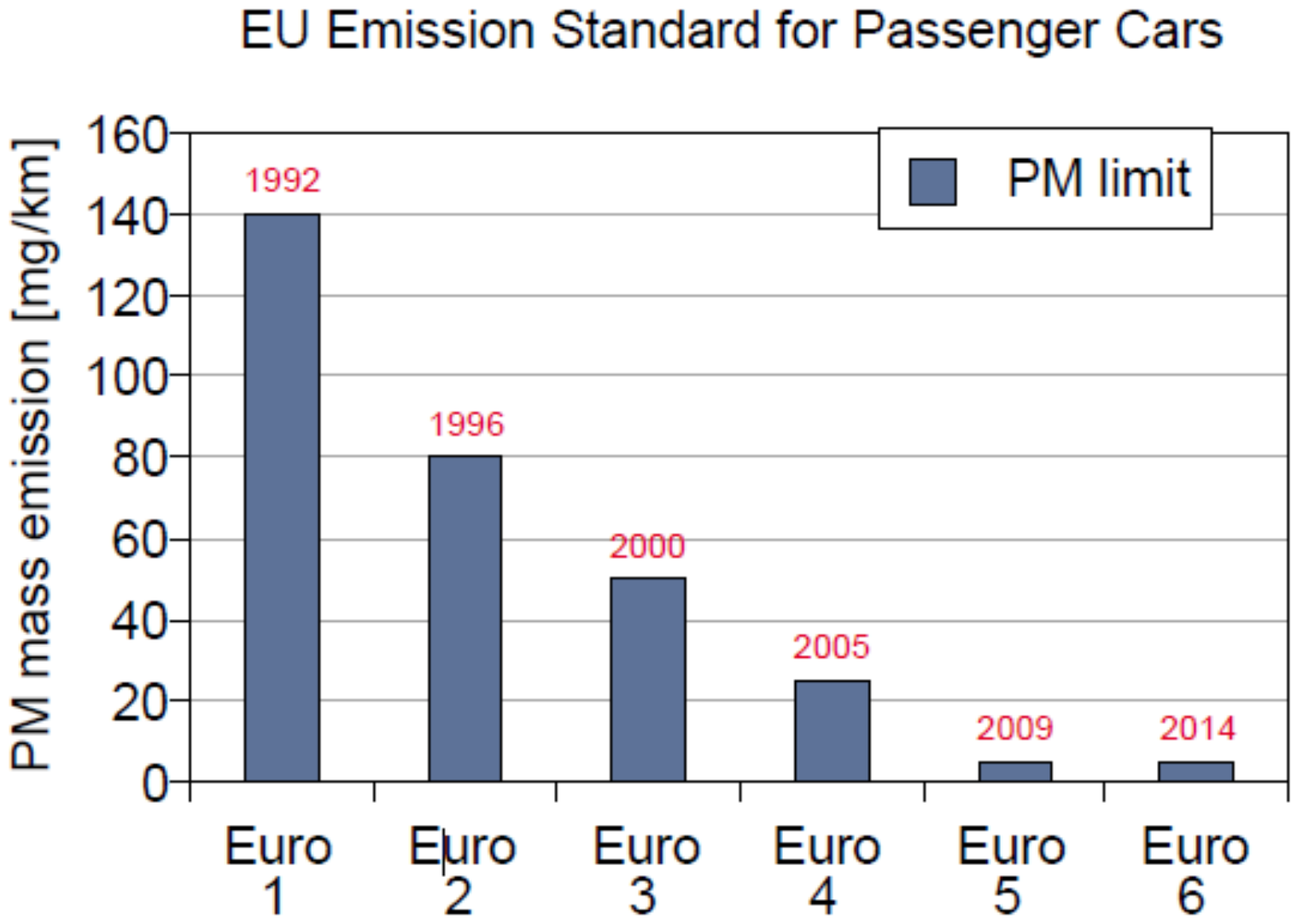


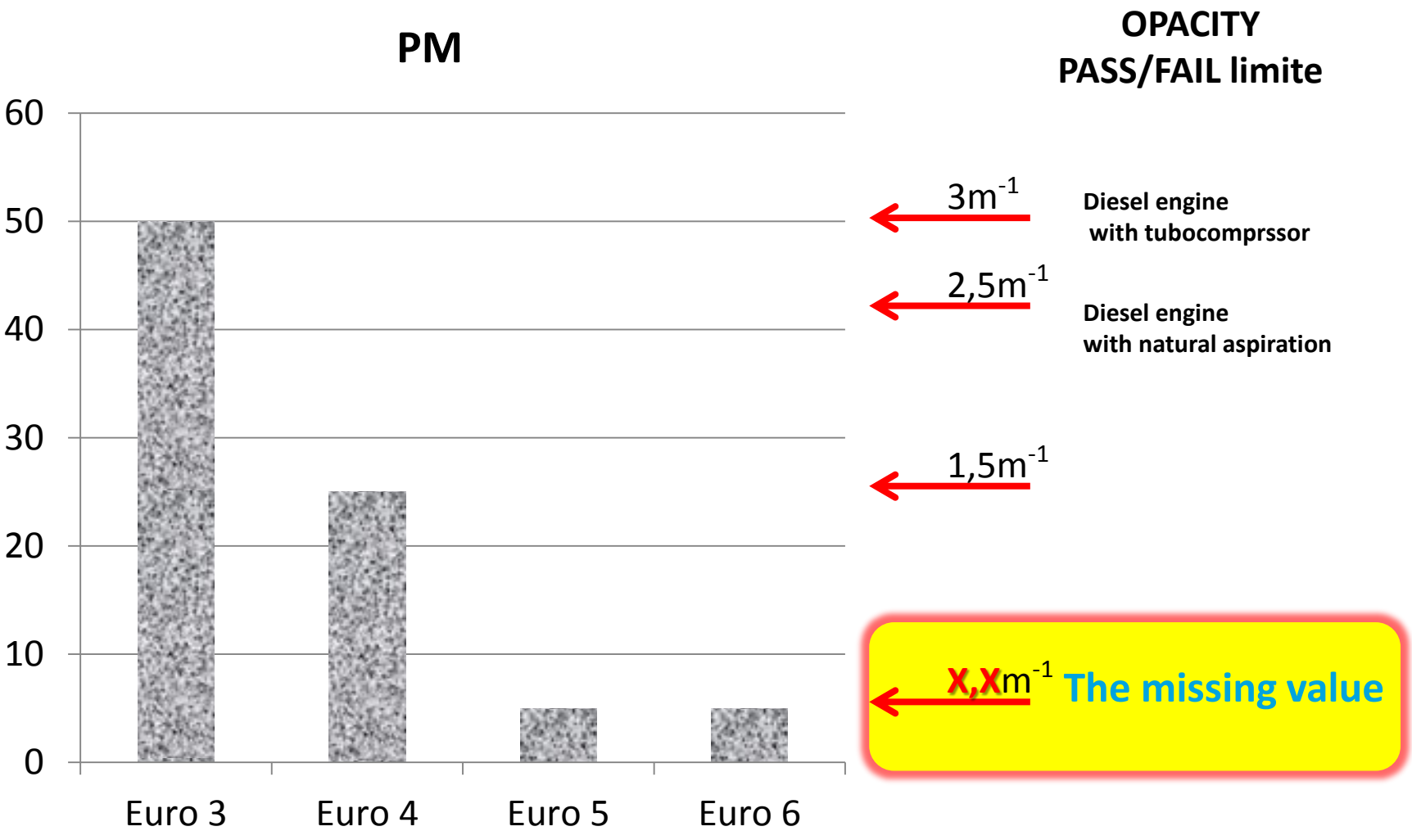
NOx measurement: Free acceleration test (PTI method)



Black carbon is rising when Nox values are folding




EU Emission Standard for Passenger Cars
PM mass emission [mg/km]
160
140
120
100
80
60
40
20
0
PM limit
1992
1996
2000
2005
2009
2014
Euro 1
Euro 2
Euro 3
Euro 4
Euro 5
Euro 6


PM
OPACITY
PASS/FAIL limite
60
50
40
30
20
10
0
Euro 3
Euro 4
Euro 5
Euro 6
3m-1
Diesel engine
with tubocomprssor
2,5m-1
Diesel engine
with natural aspiration
1,5m-1
X,Xm-1 The missing value

DPF: Diesel Particulate Filter is … a filter

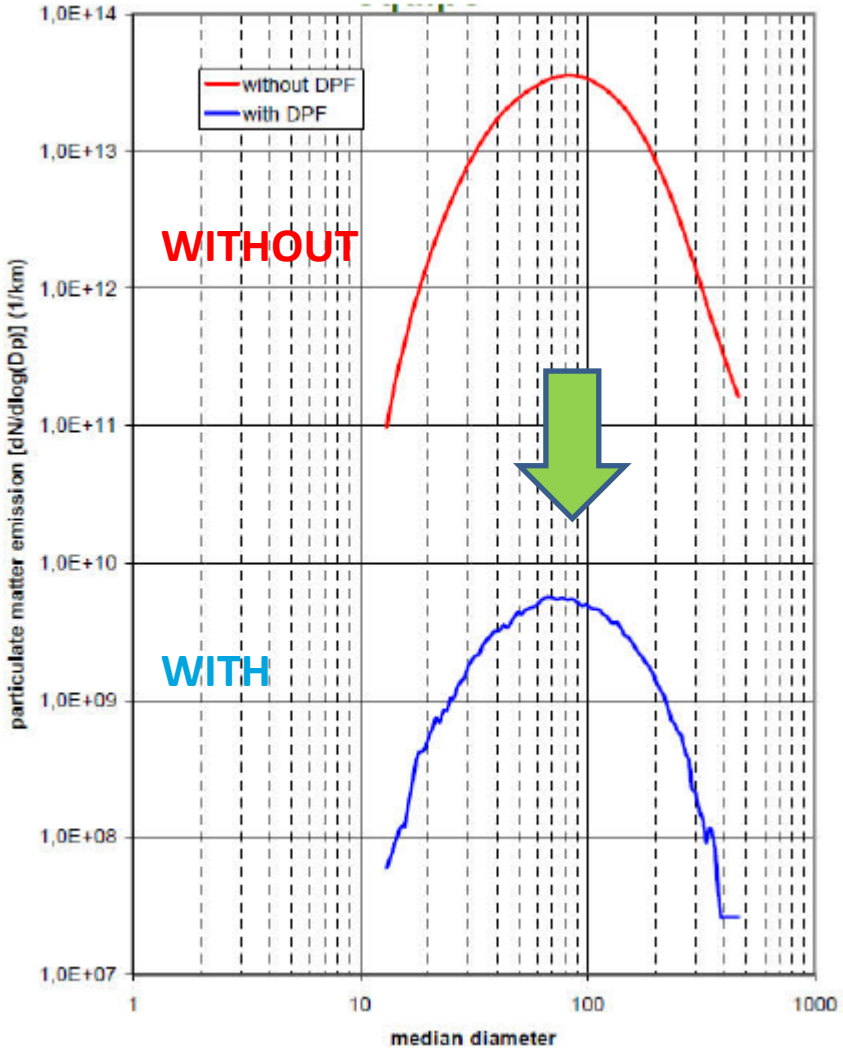
DPF is a black carbon filter

The various post treatment strategy of particulate filter are providing a result of a attenuation on the whole range of the granulometric spectrum by a ratio of

- 100 to 1 000 (in quantities)
- with no impact on the number distribution

No change

The level of emission has dropped.
The nature of those emission is still the same.
The opacity measurement is still valid as an indicator of the black carbon emission.
Only the level has to be revised.



NEW APPROACH

New OPACITY level for Euro 5/6

Pass/Fail threshold for vehicles according Euro 5/Euro6 type approval will be defined soon.
the opacity limit fro Euro 5/6 should be below 0,5m-1 will required more accurate measurement.
Repeatability, sensitivity of the measurement equipment must be improved regarding current solutions

Nox & EOBD are weapons to fight EGR valves failure

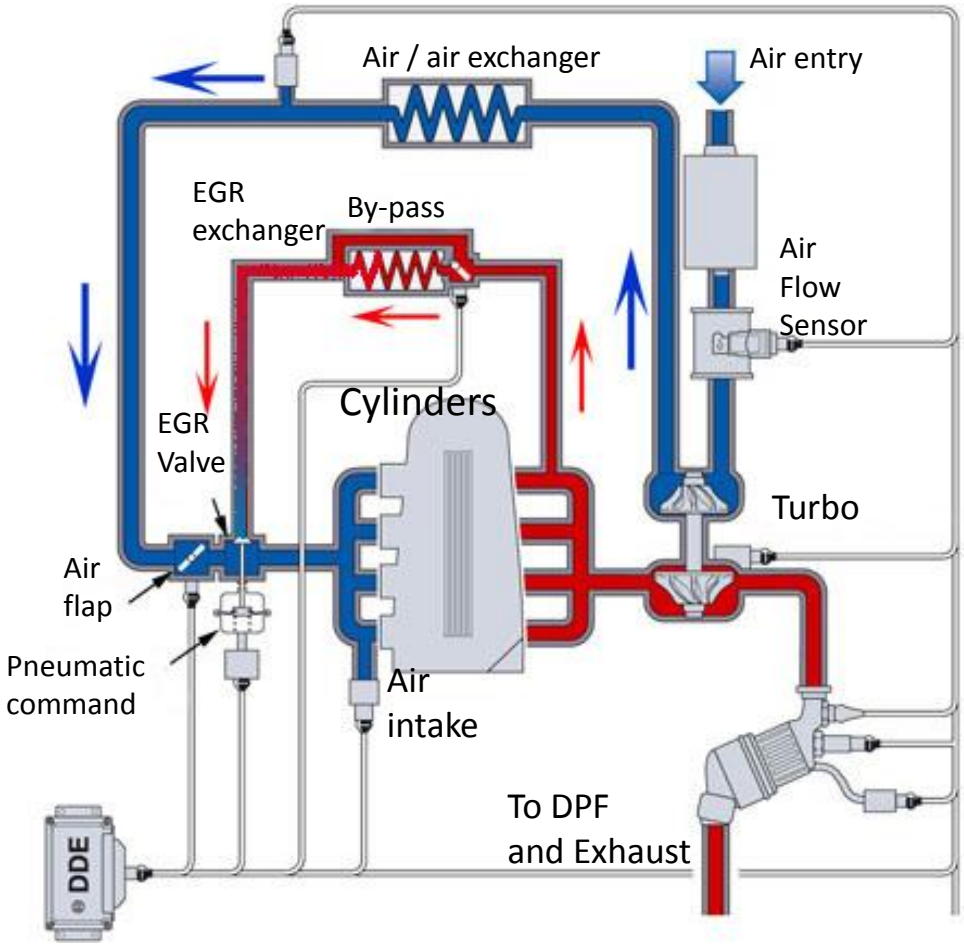
A special procedure using Nox measurement and EOBD status can point out malfunctioning of the EGR valve and the antipollution components involved in the Nox reduction:

- No need of absolute values
- NOx variation regarding Idle, fast idle and free acceleration are compared with EGR valves EOBD infos
- Non homogeneous Nox variation regarding EGR valves infos prove that there is something wrong with the antipollution system (either EGR valve, sensors …)

Early Nox fault flagging

will contribute to the **inevitable** DPF clogging and death.

EGR Valve: NOx killer

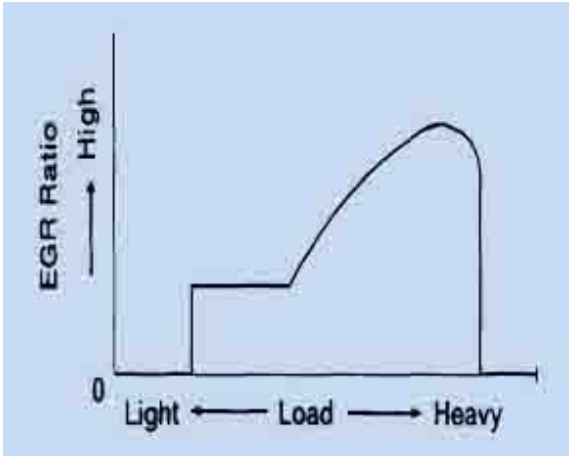


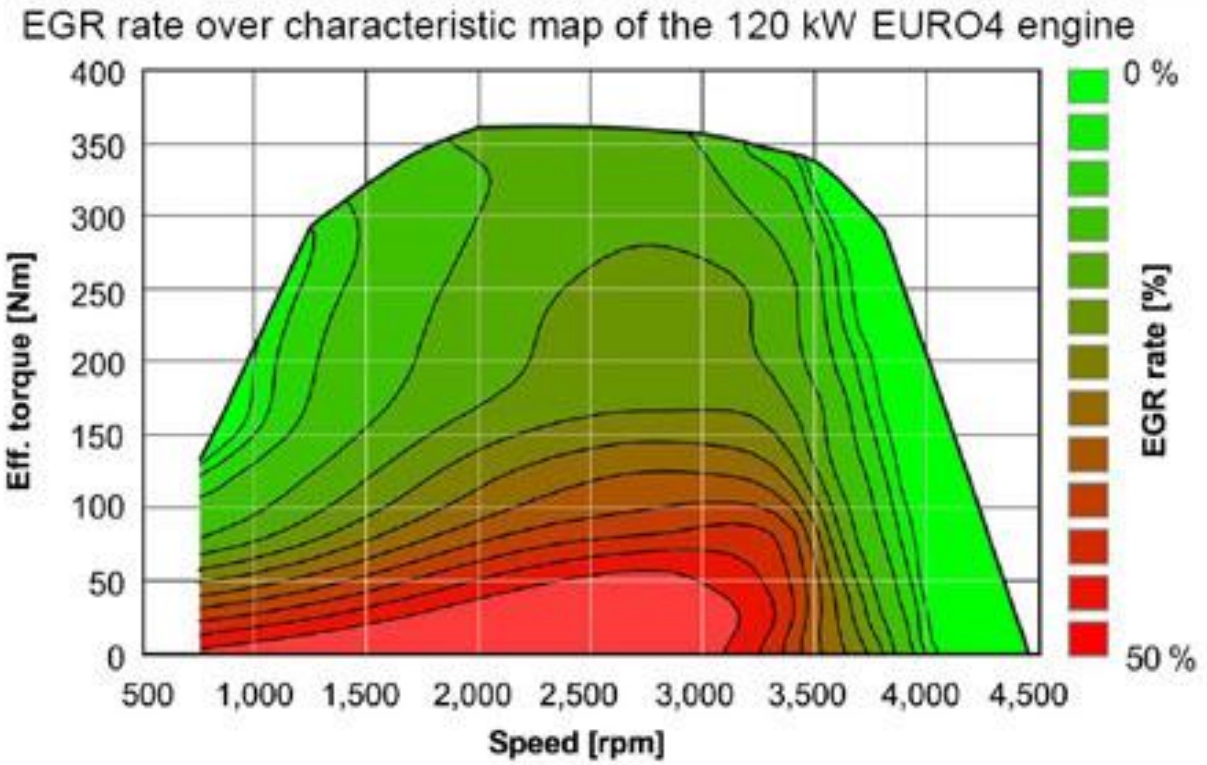
EGR is moving valve closure member to regulate the exhaust gas flow from exhaust manifold to air intake manifold:

- Reduction of the quantity of air introduced
- Drop of the combustion temperature causing a reduction (due to cool inert gas) of NOx formation

- Nitrogen oxide are created in high quantity when combustion is done at very high temperature with air exceed.
- Injection of exhaust gas is dropping oxygen's concentration, this is leads a slow down of combustion.
- In addition, high CO2 massic heat contained in the exhaust gas absorbs a part of the heat generated by the combustion.
- Due to this 2 phenomena, temperature of combustion is reduced and at exhaust pipe it may drops from usual 700°C down to 500°C; Quantity of NOx is reduced, oxygen is combining with the nitrogen of the combustion's air is generating monoxyde d'azote (NO) and dioxyde d'azote (NO2).

EGR Valve: ECU driven

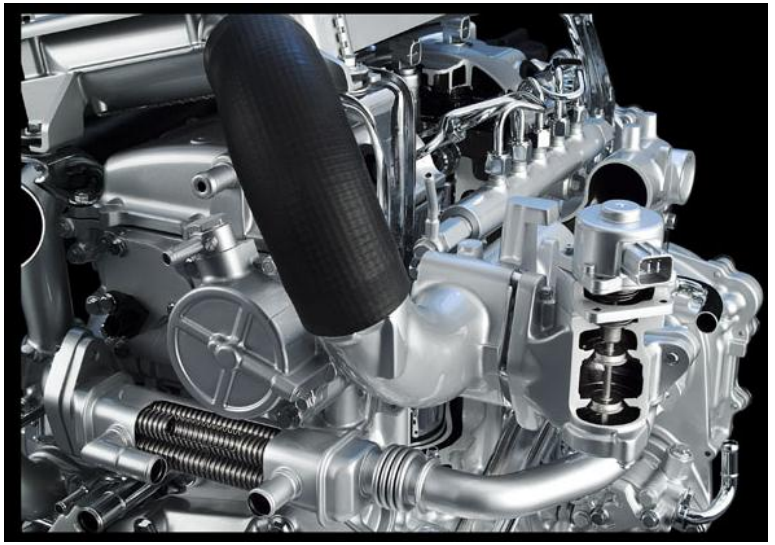




Exhaust gas recycling is performed at medium engine load, this means when engine is in air exceed condition.
EGR is sometime used at idle speed but form some duration.

Procedure robust with regard to NOx performances & ECU Strategy:

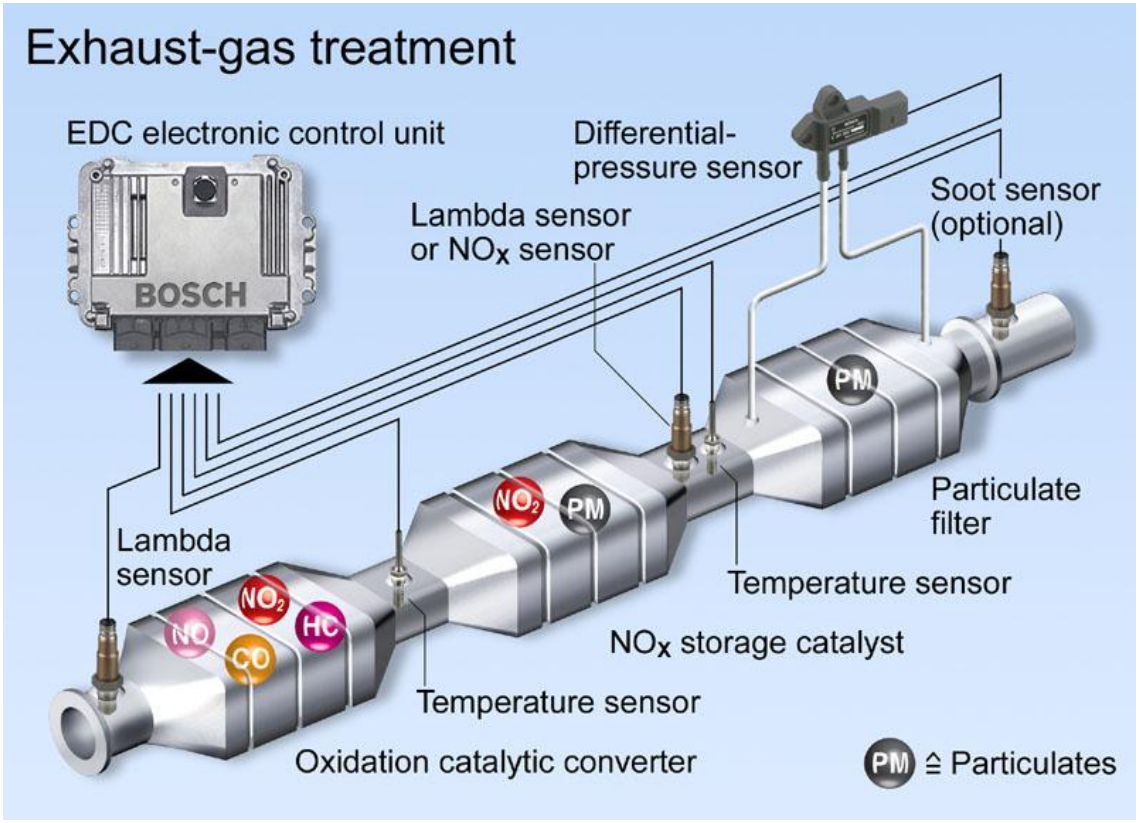
- Nox emission level is **related to the Technology and implementation of the EGR valve**
- Nox emission level is **related to the ECU strategy according Car manufacturers specifications**
- Nox emission level is **related to ambient temperature (air+ EGR feedback)**
- Excessive Oxides of Nitrogen can be caused by anything that makes combustion temperatures rise
- Maximum Nox emission level required heavy and expensive test environment



- **-> Opacinox**
- **Procedure**
- **-> EOBD reader**
- **Treatment**

Non homogeneous Nox variation proves that there is something wrong with the antipollution system (either EGR valve, sensors …)

EXHAUST GAS TREATMENT IS ELECTRONICALY DRIVEN AND DIAGNOSED BY EOBD



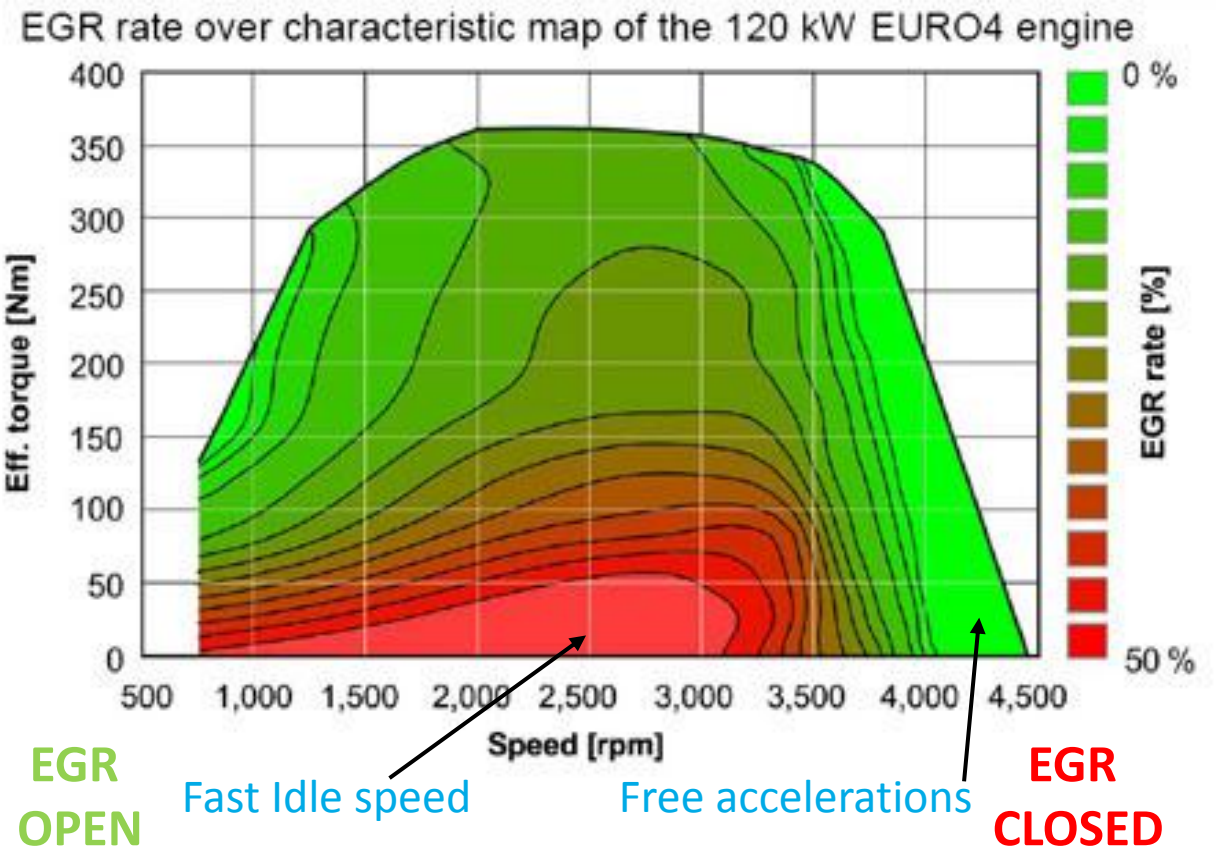
EOBD informations in combination with exhaust gas analysis can flag inoperative Exhaust gas

ISO 15031

- PID:

Status, live data from sensors:
  - Lambda sensor
  - EGR valve (EGR rate…)
  - Pressure sensor
  - Thermal sensor
  - NOx sensor
- DTC: Default Trouble Code description of trouble identified by the ECU about:
  - Lambda sensor
  - EGR valve
  - Pressure sensor
  - Thermal sensor
  - NOx sensor
- MIL : Malfunctioning lamp

EGR Valve: Test condition



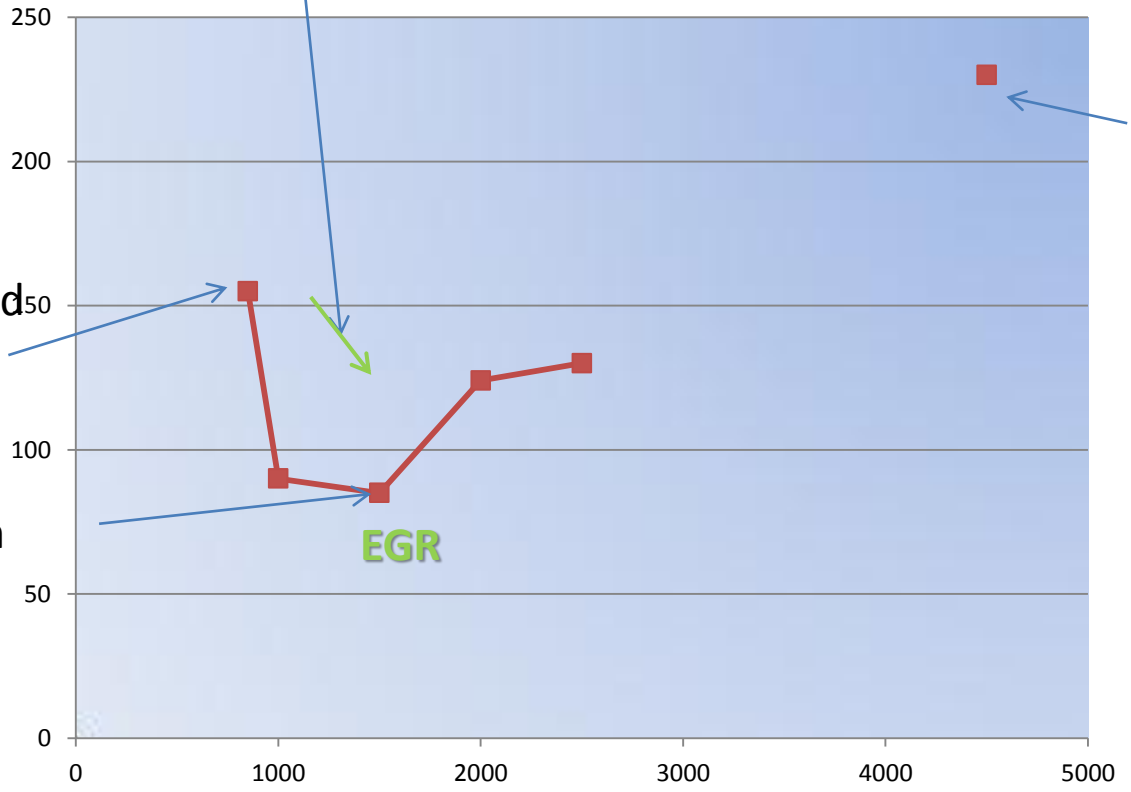
Fast idle speed is about 2500-3000 RPM, with no load.

Free acceleration is about 4000 RPM, with the load of the engine by itself (few load).

Test Phase 1: Typical valid EGR valve behavior

MAP
Drop from Idle status

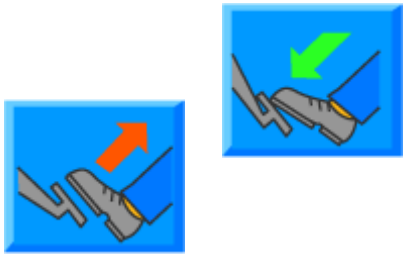
NOx wo Load (ppm)



EGR closed
Free acceleration

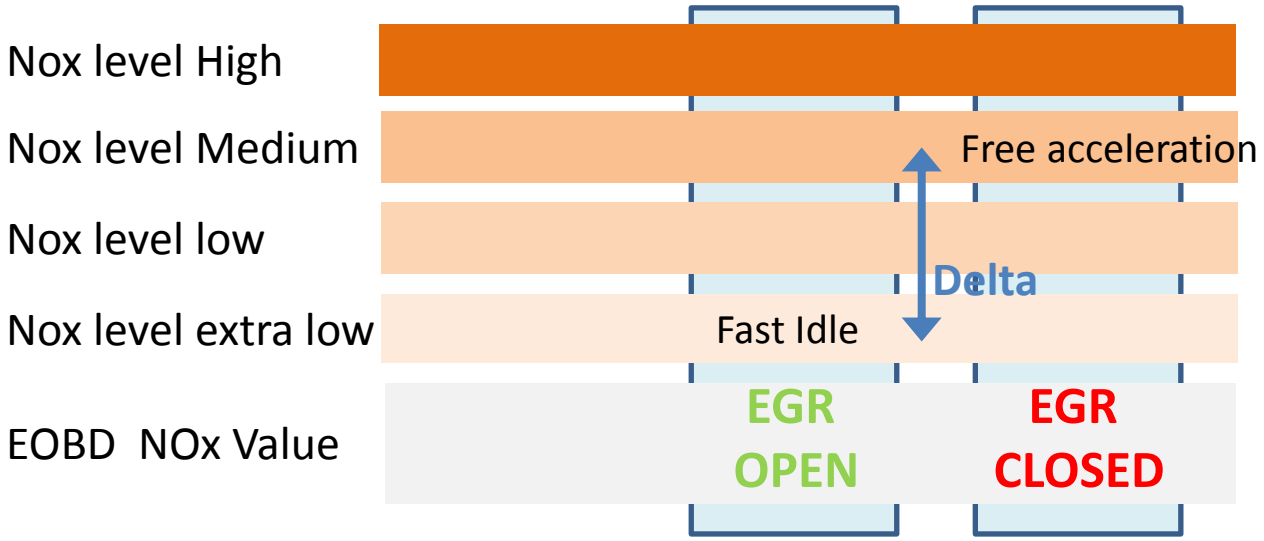
EGR closed
Idle
(since 70s)

EGR open
Fast idle
(over 3s)



Nox free acceleration Tests for Euro 6 engine

- **Test: check if Nox sensor info are in line with reality**



EGR CLOSED EOBD Nox value

Delta

EGR OPEN EOBD Nox value

And

Opacinox **Free acceleration** Nox value

Delta

Opacinox **Fast Idle** Nox value

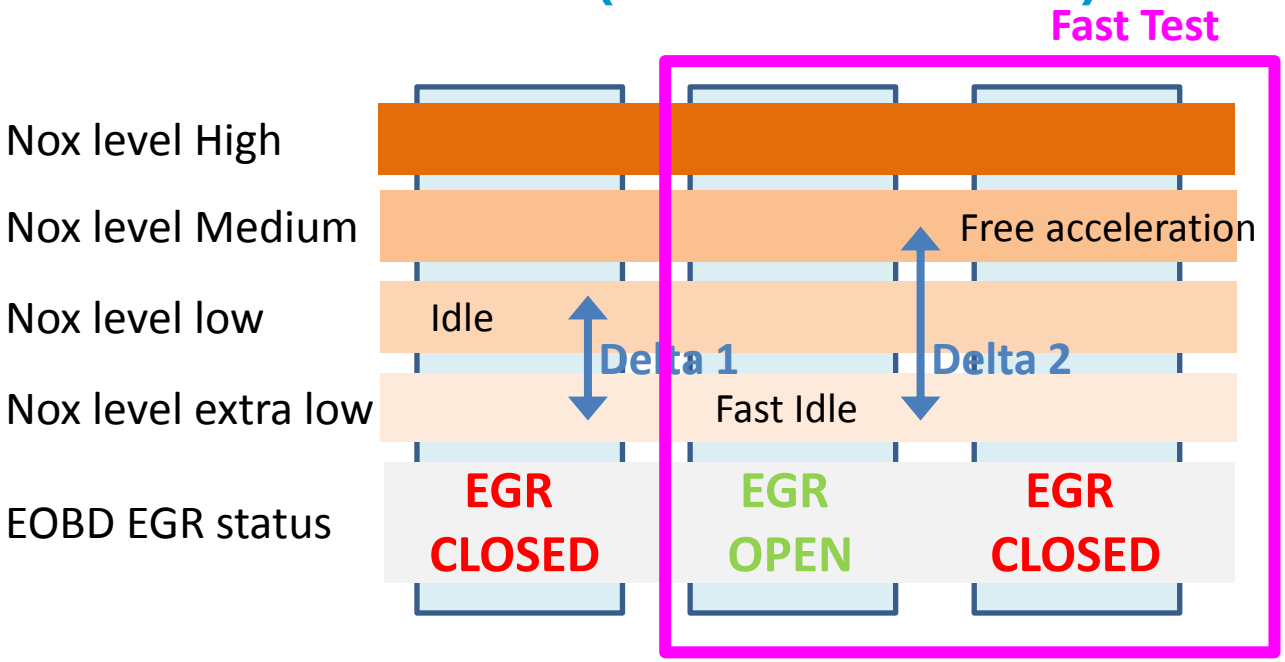
=

System OK

Vehicle embedded Nox sensors are not metrological

Nox Tests Euro 5 engine & Euro 6 engine wo Nox sensor

- **Test Phase 1: No load**
- **Test Phase 2: Small load (Free accelerations)**



Opacinox **Idle** Nox value

Opacinox **Free acceleration** Nox value

Delta 1 **And** Delta 2 =

Opacinox **Fast Idle** Nox value

Opacinox **Fast Idle** Nox value

System OK

Black Carbone: Opacity / NOx measurements new specs

Opacity:

- Dynamic Accuracy : 0.05 m^{-1}
  (derived particle mass concentration : 10mg/m^3)
- Zero Accuracy : < 0.005 m^{-1}
  (derived particle mass concentration : 1mg/m3)
- Static Accuracy : 1% (filter)
- Resolution :
  - 0.001m-1 if K < 0.50m^{-1}
  - 0.01 m-1 if K > 0.50 m^{-1}

NOx:

Range: 0 – 5000ppm

Accuracy : ± 15ppm (0 to 1000)
± 1,5% from 1000

Lambda:

Range: 0.4 to 25

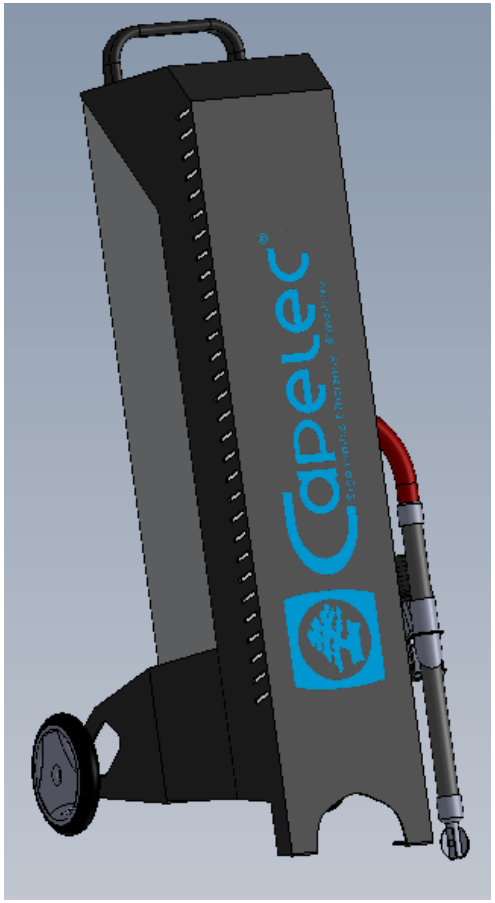
Accuracy : ± 0,008

O2:

Range: 0-25%

Accuracy : ± 0,4% around 0
± 0,8% on the range

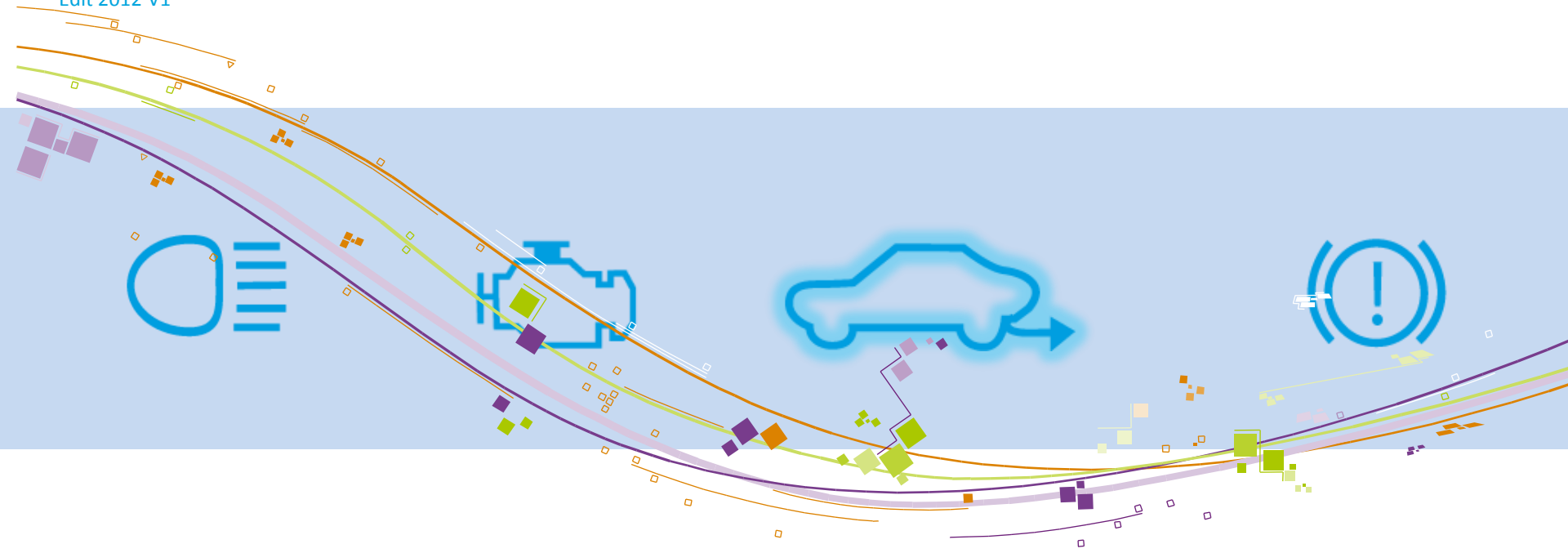
OpaciNOx



Euro 5/6 Diesel and beyond & PTI CHECK

IFP LABORATORY TEST CAMPAIGN

Edit 2012 V1



IFP – ENERGIES NOUVELLES

Independant laboratory

IFP Energies Nouvelles is a public-sector research, Innovation and training center active in the fields of energy, transport and the environment.

Its mission is to develop efficient, economical, clean and sustainable technologies in the fields of energy, transport and the environment.

Power train expertise

IFP Energies Nouvelles is globally recognized for its expertise in powertrain systems and fuels :

- Diesel combustion, with ongoing research focusing on the best global service in terms of fuel consumption/pollution/noise,
- Engine control, especially with respect to the management of new combustion processes (HCCI, LNC, LTC),
- After-treatment, in order to identify the most appropriate system pairs at an upstream stage (DOC, particulate filter, LNT, SCR, etc.),
- Engine and vehicle calibration

Testing methods

IFP Energies Nouvelles has a complete range of services covering standard tests, tests on specific test benches and vehicle integration.

Innovating for energy

IFP Energies Nouvelles– Testing resources

Engine test benches

A complete set of heavy equipment dedicated to engine R&D incorporating:

- engine test benches for light vehicles and trucks,
- transient HIL (Hardware in-the-Loop) test bench for the performance of high-dynamic tests
- transient climatic test bench and a cold-start cell.

Vehicle test benches

Chassis dynamometers equipped for measurement of regulated and non-regulated pollutant emissions of vehicles, on running cycles (standardized or specific).

X-ray scanner

A scanner used for digitization, CAD reconstruction, meshing and computation.

Injection test bench

A laboratory dedicated to the measurement of injected quantities, along with an injection system modeling room.

Energy storage test bench

A battery and super capacitor test bench

Electric motor test benches

A small-scale test bench (1/20 power) for testing hybrid powertrains

Optical test benches

An optical diagnostics laboratory is used to study internal mixing and combustion phenomena,

Test conditions

Vehicle & variants

RENAULT VELSATIS 2L Diesel (Pmax > 100ch):

- ECU disconnected : engine management driven by IFP software:
- In work EGR
- In work SCR Catalyser
- 3 test variants
  - NEDC euro5 diesel correct perfomances
  - Faulty DPF (OBD euro5 threshold: 8mg/km
  - Brand new DPF

TEST Bay

IFP Energies nouvelles test bay:

- Single Roller Dynamometer IFPEN.
- Real time sampling bay :
  - Gas : CO, CO2, THC, O2, NO, NO2, NOX, etc…
  - Opacity : opacimètre AVL439
  - Engine datas : EGR valve position, BGR ratio, pressures…
- Vehicle human operated

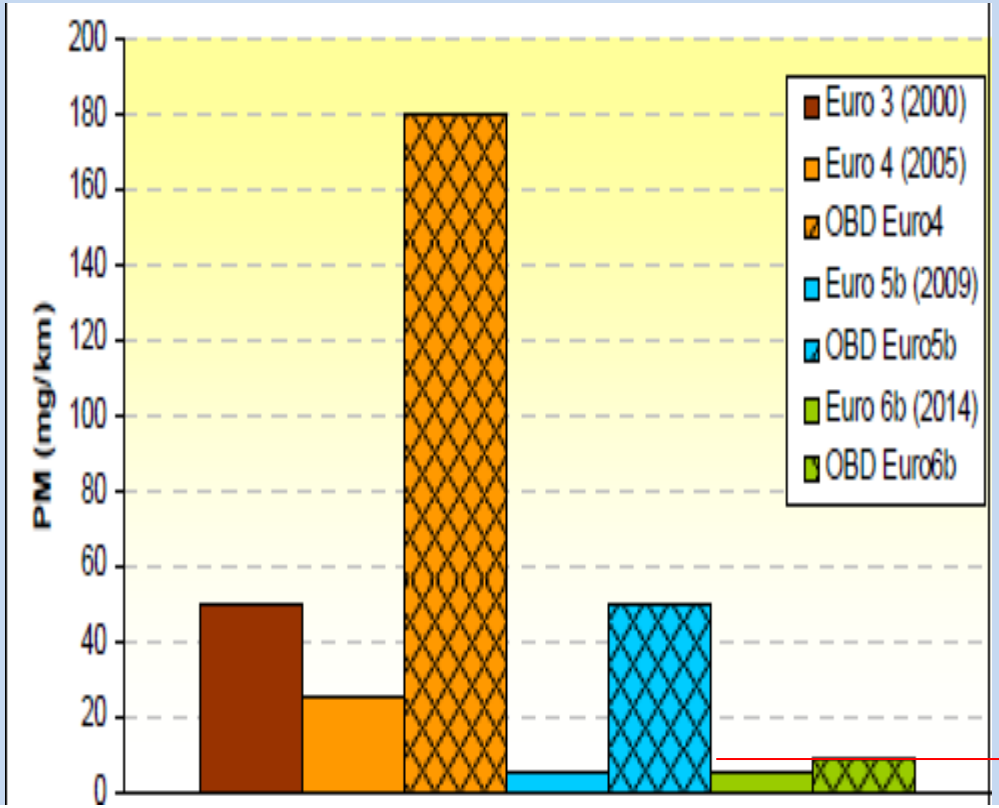
New TEST Equipment: OPACINOX

New test equipment for Opacity and NOx measurement

Faulty DPF

DPF has been “fine” tuned to reach EUROv6 just below EOBD threshold

- 1 hole has been drilled
- EOBD threshold is about 8mg/km
- Level ajusted : **6mg/km**



Euro 6

Euro 6

Opacity measurement: Test 1 (NEDC Approval test)

NEDC
Approval test

Vehicle (Euro 5)

NEDC cycle

Test condition

DPF: particulate filter

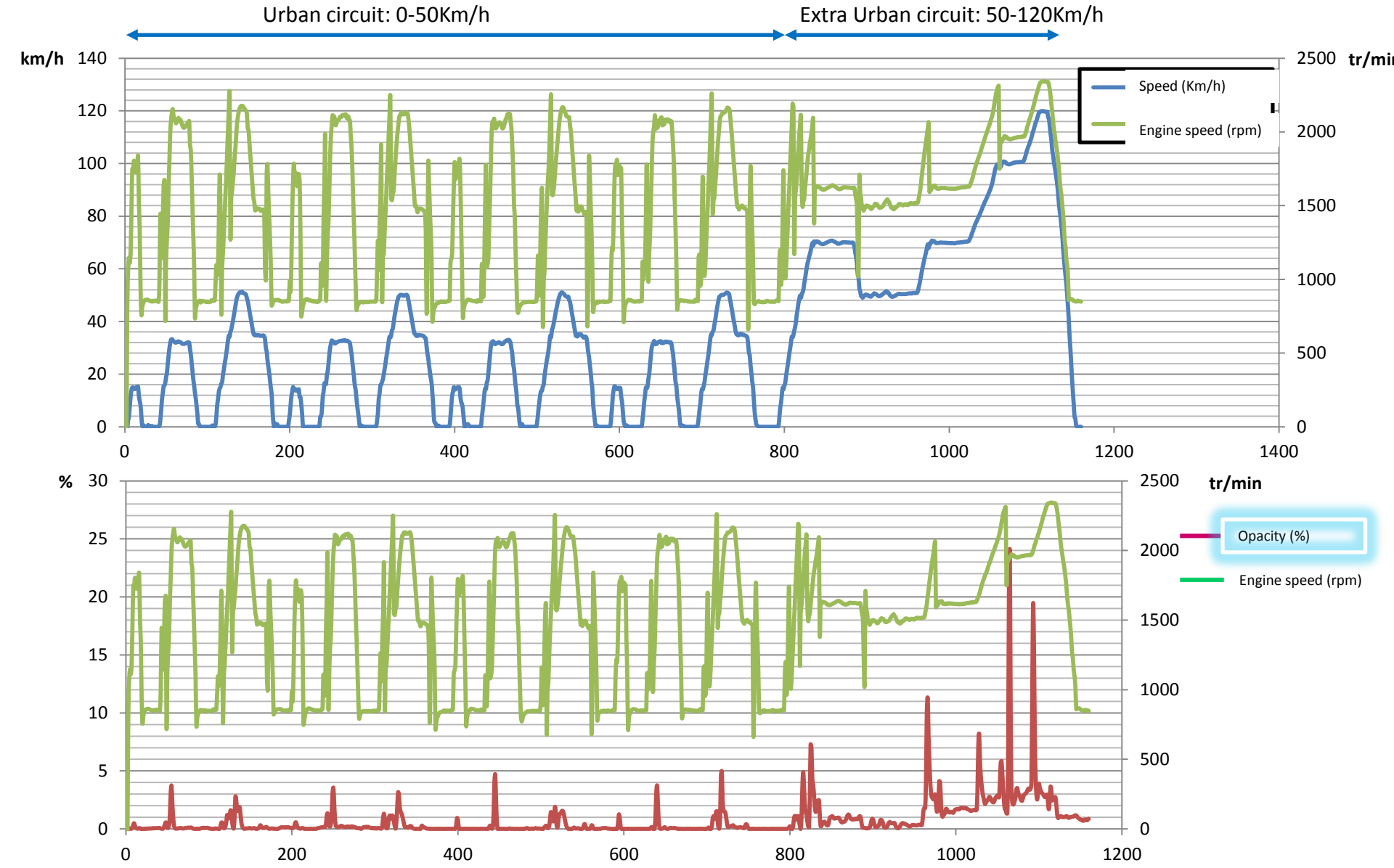
Opacity

Cycle

Urban circuit: 0-50Km/h

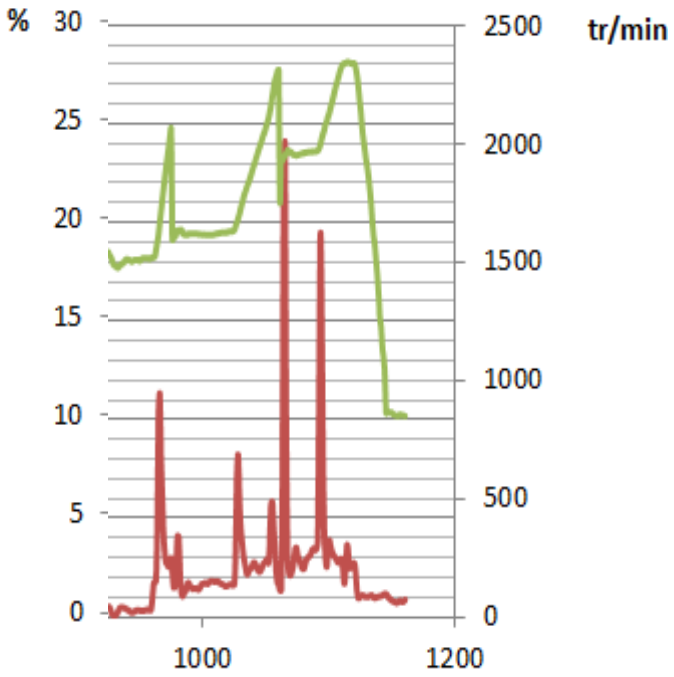
Extra Urban circuit: 50-120Km/h

Opacity measurement: Test 1 (NEDC Approval test)



Opacity measurement: Test 1

NEDC Approval test



Vehicle is equipped with a faulty DPF measured just below the OBD Euro6 threshold: 6 mg/km

In this condition, the previous figures illustrate that opacity level is directly linked to engine load.

This use case is obtained during a rolling phase.

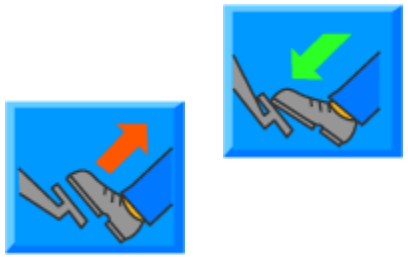
Opacity level is relatively low even if a maximum pic has been recorded at 24%.

Such opacity level is matching opacimeter technology.

Opacity measurement: Test 2 (Free acceleration test: PTI method)

Free accelaration Test (PTI method)

Vehicle (Euro 5)



Free acceleration test

Test condition

DPF: particulate filter

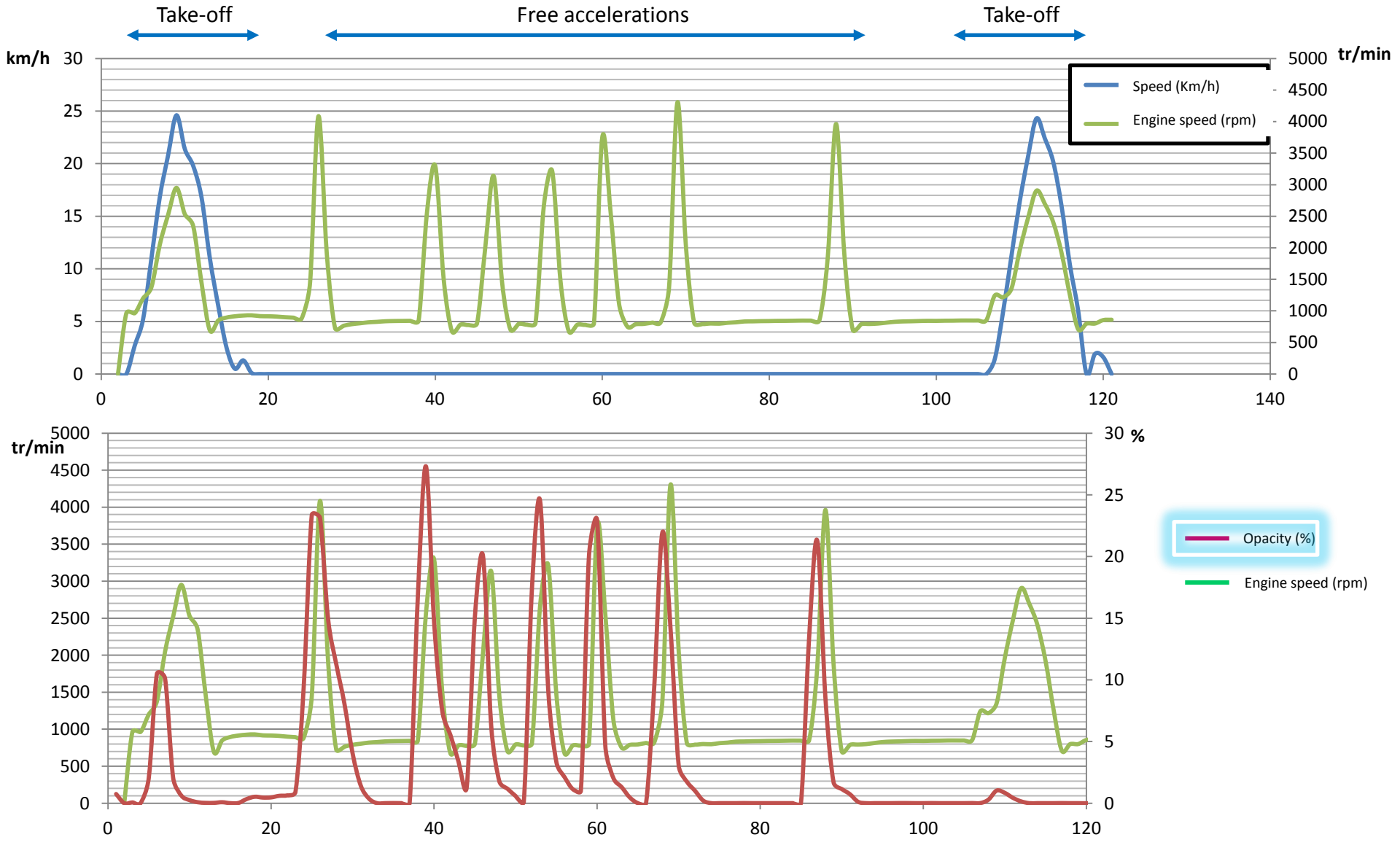
Opacity

Cycle

STATIC

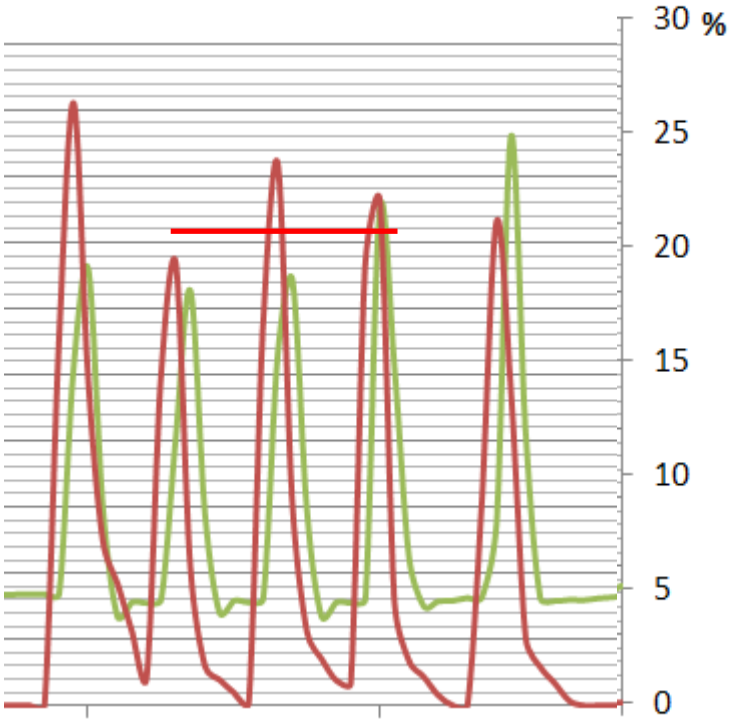
PTI method

Opacity measurement: Free acceleration test (PTI method)



Opacity measurement: Test 2

Free acceleration test (PTI method)



Vehicle is equipped with a faulty DPF measured just below the OBD Euro6 threshold: 6 mg/km

In this condition, the previous figures illustrate that opacity level is directly linked to engine load, even low ones.

This use case is obtained in static mode.

The computed average for acceleration results is about N_{moy}=21% so K_{moy}=0.52m^{-1}

Opacity level is closed to the one obtained with the NEDC test.

Such opacity level is matching opacimeter technology

NOx measurement: Test 3 (Direct action on EGR valve)

Electronically driven

Vehicle (Euro 5)

Steps by steps commands

Test condition

☑Euro 5/6

DPF: particulate filter

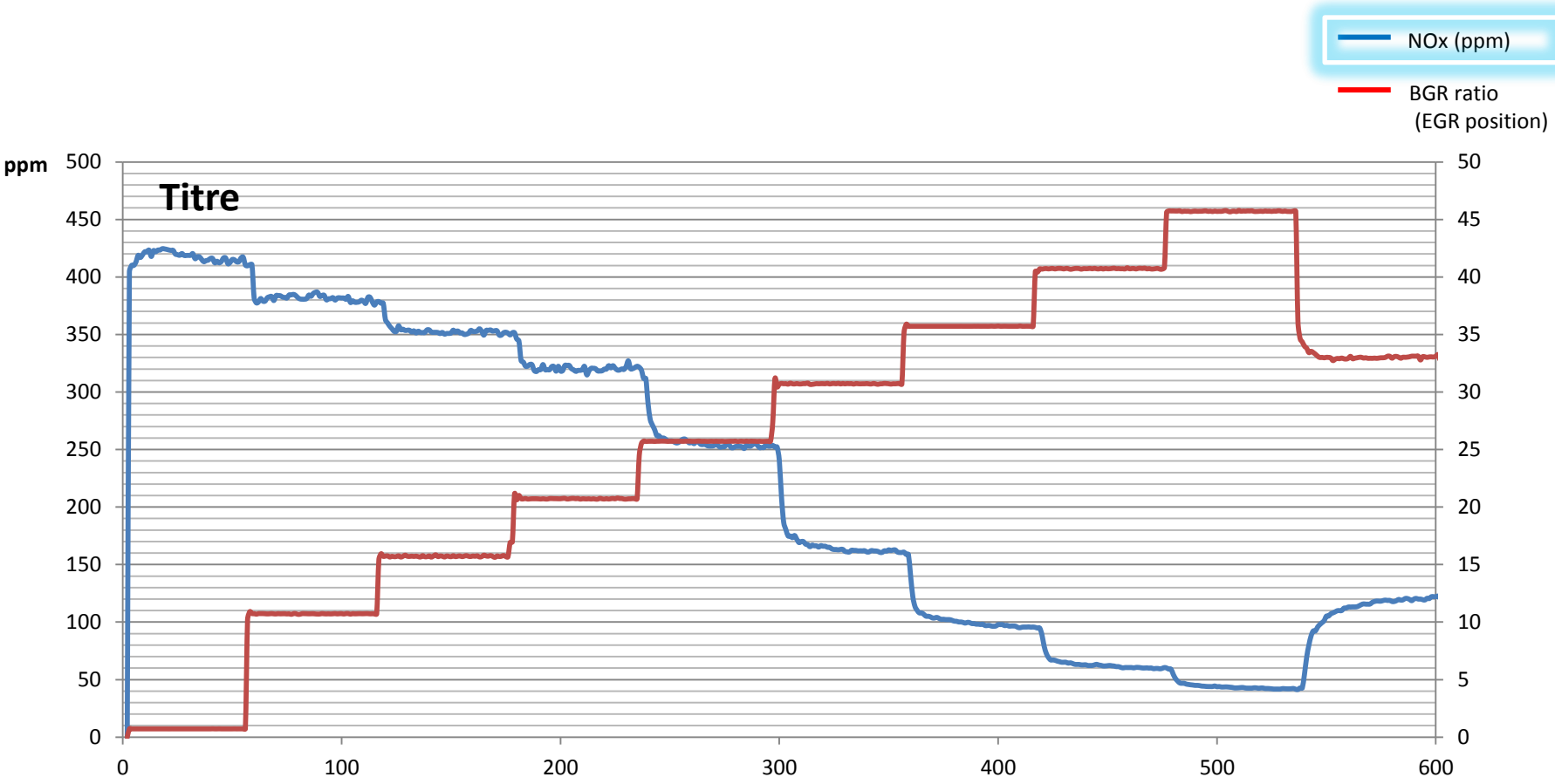
NOX

Nox gas

Cycle

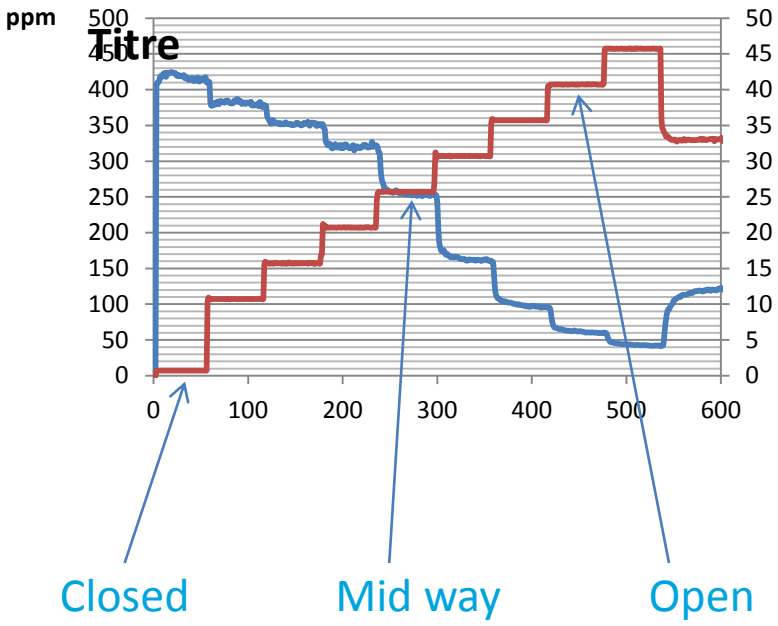
STATIC

NOx measurement: Test 3 (Direct action on EGR valve)



NOx measurement: Test 3

Test 3 (Direct action on EGR valve)



Vehicle is equipped with a DPF.

This use case is obtained in static mode at idle speed.

EGR position was driven electronically from close position (0) to wide open 45..

EGR position (BGR ratio):
0 (closed) -5-10-15-20-25-30-35-40-45-normal

Nox emisson level is dropping from 430ppm down to 40ppm.

Relation between EGR position and Nox level is crystal clear

NOx measurement: Test 4 Free acceleration test (PTI method)

Electronically driven

Vehicle (Euro 5)

Steps by steps commands

Free acceleration test

Test condition

☑Euro 5/6

DPF: particulate filter

NOX

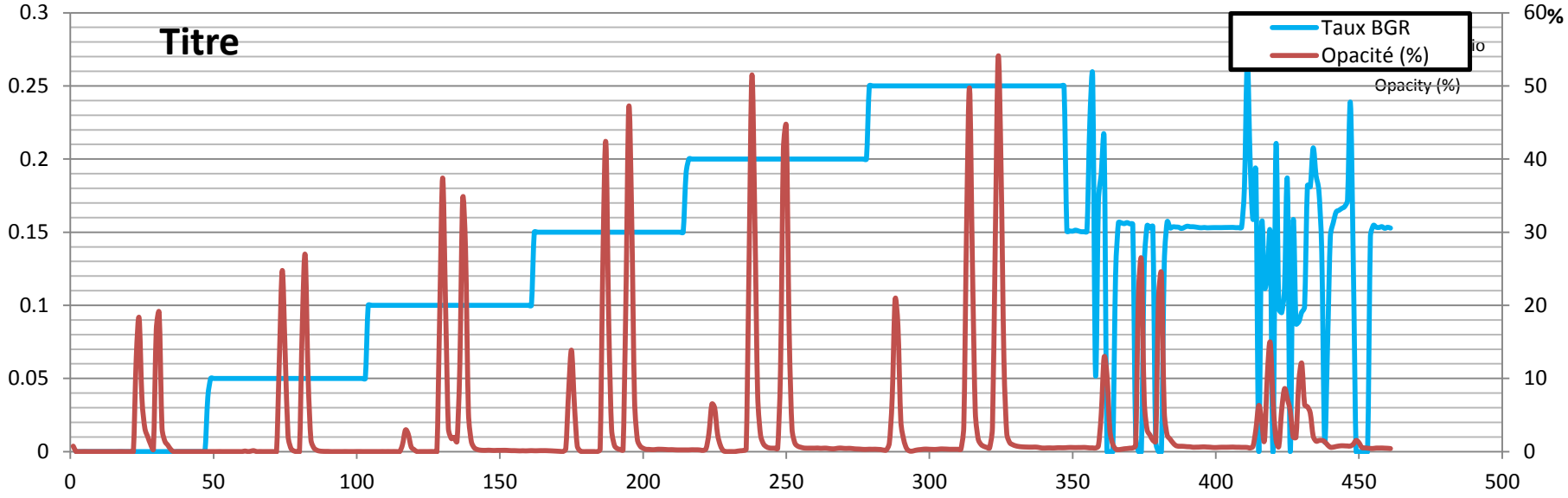
Nox gas

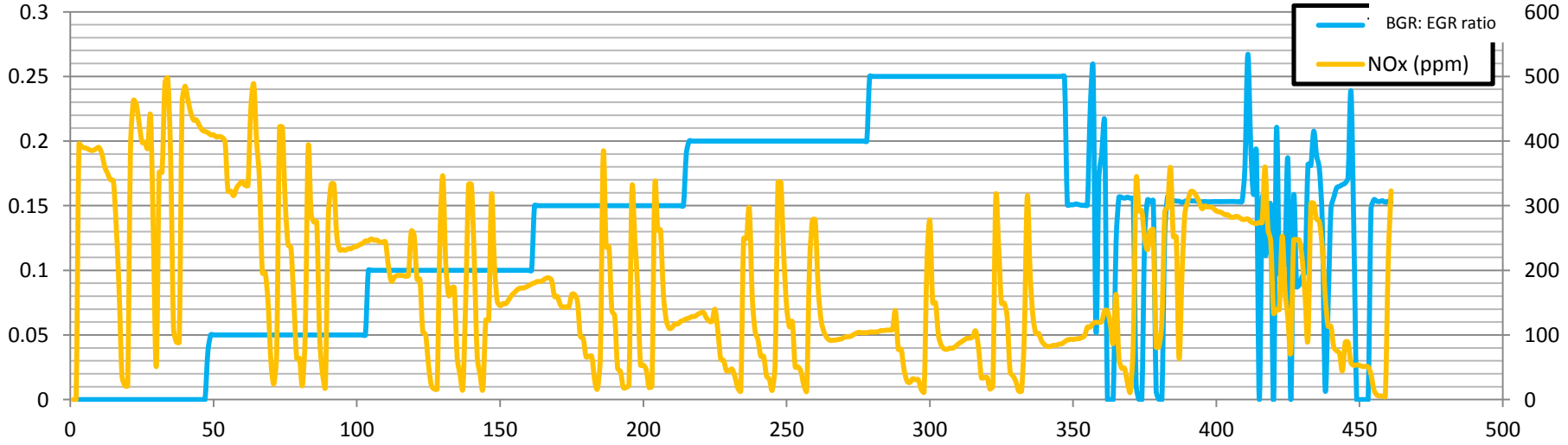
Cycle

STATIC

PTI method

NOx measurement: Free acceleration test (PTI method)

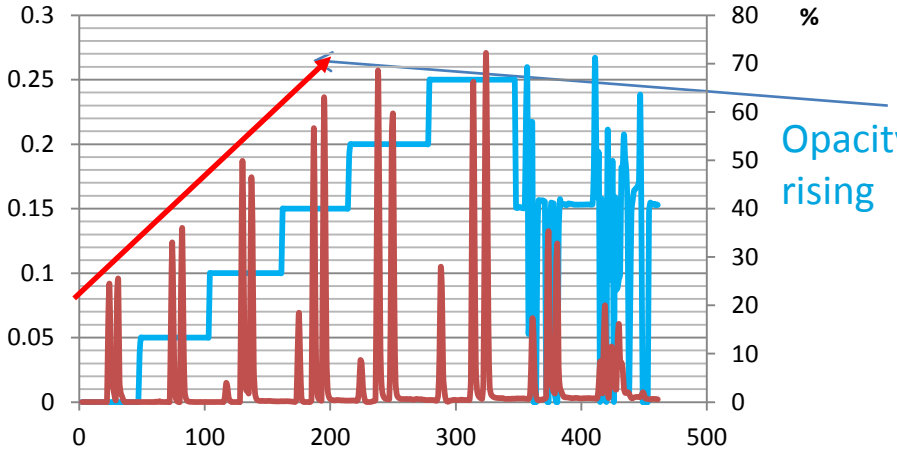


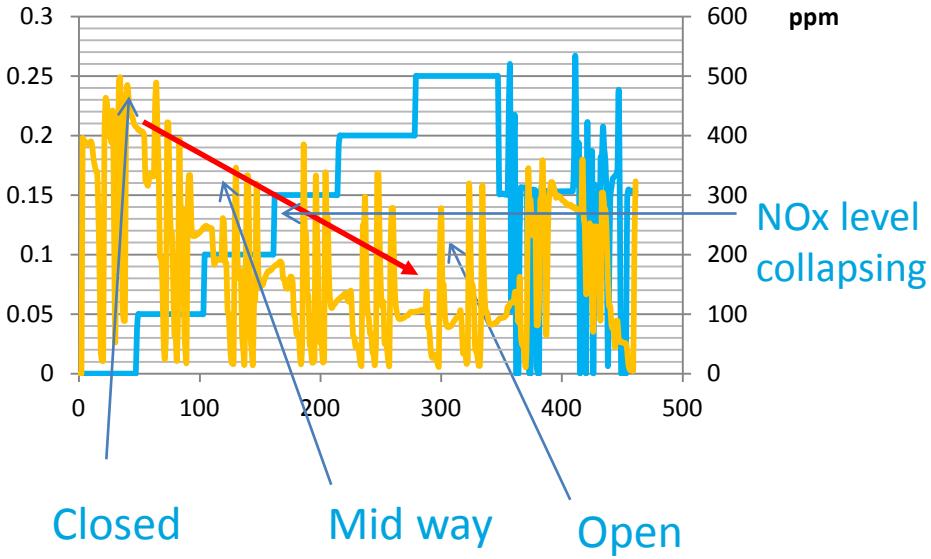


NOx measurement: Test 4

Free acceleration test

Step by step EGR command





This use case is obtained in static with free acceleration phases with the following scenario:

- EGR 0% : - 1 take-off + 2 free acceleration+ 1 idle
- EGR 10%: - 1 take-off + 2 free acceleration+ 1 idle
- EGR 15%: - 1 take-off + 2 free acceleration+ 1 idle
- EGR 20%: - 1 take-off + 2 free acceleration+ 1 idle
- EGR 25%: - 1 take-off + 2 free acceleration+ 1 idle
- "Automatic "EGR 10%:
    - 1 take-off + 2 free acceleration+ 1 idle
    - 1 free acceleration+ 1 stable cession at 90Km/h

-BGR ratio has a direct link to opacity increase and Nox level collapse

-Smoke by pass for exhaust to inlet air (inert gas) is dropping the combustion temperature minimizing Nox but with drawback on particulate emission.

-ECU strategy is searching the right balance between them

OPACINOX: CONCLUSION

Range & Accuracy

Euro5/6 opacity check are possible.
PTI limits and Pass/Fail threshold have to be updated.
OPACINOX allow to use new test limits with actual test procedure.
OPACINOX precision is 4 x the one of the actual opacimeter.
Range is now from 0,1m-1.

Opacity & NOx

OPACINOX provides measurement both both key values:
Opacity & NOX

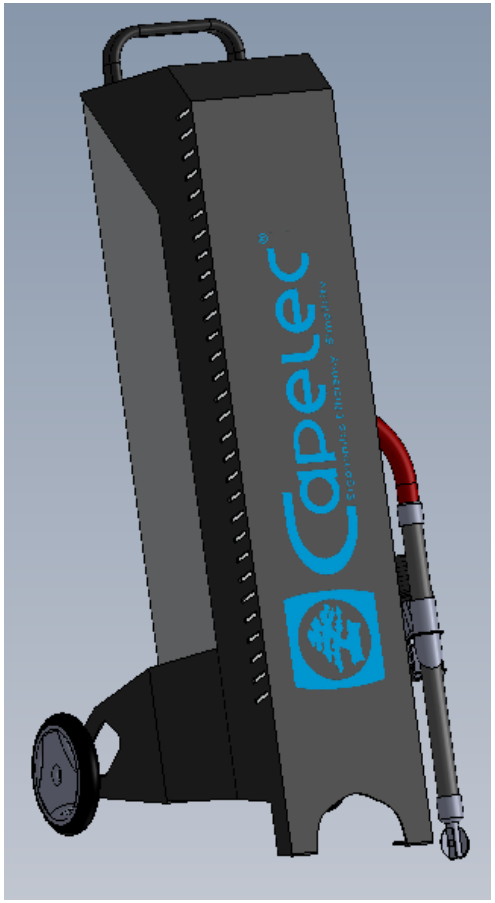
Test procedure

OPACINOX is matching with regular/basic Free acceleration procedure very popular in the PTI world.
No need of costly dynamometer.

Robust technology

OPACINOX is using mature & robust technology matching PTI working condition (no pump).
Calibration method are popular and useable on field

OpaciNOx

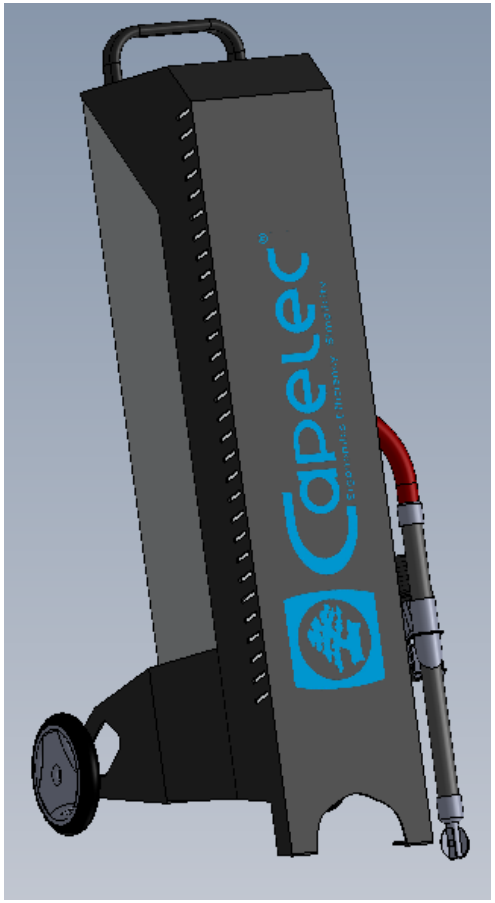


OPACINOX: CONCLUSION

Nox measurement technology

- Fast response time: below 1 seconde (compatible with free acceleration procedure)
- Hight data thoughtput: 10 values per seconde
- Fast pre heating phase: less than 2mm
- Nox precision (in ppm) stable on PTI range use
- Compatible with hight exhaust gas temperature (950°C during 100h)
- Compatible low heat exhaust gas (80°C)
- Long life time (nothing with chemical version drawback)
- Robust: choc proof (490 m/sec²), vibration proof(250hz, 50G) IP67, onboard diag
- Resistant regarding Gasoline, LLc, Engine oil, Brake oil stress
- On side recalibration mechanism (if required)

OpaciNOx



And now…? the next steps

Black Carbon /opacity

X,Xm^{-1} The Euro5/6 missing value

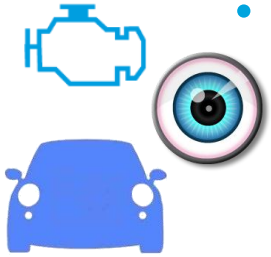
TEDDIE 2

NOx

- Procedure
- Delta value threshold

TEDDIE 2

Nox sensors Embedded on Euro6 vehicle



- Knowledge

TEDDIE 2

Large test campaign

Opacity and NOx measurement are reflecting the health and operating status of Diesel euro 5/6 engine

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