VETC

Diesel Particle Filter Testing for In-Use Vehicle Retrofit

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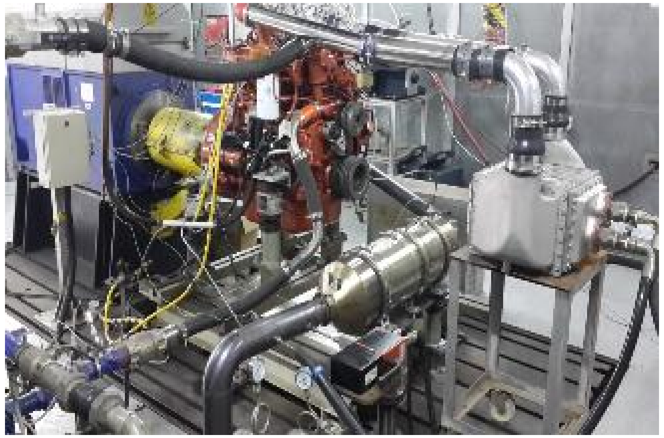
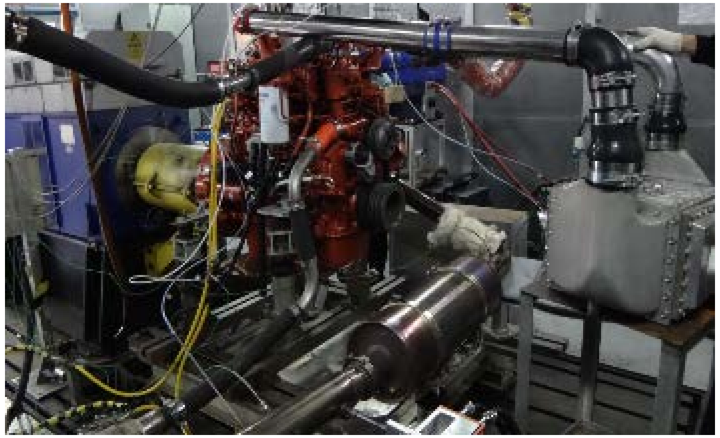
Agenda

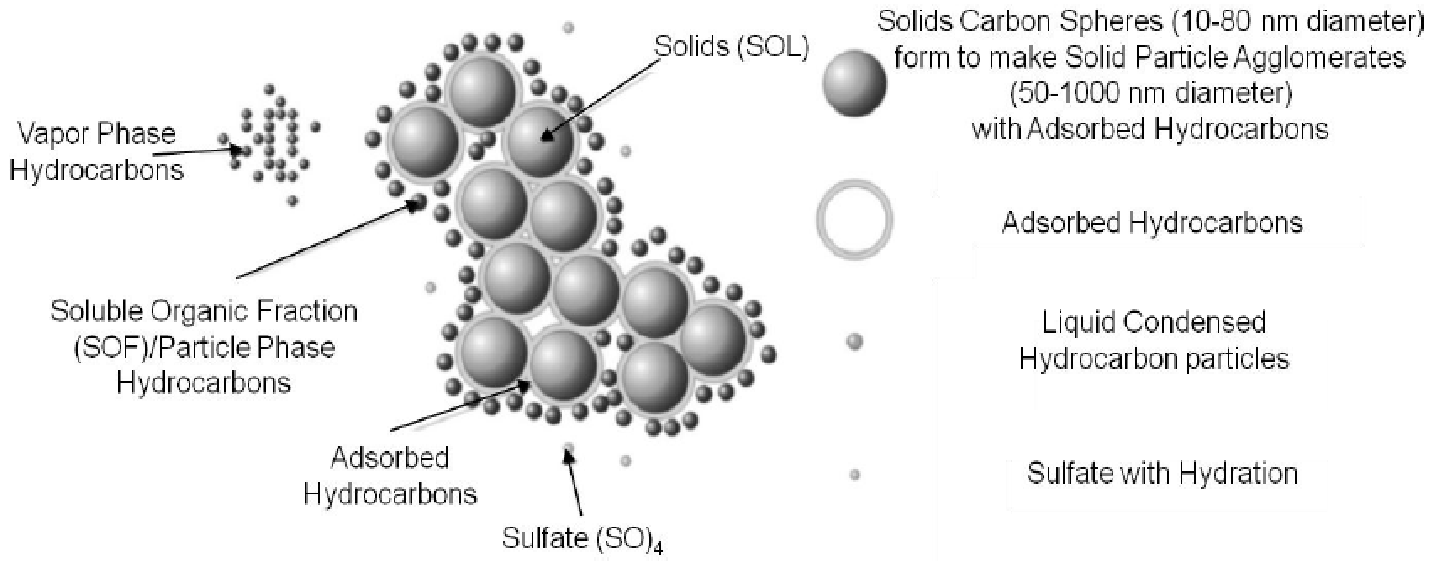
- Background
- Test Procedure and Results
- Summary





Background

- Particles can penetrate deep into the human lungs due to their respirable size.
- A short-lived climate forcer with a high global warming potential.



Complex mixture of solid and liquid materials

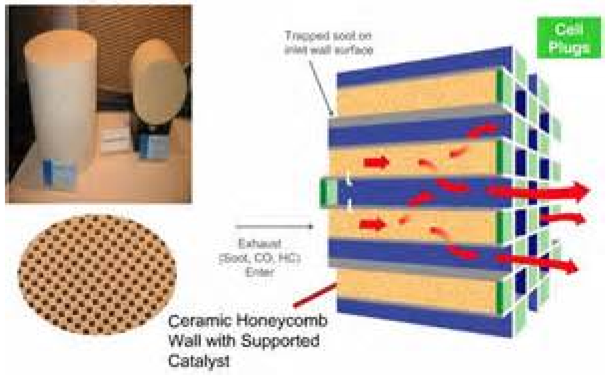
(1) elemental carbon (EC, solid), i.e. soot,

(2) soluble organic fraction (SOF, solid or liquid substances finely distributed in gases) from fuel and engine lubricant oil,

(3) sulfates (hydrated sulfuric acid, metal sulfates, and liquid, depending on the sulfur content of the fuel),

Background

- DPF has been proved as a high efficacy technology to control diesel particle emission
- Recently, the verified wall-flow DPFs are available and have been widely retrofitted on on-road and off-road in-used diesel engines.



Background

- **On-road Vehicles**
  - VECC-MEP (Vehicle Emission Control Center of Ministry of
    - City of Nanjing City buses
    - City of Xiamen City buses
    - **XM VETC Bench testing**
- **Off-road mobile machinery**
  - BJ-EPB (Beijing Environmental Protection Bureau)
    - BJ VEMC/BIT Construction machine
    - BJ VEMC/JN ATC Bench testing

- China-Swiss cooperation programme CCLP (the Clean Air & Climate Change Legislation and Policy Framework)
- BCEMS (Black Carbon of Mobile Sources)
- The Vehicle Emissions Control Centre of Chinese MEP (MEP-VECC) wishes to explore the possibilities for lowering particulate emissions by retro-fitting DPFs onto commercial vehicles.

Background

VETC

- It is planned that a pilot trial will be run with a number of Xiamen and Nanjing city buses retro-fitted with DPFs. The first phase of the project involves the selection of a suitable DPF for the trial.
- The selection will be made based primarily on the results from engine tests to be undertaken on the test bench utilizing a typical Xiamen city bus engine.
- The testing is to be accomplished by making use of the experience, assistance and test methods from the Swiss organization "Verification of Emission Reduction Technologies" (VERT).
- Xiamen Environment Protection Vehicle Emission Control Technology Center (VETC) undertakes the engine tests with different DPFs manufactured by three different manufacturers.

Key elements

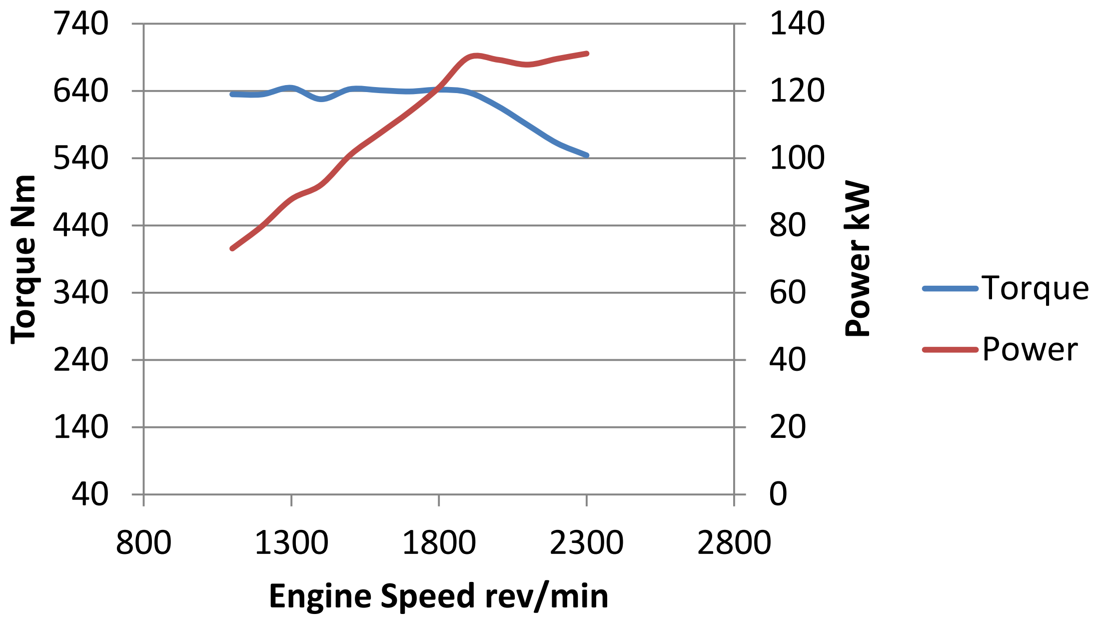
- Typical in-used engine & engine out PM emission levels
  - typical Xiamen city bus engine
- Representative fuel
  - China Stage3 commercial diesel
- Suitable lubricant
  - Low SAPS lubricant

Engine

Chinese Stage 3 emission legislation
4 cylinders in line
Rate power 132kW
Turbo charger + Common rail + Direct injection
No EGR and A/T

Manufacturer / type	Yuchai Machine / YC4G180-30
Emission legislation level	GB17691-2005 phase3 (=EU3)
Cylinder number and configuration	4 cylinders in-line
Bore x stroke / overall displacement	112 x 132 [mm] / 5.202 [L]
Compression ratio	17 [-]
Cooling medium (air, water, etc.)	Water
Combustion process	direct injection
Supercharging / Charge air cooling / Charge pressure max.	TC / IC engine water / 1.2 [bar]
Exhaust aftertreatment measures to reduce emissions	None
EGR	None
Rated power / Rated speed	132 [kW] @ 2300 [min^{-1}]
Max.Torque @ RPM	660 [Nm] @ 1300~1500 [min^{-1}]
Max mass flow ; max volume flow @ nominal RPM	1008kg/h@2300 [min^{-1}]
Max exhaust temperature downstream TC @ nominal RPM	n.a.
Low idle speed / high idle speed	650~700 [min^{-1}]; 2570~2640 [min^{-1}]

Engine



Stage	5	7	3	1	5(r.)
Engine speed (rev/min)	1500	1500	2300	2300	1500
Engine load	100%	50%	50%	100%	100%
Engine load (Nm)	645	322	273	544	645

- Test stages utilised for this project are stage 5, 7, 3, 1, 5, as defined in ISO 8178, according to VERT certification procedure.
- The space velocities (SV) were checked at these points to ensure that the DPF is a correct match for the engine.

Fuel and lubricant

Base fuel (without additive)		
Type	GB 252-2011 market fuel	
Manufacturer	SINOPEC	
Properties		Unit
Density @20℃	0.8537	kg/litre
Cetane number	42.4	
Sulphur content	**164**	mg/kg
Cloud point	-	° C
Pour point	<-4	° C
Flash point	>65.0	° C
Viscosity@20℃	5.721	mm^2/s
Aromatic hydrocarbons	-	% vol
50 vol %	282	° C
90 vol %	338	° C
95 vol %	353.5	° C

Manufacturer / specification	Shell RIMULA R6LM 10W-40
Kinematic Viscosity @40℃ [mm2/s]	82
Kinematic Viscosity @100℃ [mm2/s]	13
Sulphate ash (ASTM D874) [% mass]	0.9
ACEA or API category	API CI-4
Sulfur content [%]	0.12
Phosphorus content [%]	0.05

- China Stage3 commercial diesel with the **164ppm** Sulphur content was used.
- A certain amount of FBC were mixed into the diesel as required by the DPF manufacture
- Low SAPS lubricant was used

DPFs

OEM	Sample ID	Substrate materials		Regeneration mode
OEM1	DPF-1	Ceramic	PGM-Coated	Passive
	DPF-2	Ceramic	Uncoated	Passive
OEM2	DPF-3	Ceramic	DOC+DPF	Passive/Active
OEM3	DPF-4	Metal	Uncoated	Passive

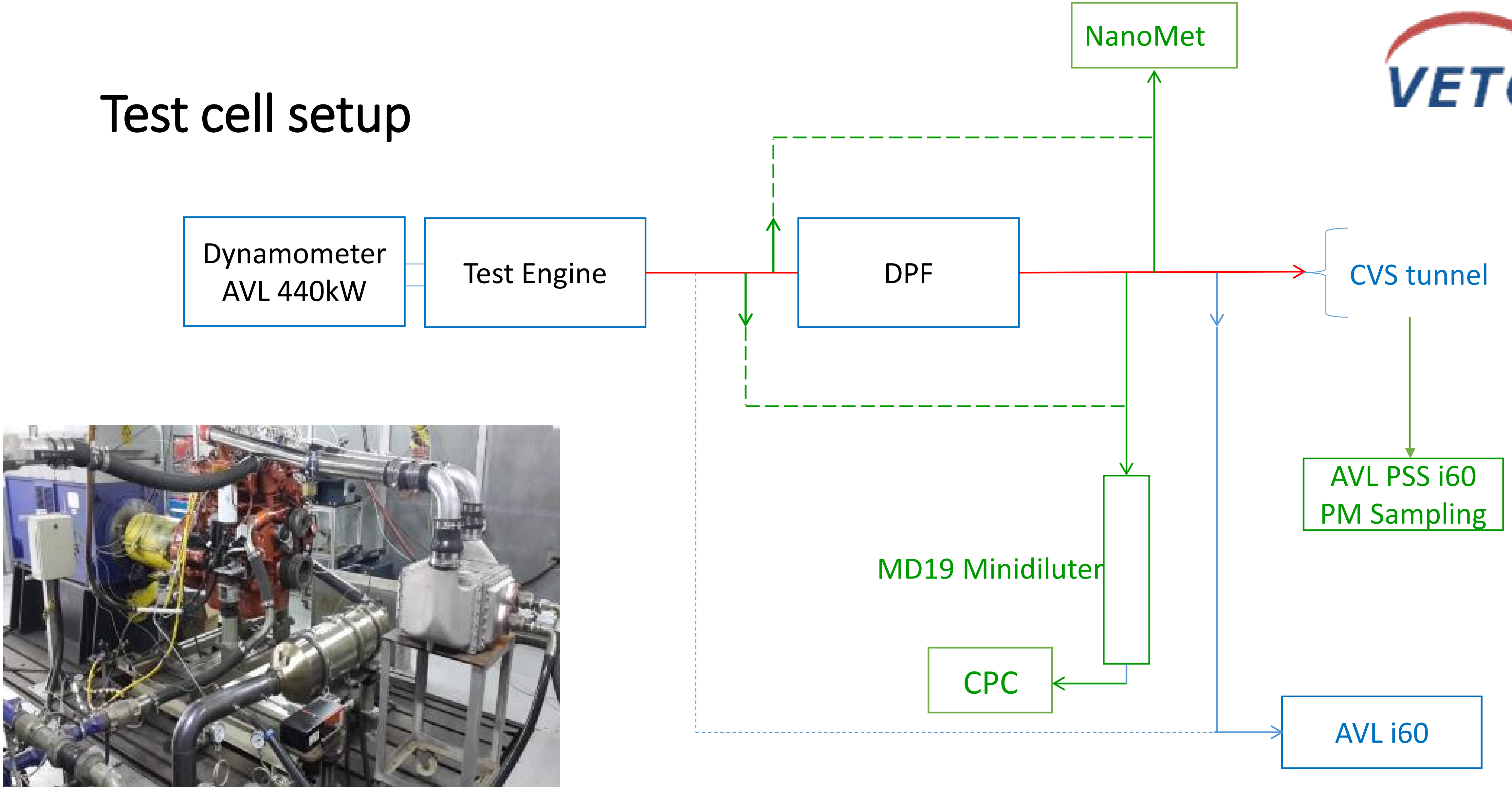
VERT certified DPFs




Test Items

- Test cell setup
- Base line - Engine out emission test
- Filtration test before/after regeneration
- Regeneration test
- WHTC tests

Test cell setup



Baseline

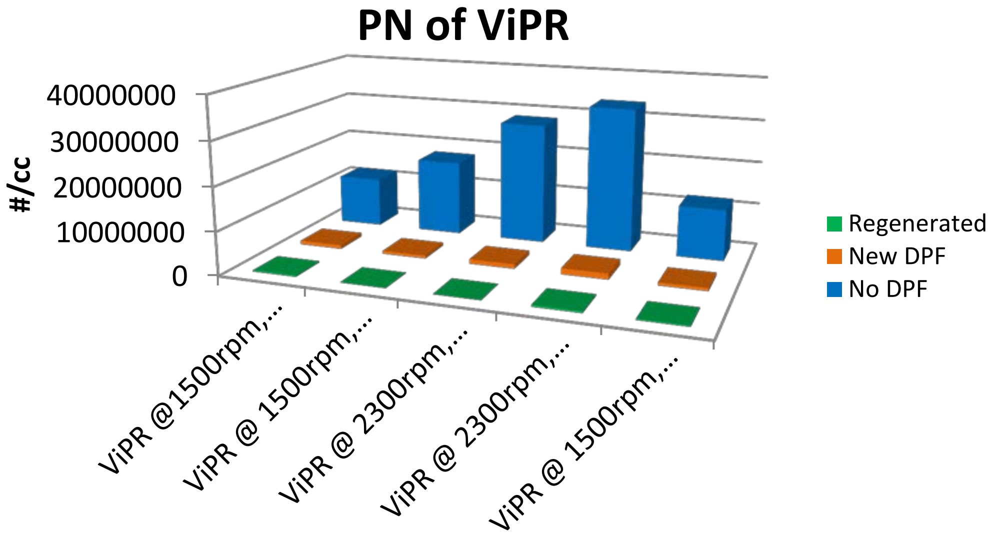
- Measurement of the raw exhaust emission of the test engine without exhaust gas aftertreatment. These measurements are used as baseline for the qualification of the tested DPF's.
- Consist of:
  - 4 points test (4PTS) / stationary test cycle 5-7-3-1-5
  - WHTC cold-hot tests

Stationary 8-point cycle	Rated speed				Intermediate speed			Idle
Test stage	1	2	3	4	5	6	7	8
Relative torque M [%]	100	75	50	10	100	75	50	0
Duration of test stage [minutes]	15	15	15	10	10	10	10	15

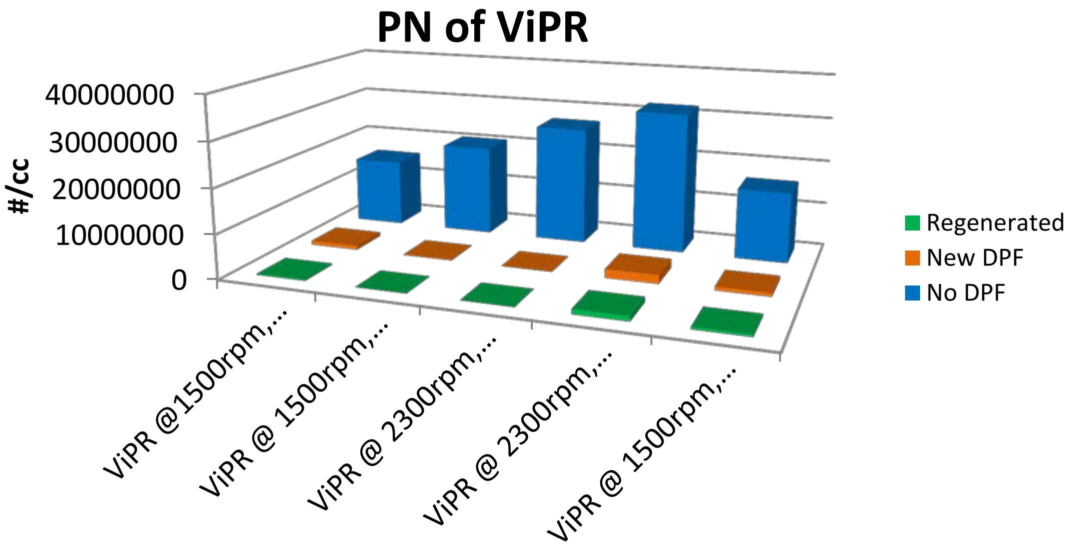
Filtration test

- Measurement of the exhaust emissions of the test engine equipped with a DPF.
- Consist of:
  - 4 points test (4PTS) / stationary test cycle 5-7-3-1-5 before/after DPF regeneration
  - WHTC cold-hot tests

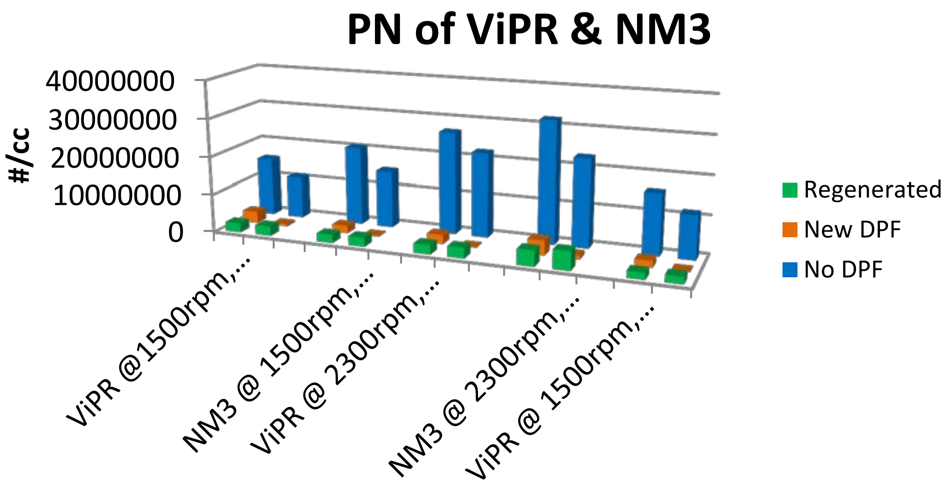
Stationary 8-point cycle	Rated speed				Intermediate speed				Idle
Test stage	1	2	3	4	5	6	7	8
Relative torque M [%]	100	75	50	10	100	75	50	0
Duration of test stage [minutes]	15	15	15	10	10	10	10	15



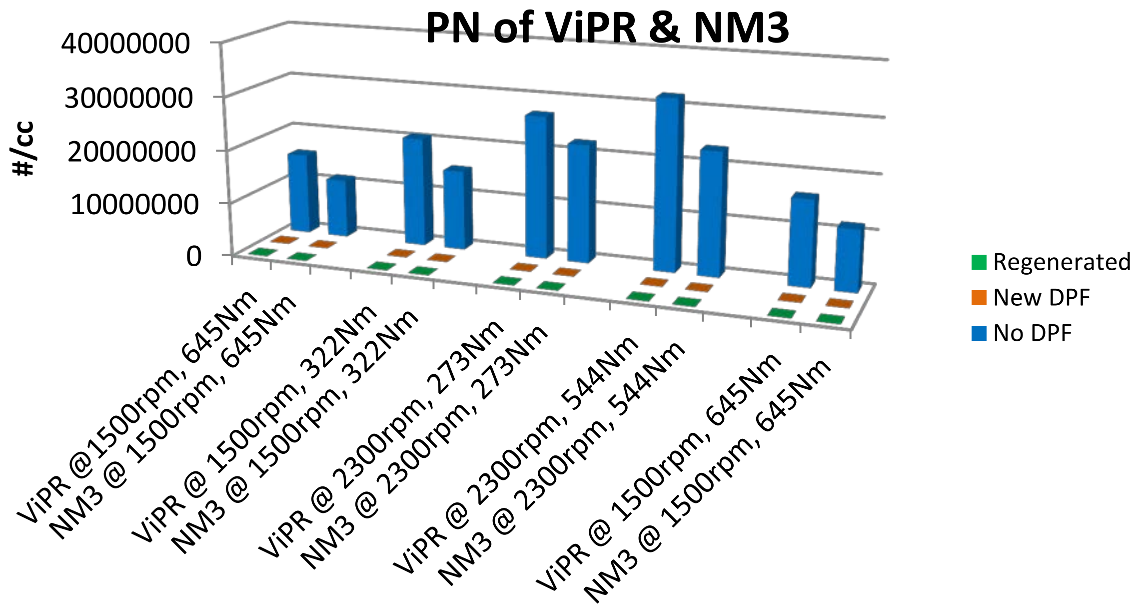
DPF-1 PN results



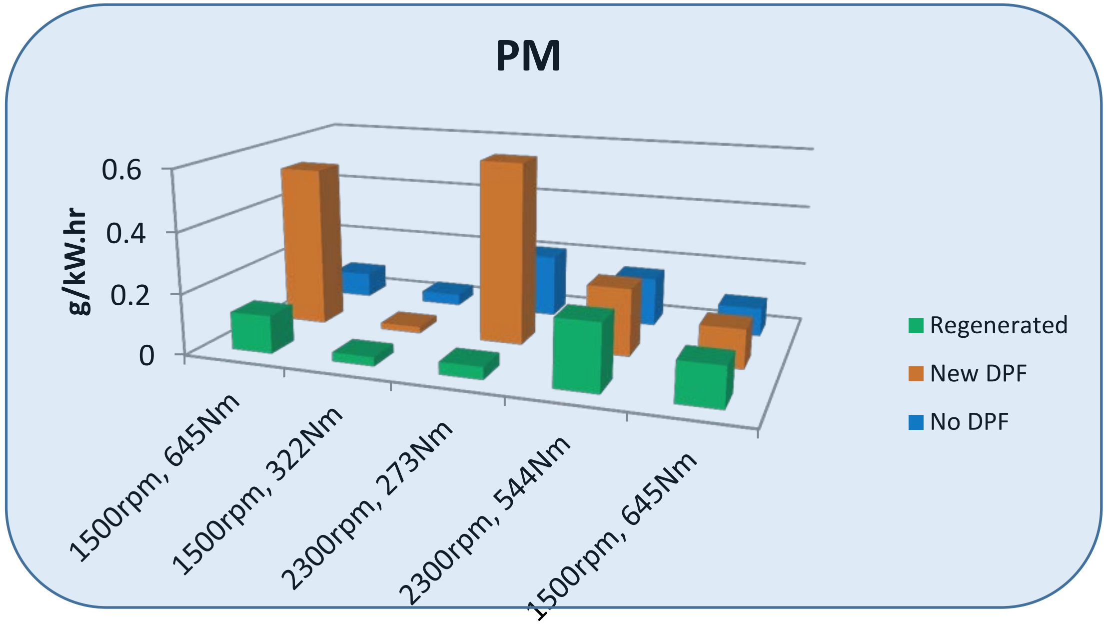
DPF-2 PN results



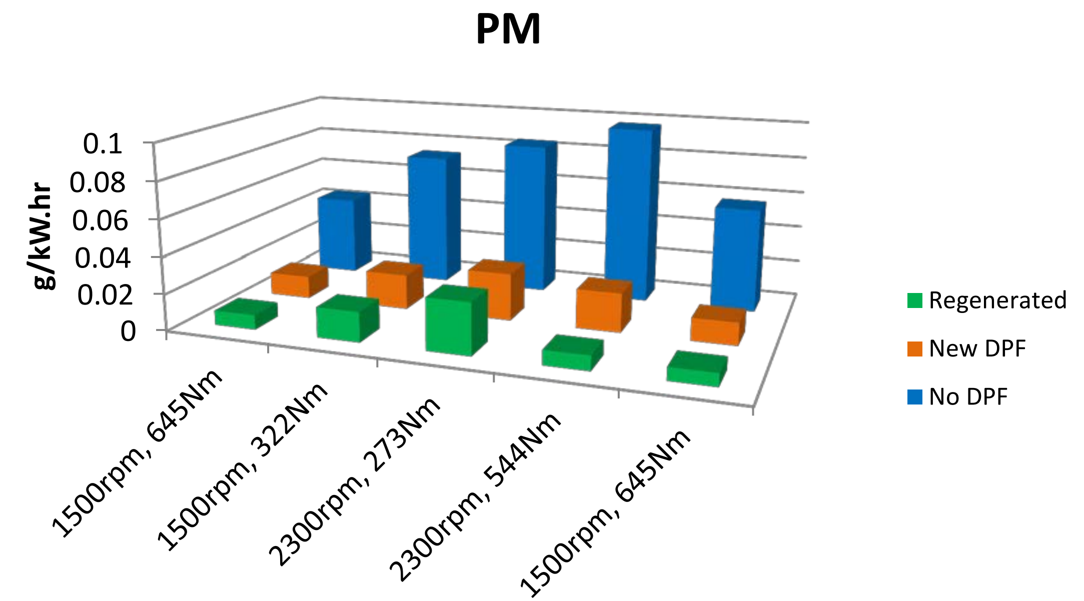
DPF-3 PN results



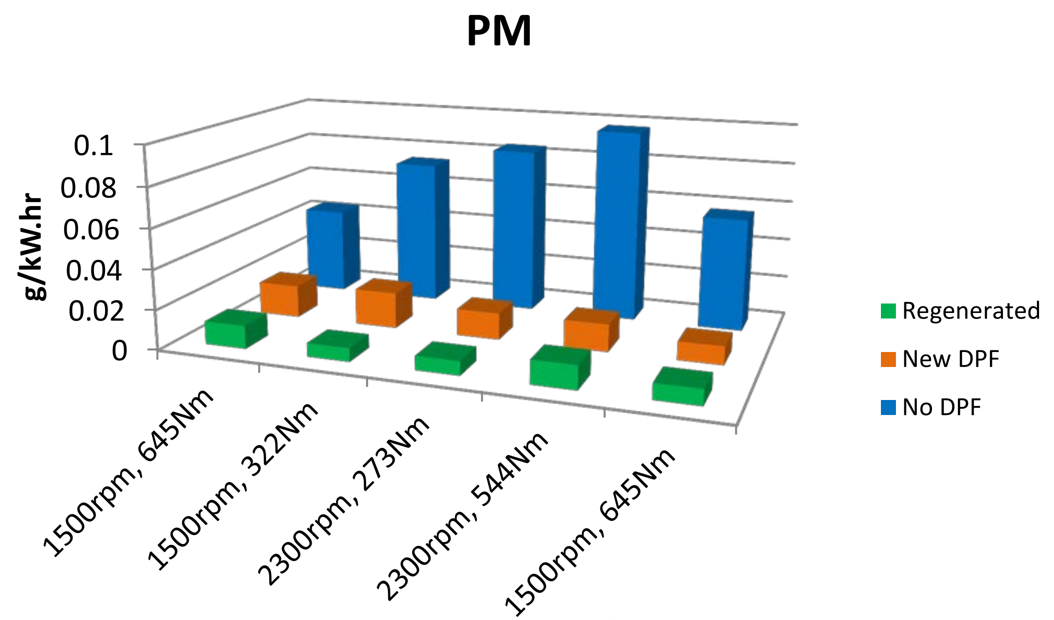
DPF-4 PN results



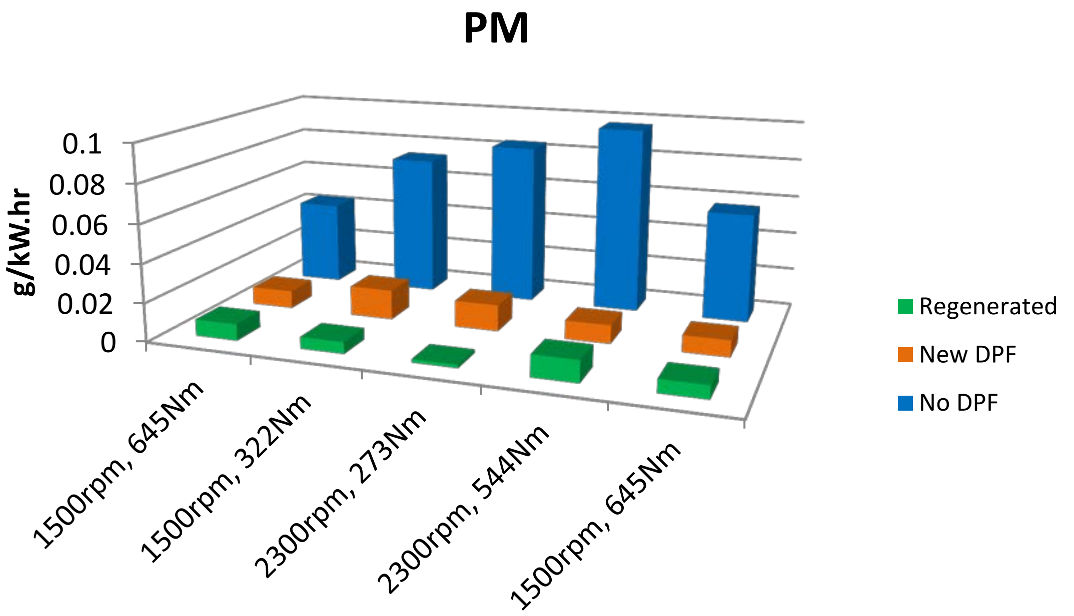
DPF-1 PM results PMG-Coated DPF



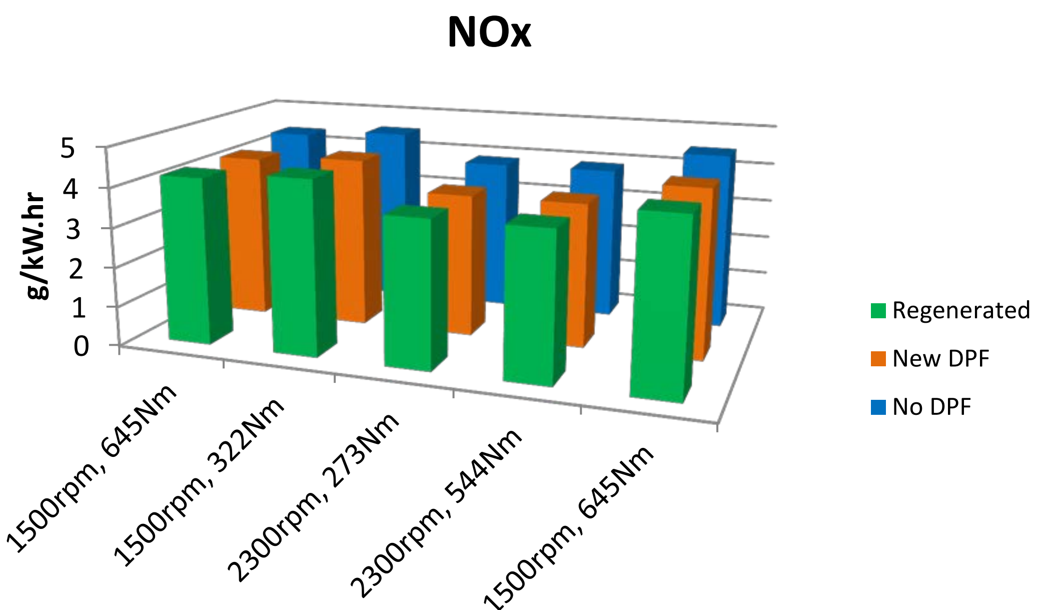
DPF-2 PM results



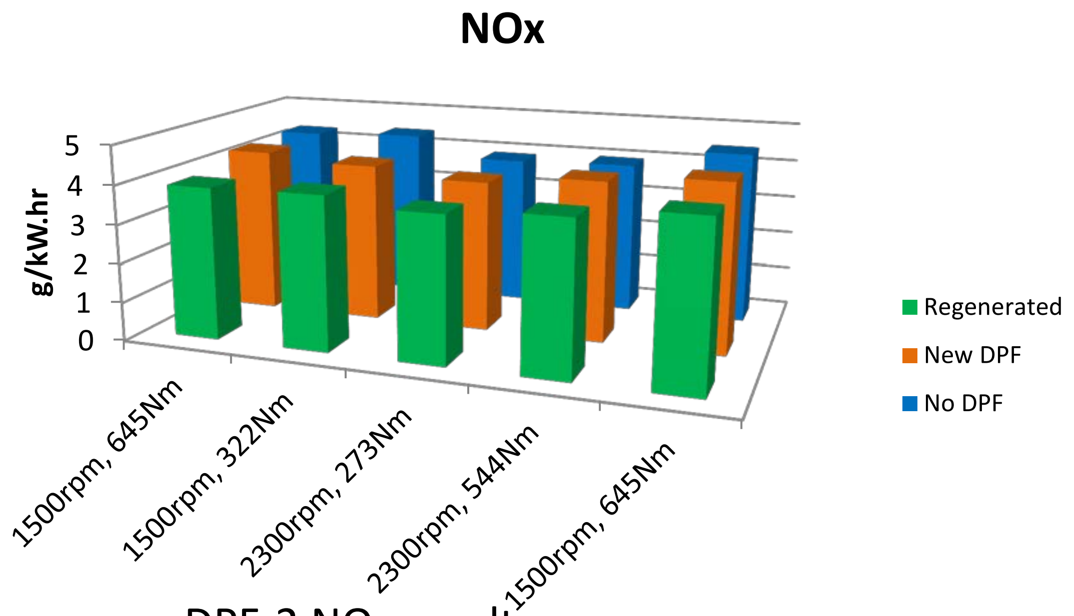
DPF-3 PM results



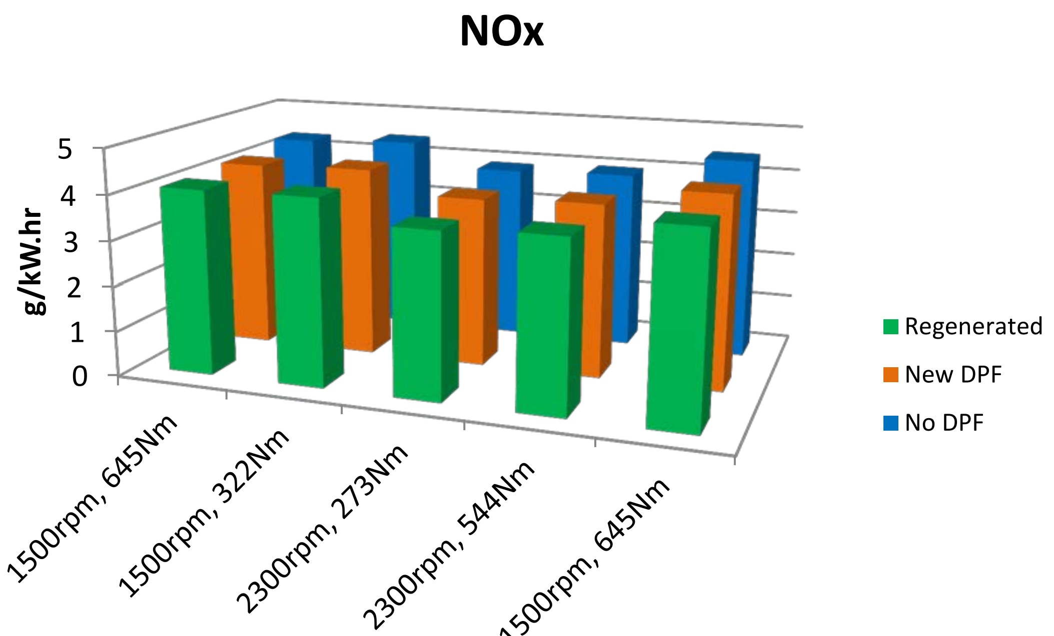
DPF-4 PM results



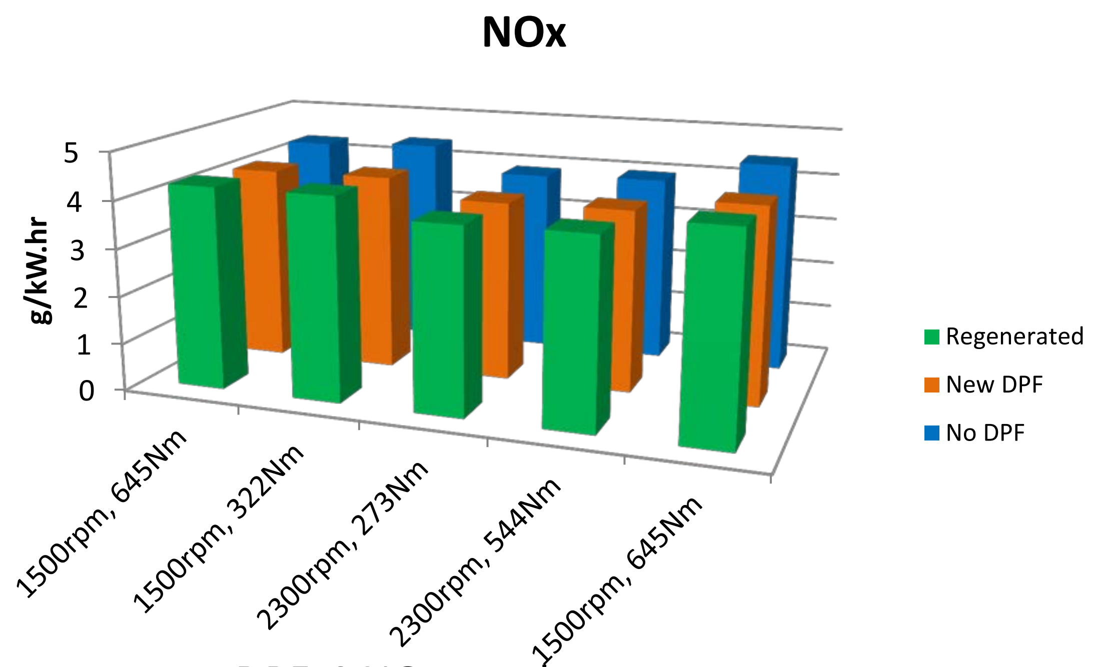
DPF-1 NOx results



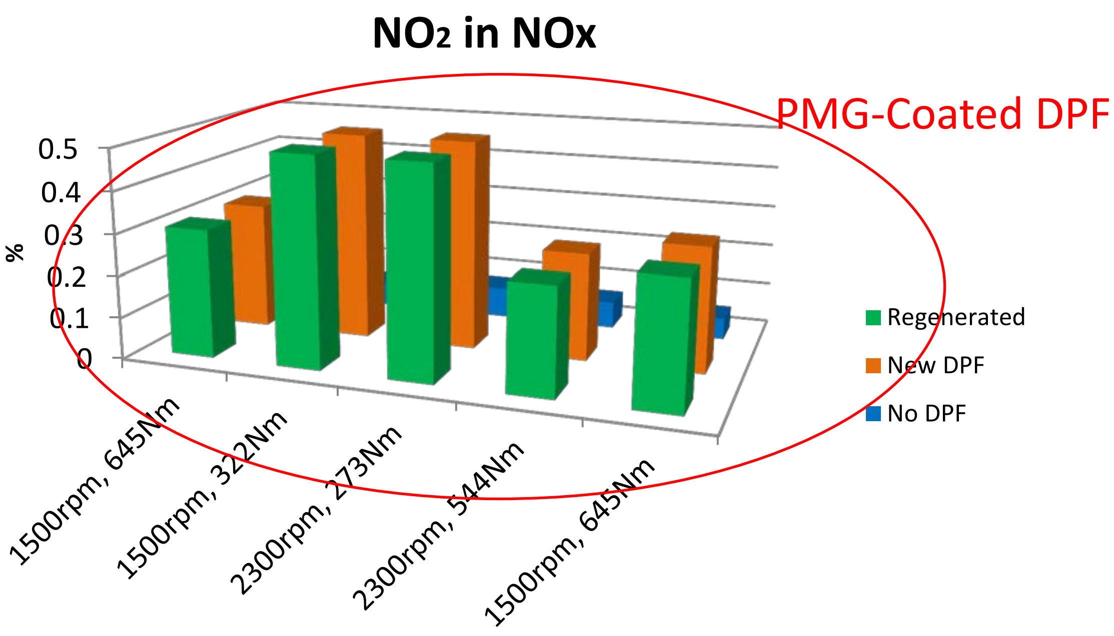
DPF-2 NOx results



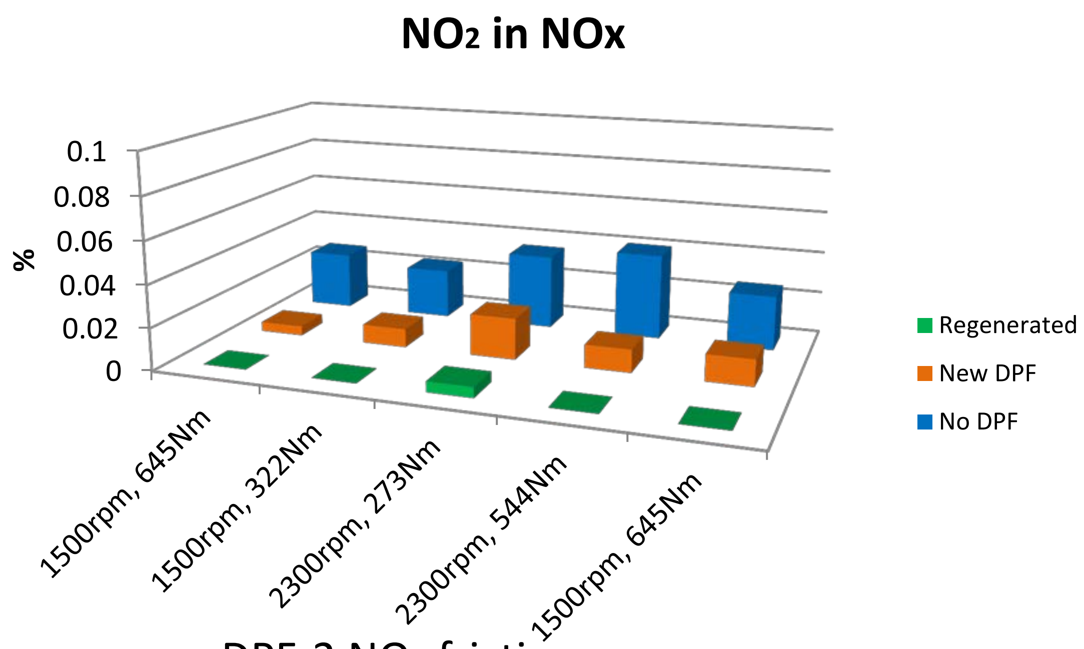
DPF-3 NOx results



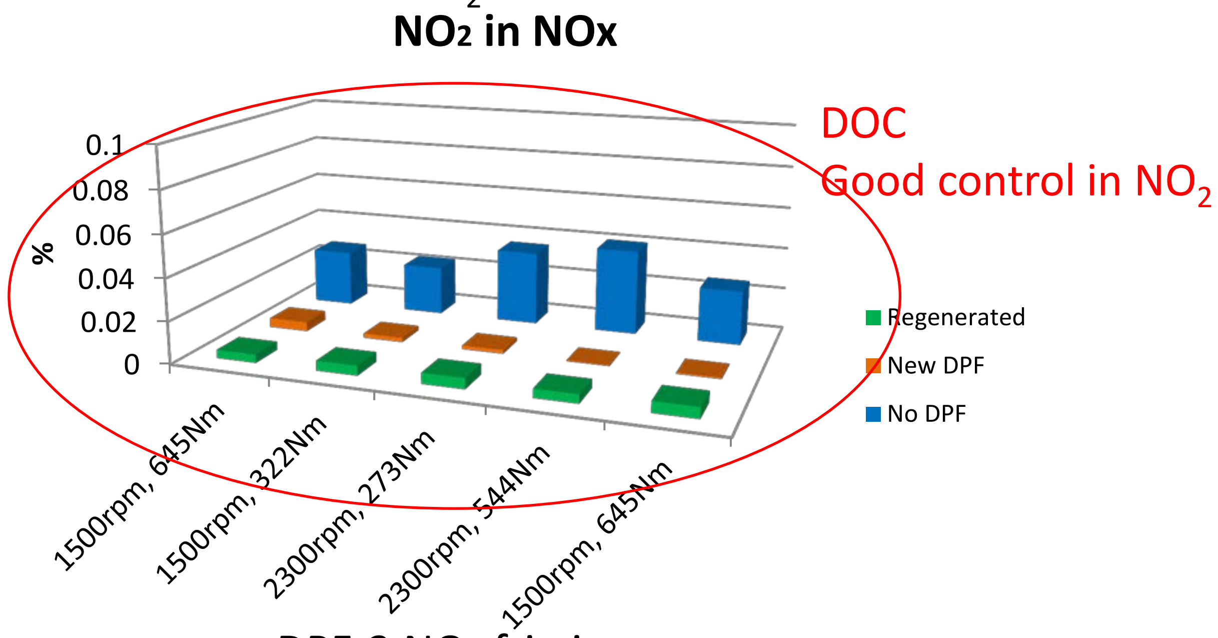
DPF-4 NOx results



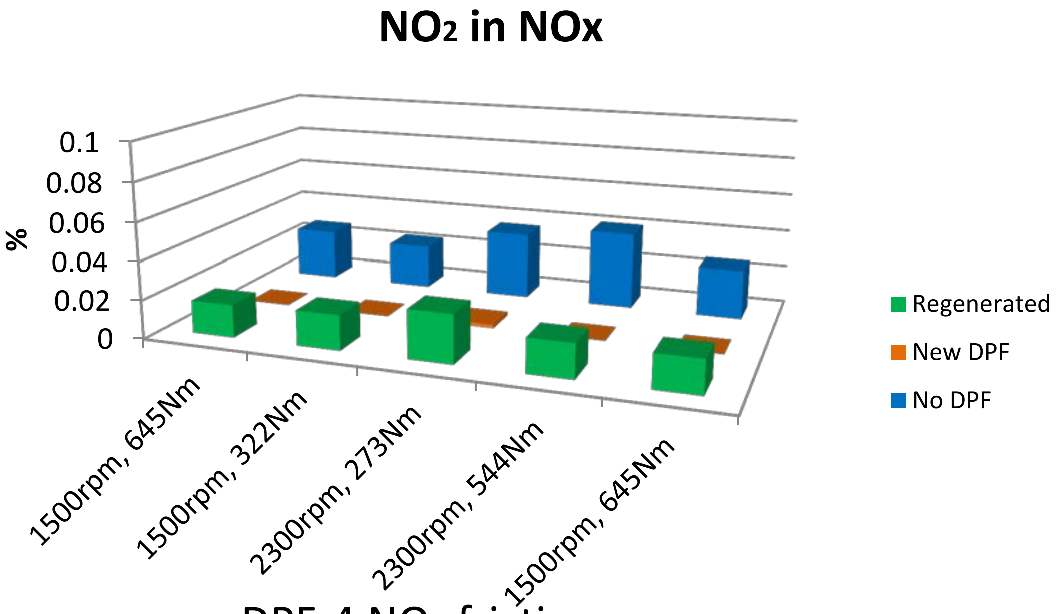
DPF-1 NO_2 friction



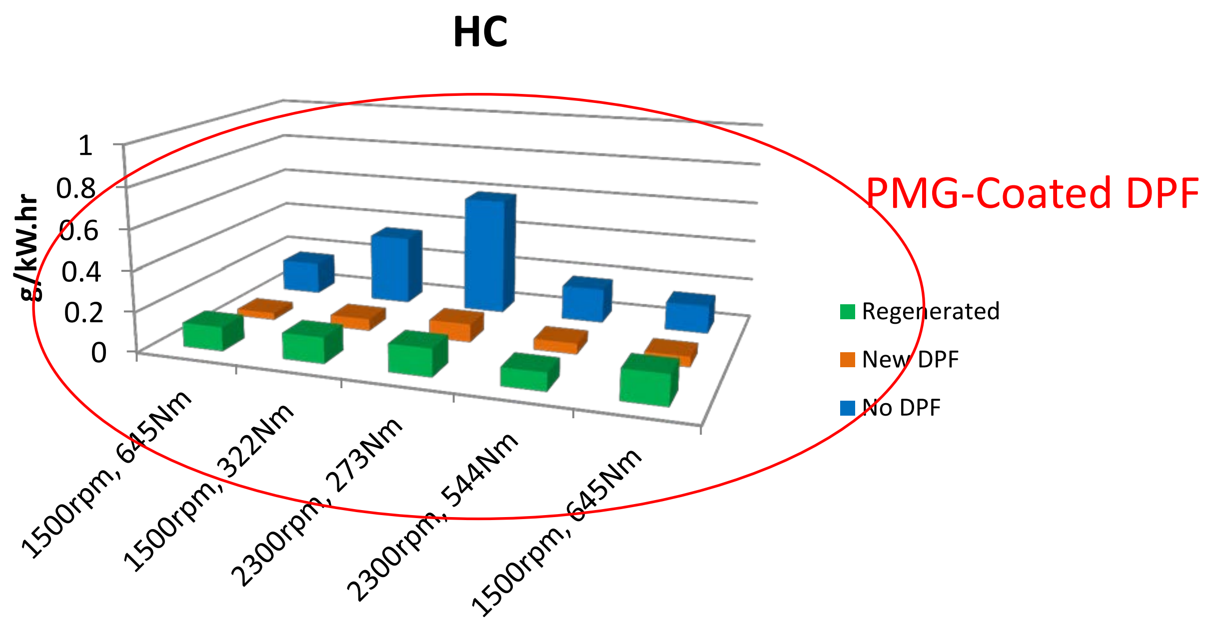
DPF-2 NO_2 friction



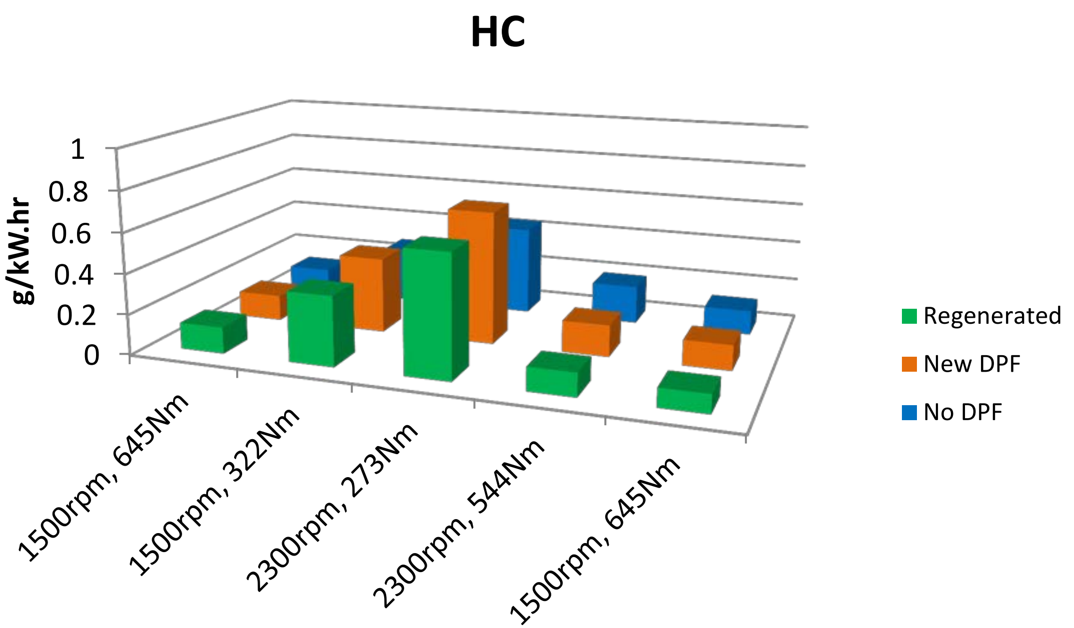
DPF-3 NO_2 friction



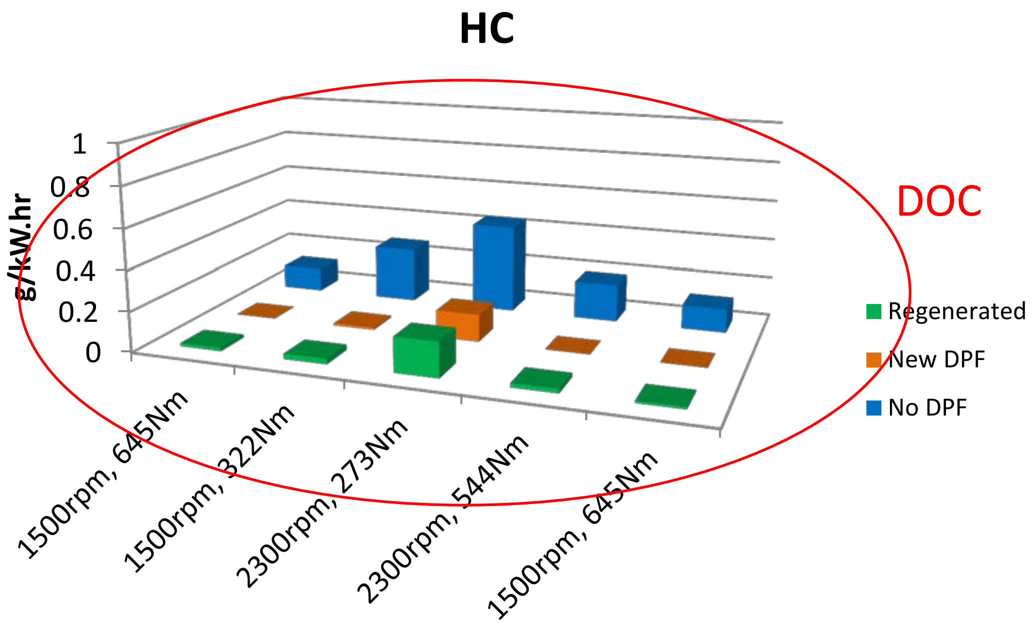
DPF-4 NO_2 friction



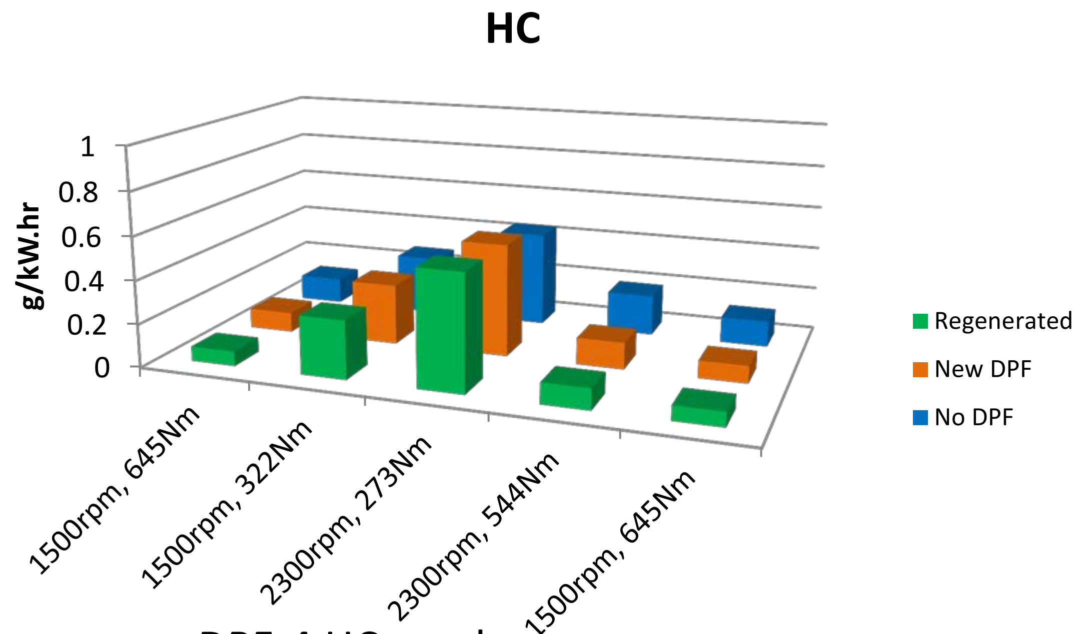
DPF-1 HC results



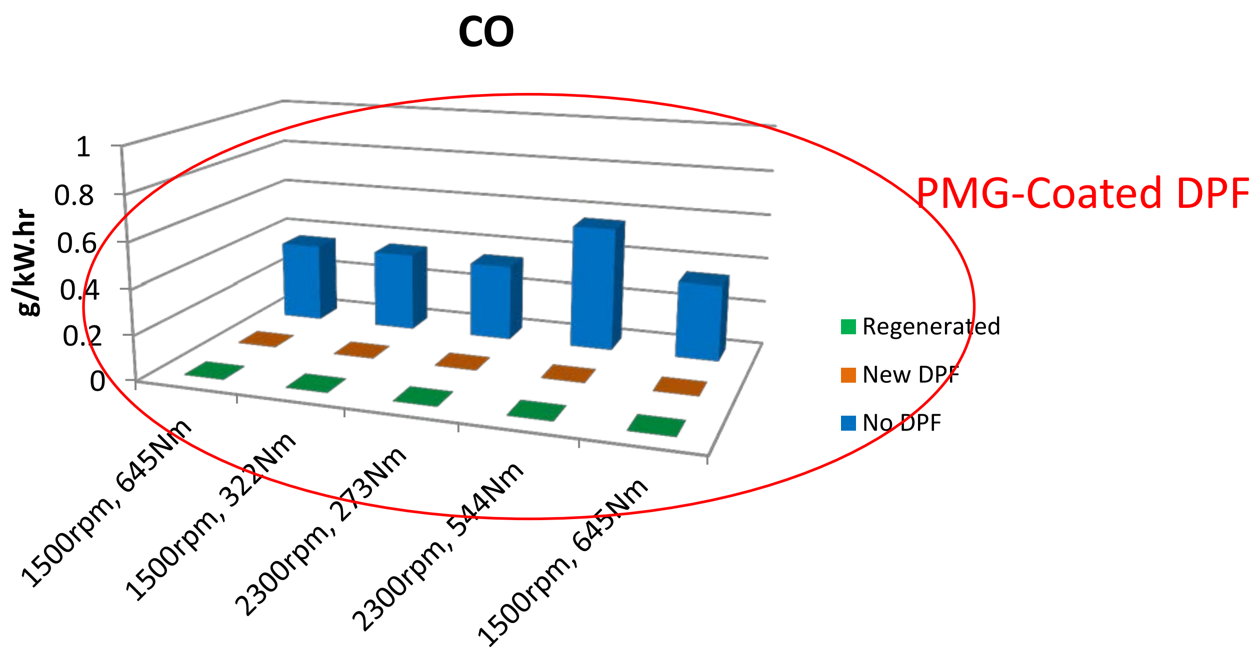
DPF-2 HC results



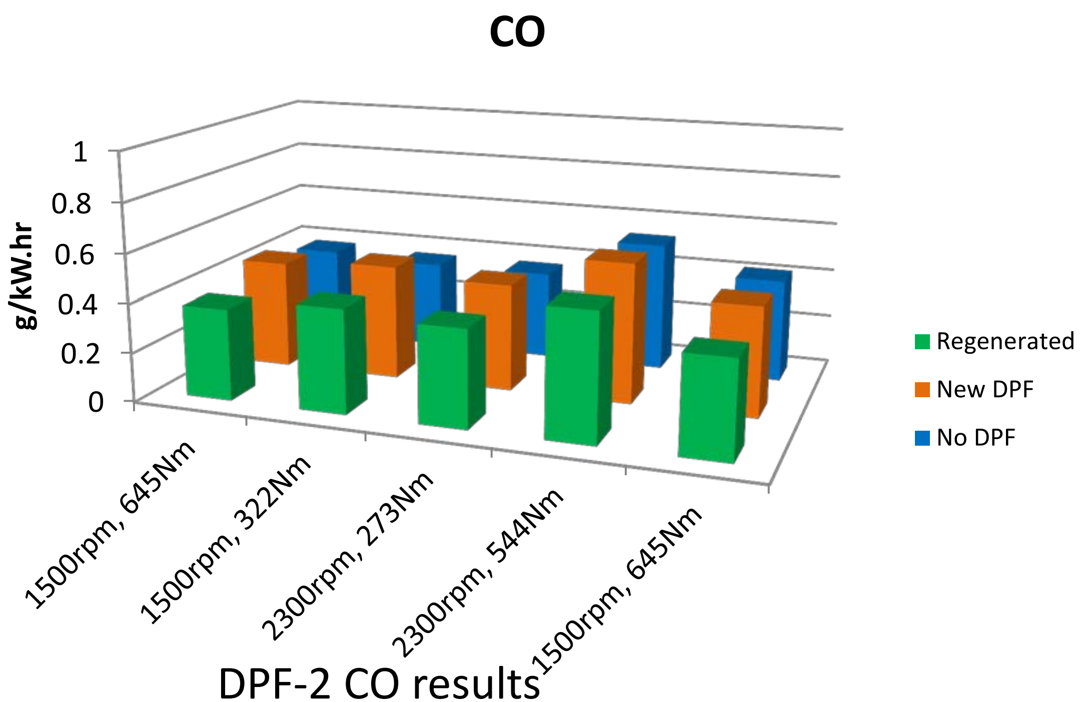
DPF-3 HC results



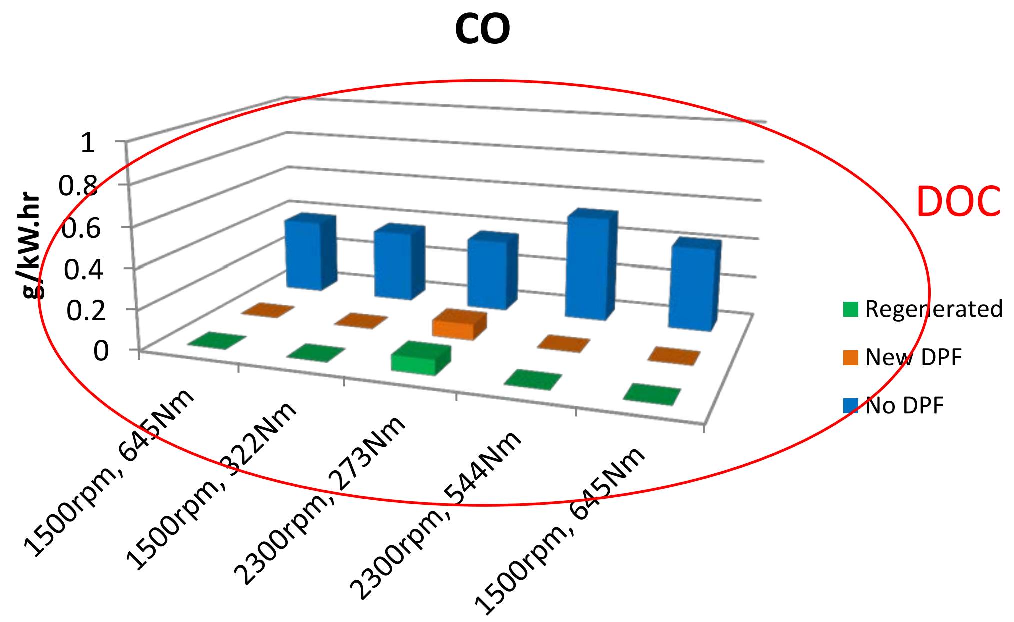
DPF-4 HC results



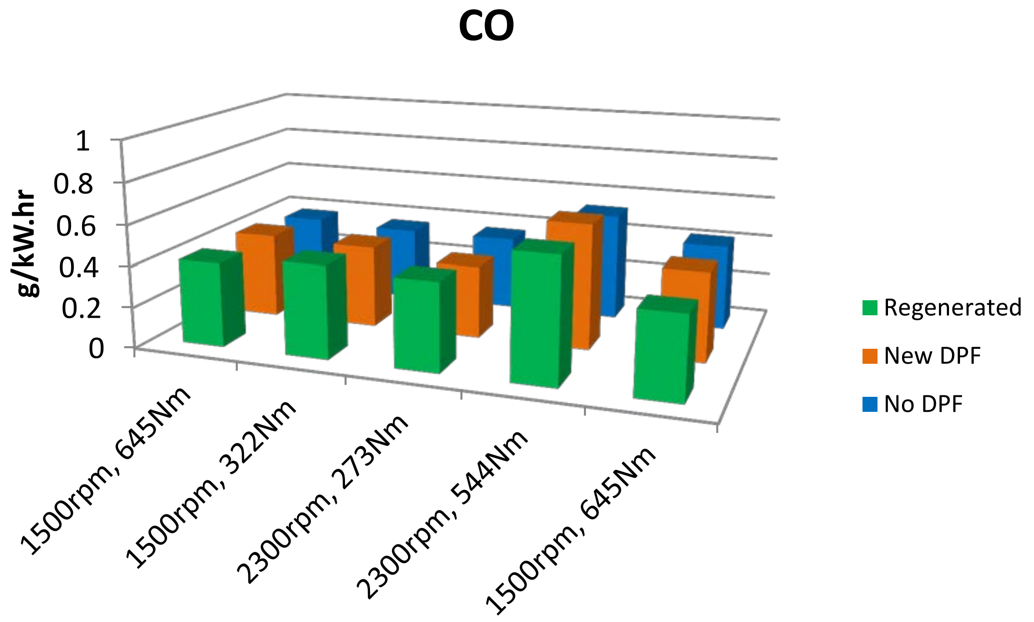
DPF-1 CO results



DPF-2 CO results



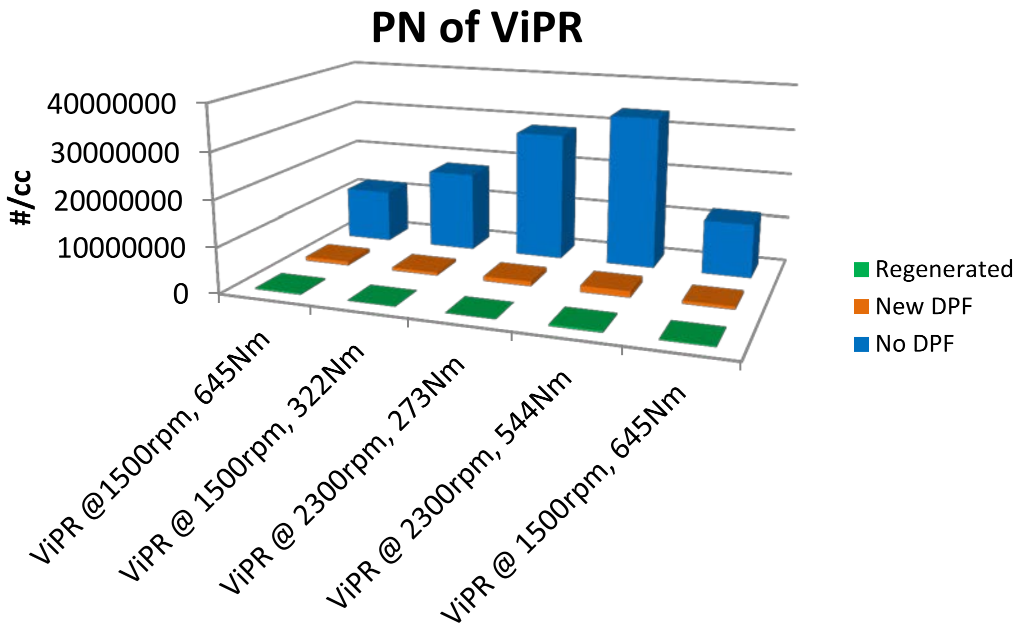
DPF-3 CO results



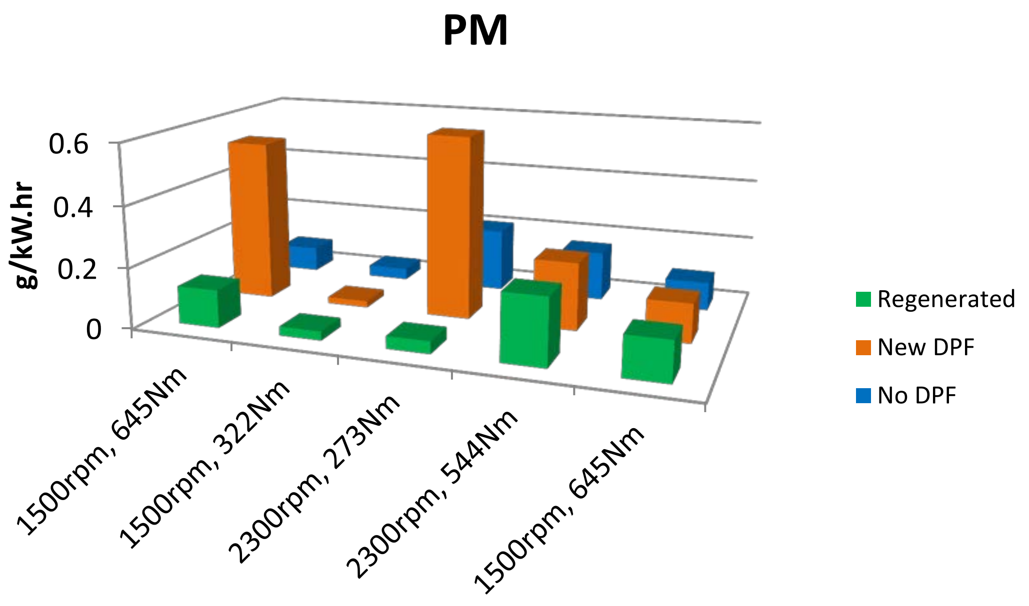
DPF-4 CO results

PM reduce efficiency of PGM-coated DPF

- PN after DPF were significant reduced. However, PM were found increased.
- A filter baking test was carried out to preliminarily investigate the PM components.

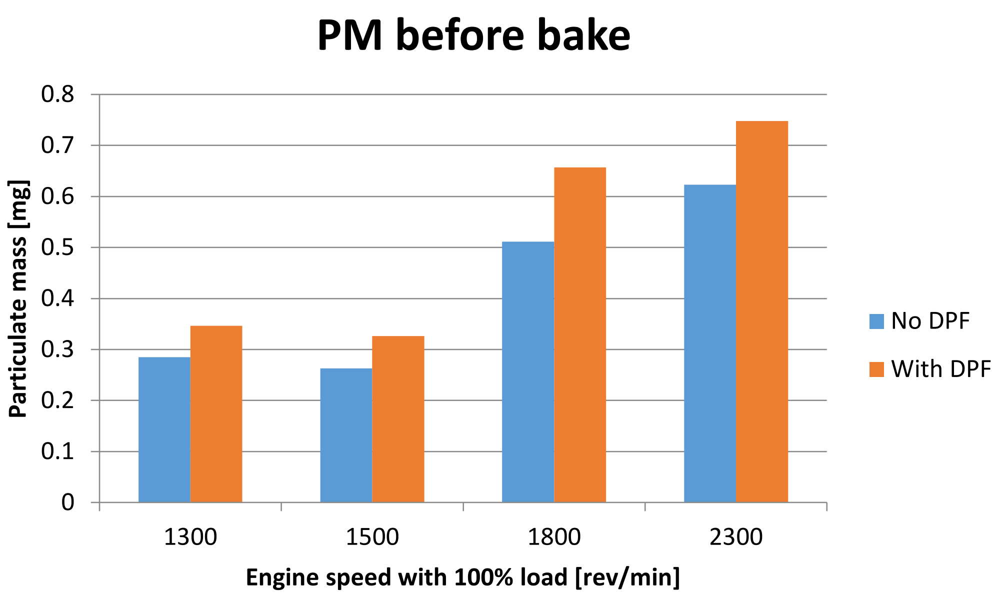


DPF-1 PN results

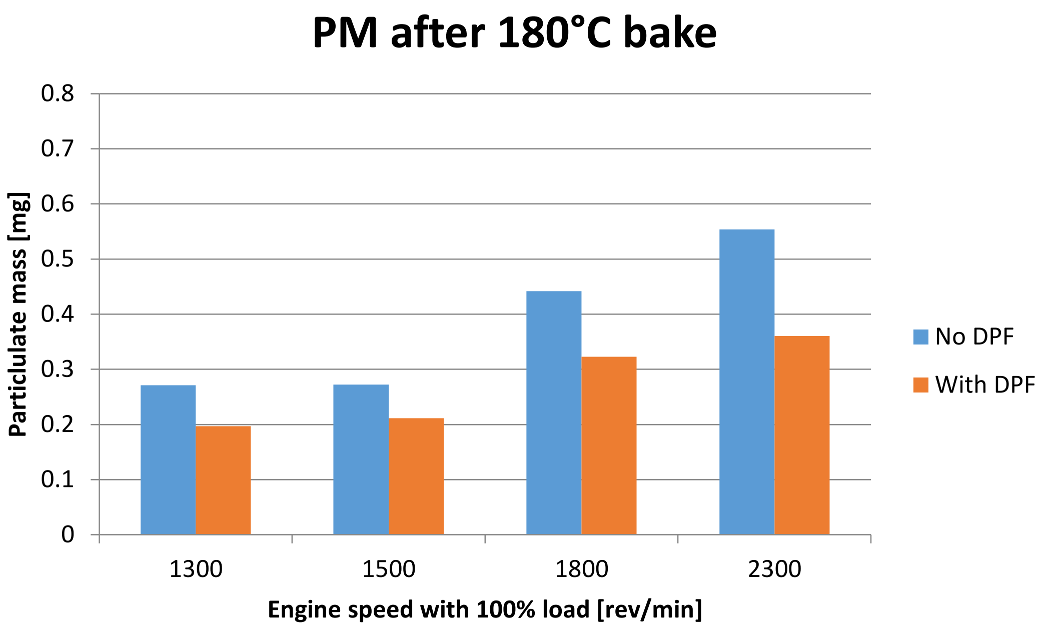


DPF-1 PM results

Filter baking test



DPF-1 PM results



DPF-1 PM results after baking

- Some volatile material was removed on the bake, especially the “with DPF” filters
- Those volatile material by the coated DPF might the primary cause of increasing of PM

- The PGM-coated DPF promote oxidize sulfur dioxide (SO_2) in diesel exhaust to sulfur trioxide (SO_3) with the subsequent formed hydrated sulfate particulates during PM sampling <52℃.
- This reaction is dependent on the level of the sulfur content of the fuel.

$$SO_2 \xrightarrow{[O]} SO_3$$
$$SO_3 + 8H_2O \rightarrow H_2SO_4 \cdot 7H_2O$$

- PN measure is based on the dry material after pretreated over 300℃.

PM Sampling System

PSS i60 for PM sampling

- PM is a mass filtered out of the gas below 52℃, so it may contain condensates of sulfates, sulfites hydrocarbon and water

- Hydrated sulfuric acid was formed and increases the mass downstream.

PN Counting System

Exhaust Gas

PND1 (First PN dilution device)	
T: 150°C-400°C	DF: 10-200

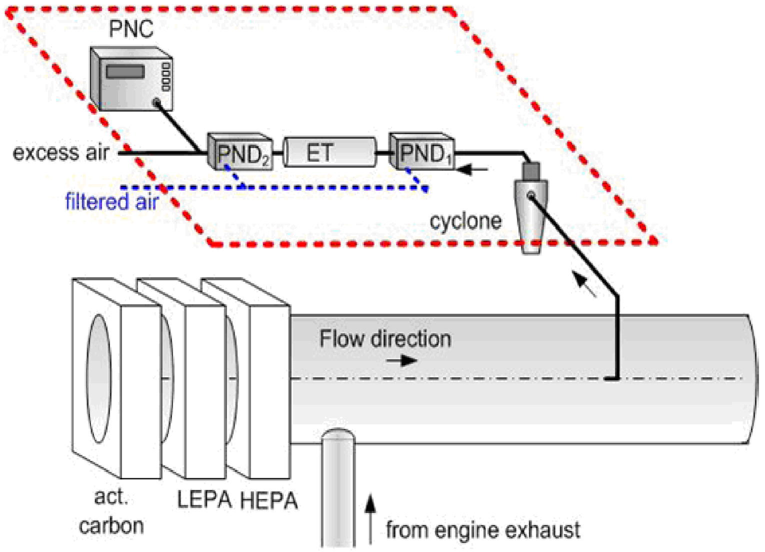
ET (Evaporation Tube)
T: 300°C-400°C

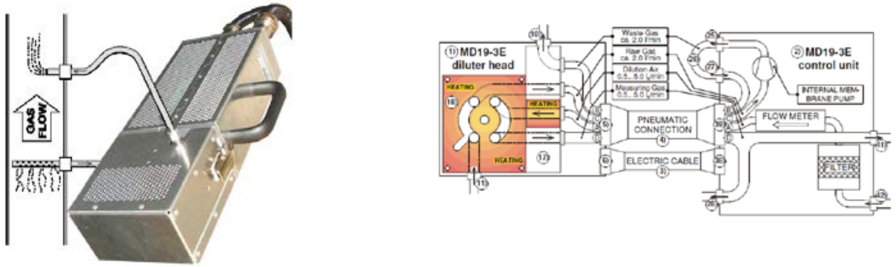
PND2 (Second PN dilution device)	
T: <35°C	DF: 10-30

PNC

All water, sulfate, sulfite evaporated

Dry material



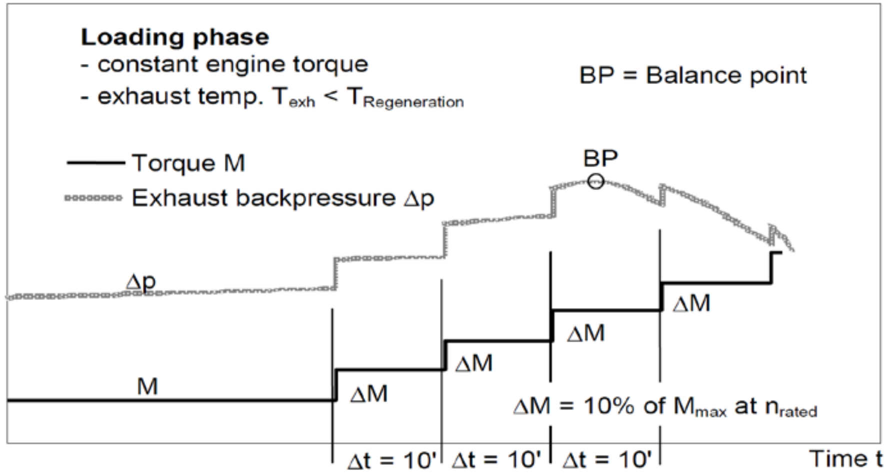


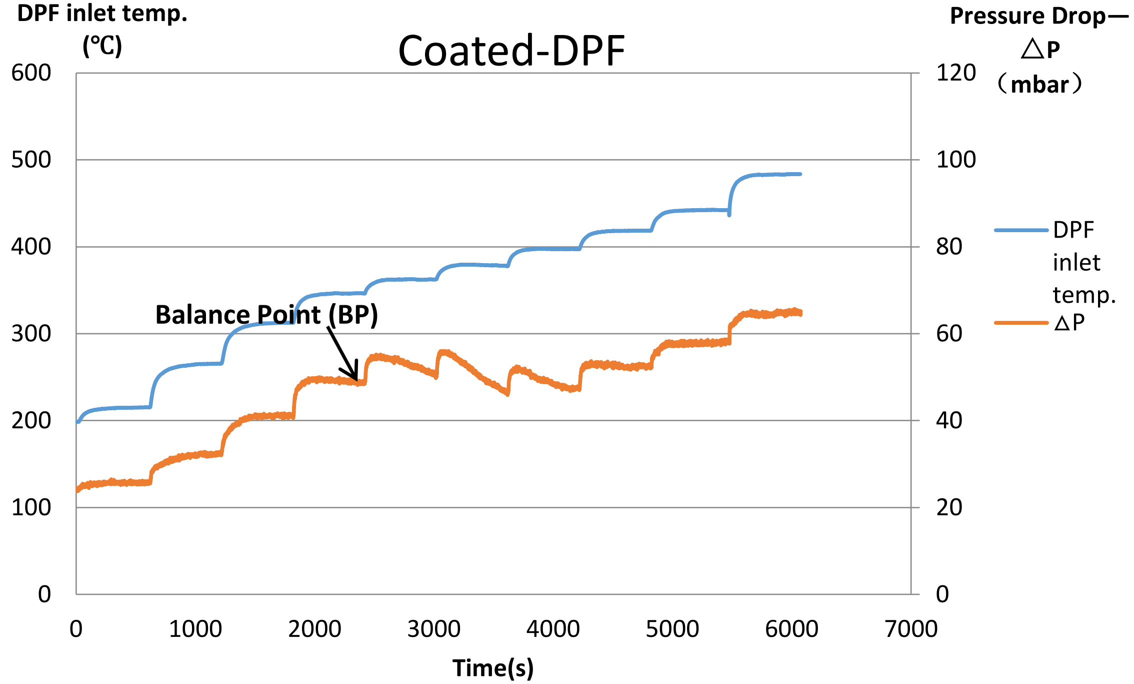
MD19 Mini-diluter for CPC

NanoMet for PN counting

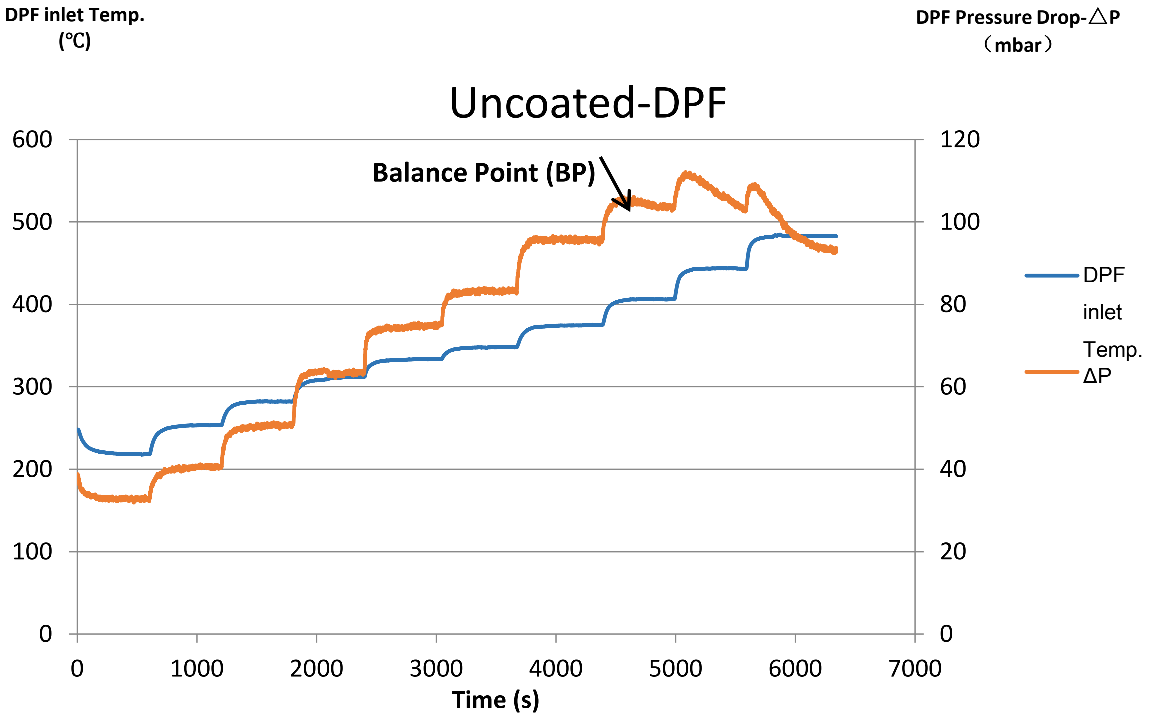
Regeneration test

- Repeat soot loading for more than 10 hours until the pressure drop of DPF increased to 10 mbar.
- After the pre-loading of the DPF, a steps-test is performed to demonstrate the regeneration behaviour of the system.
  Consist of:
  - 10-steps regeneration-test (each 10 min.) from 10% to 100% load at rated speed
- Compare of different regeneration mode





DPF-1 Passive regeneration

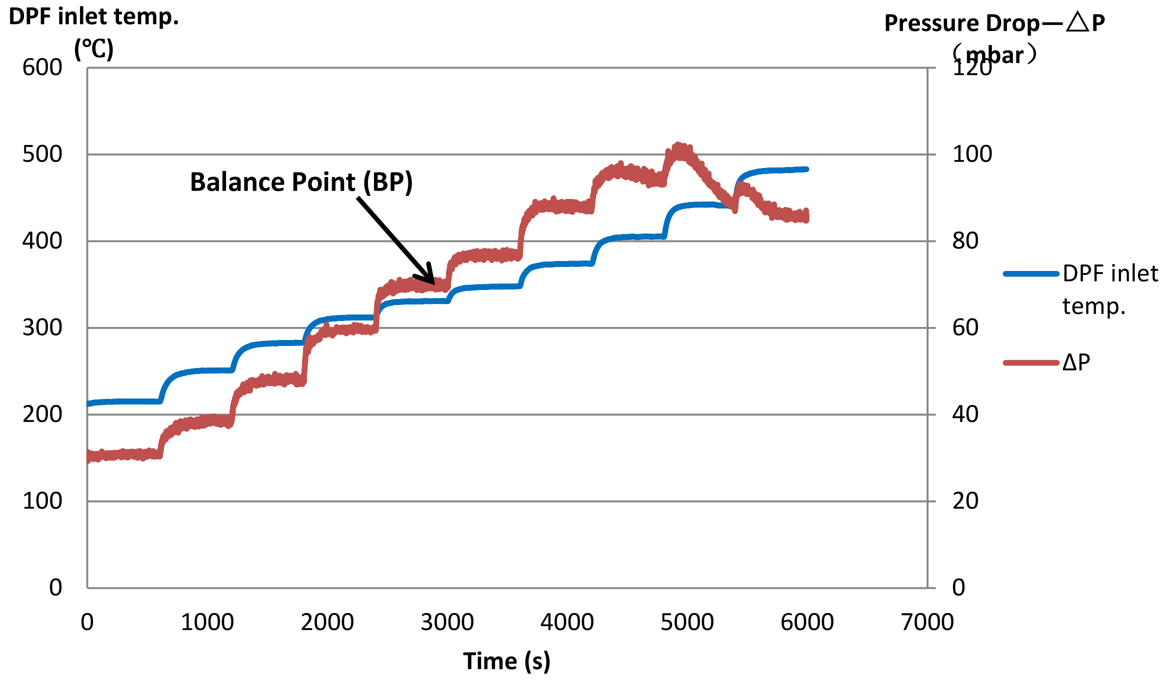


DPF-2 Passive regeneration

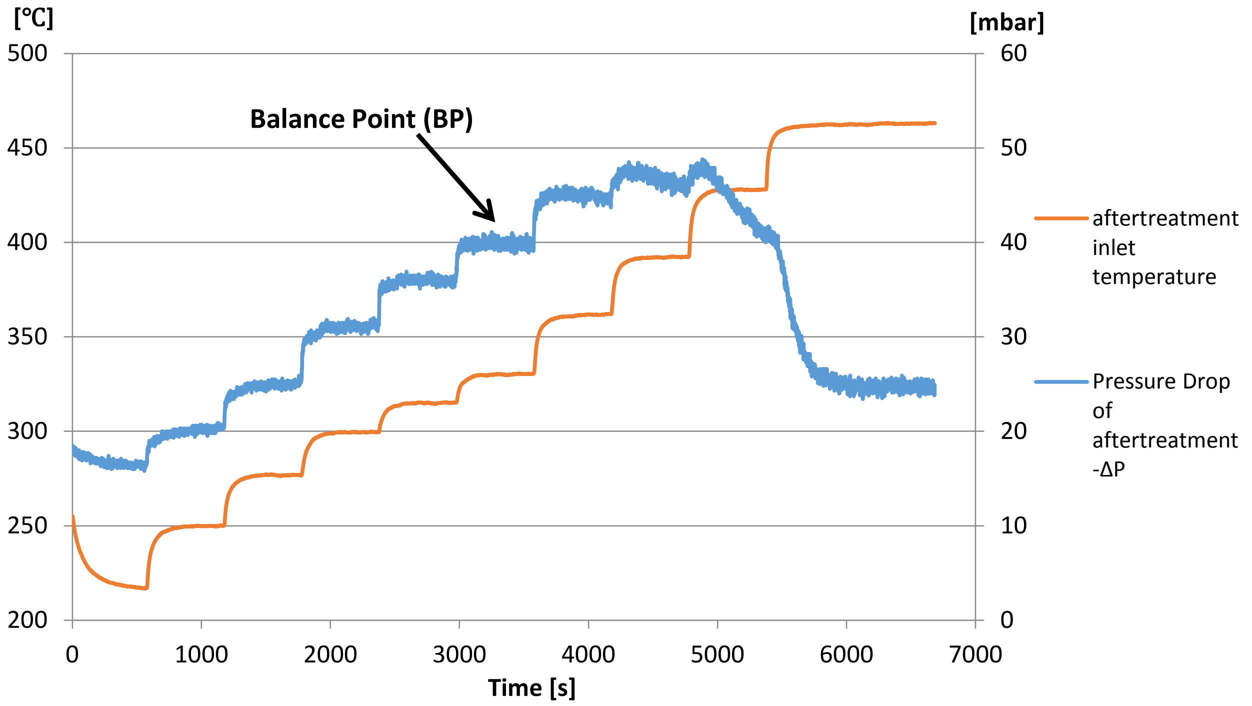
The balance point was reached after 2000 seconds at a load of 500 Nm and a delta P of 50 mbar. The inlet exhaust temperature was 343° C at the balance point.

The balance point was reached after 4000 seconds at a load of 377 Nm and a delta P of 95.5 mbar. The inlet exhaust temperature was 374.4° C at the balance point.

- Compare to uncoated DPF, coated DPF is easier to trigger the passive regeneration



DPF-3 Passive regeneration



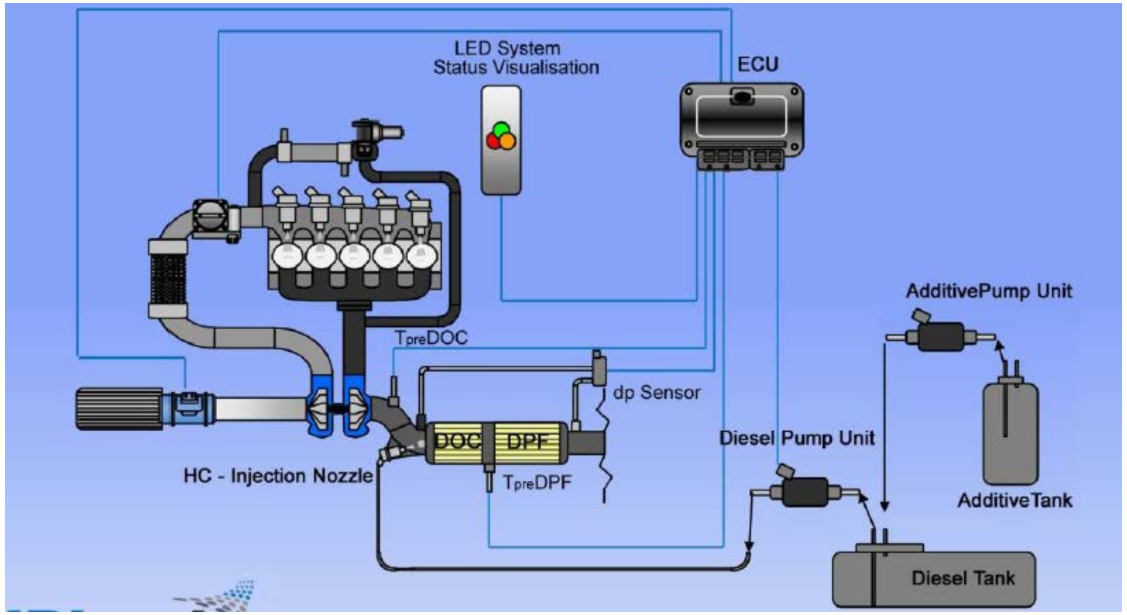
DPF-4 Passive regeneration

The balance point was reached after 2700 seconds at a load of 270 Nm and a delta P of 70 mbar. The inlet exhaust temperature was 330° C at the balance point.

The balance point was reached after 3000 seconds with a load of 270 Nm at 2300rpm and a delta P of 40 mbar. The inlet exhaust temperature was 330° C at the balance point.

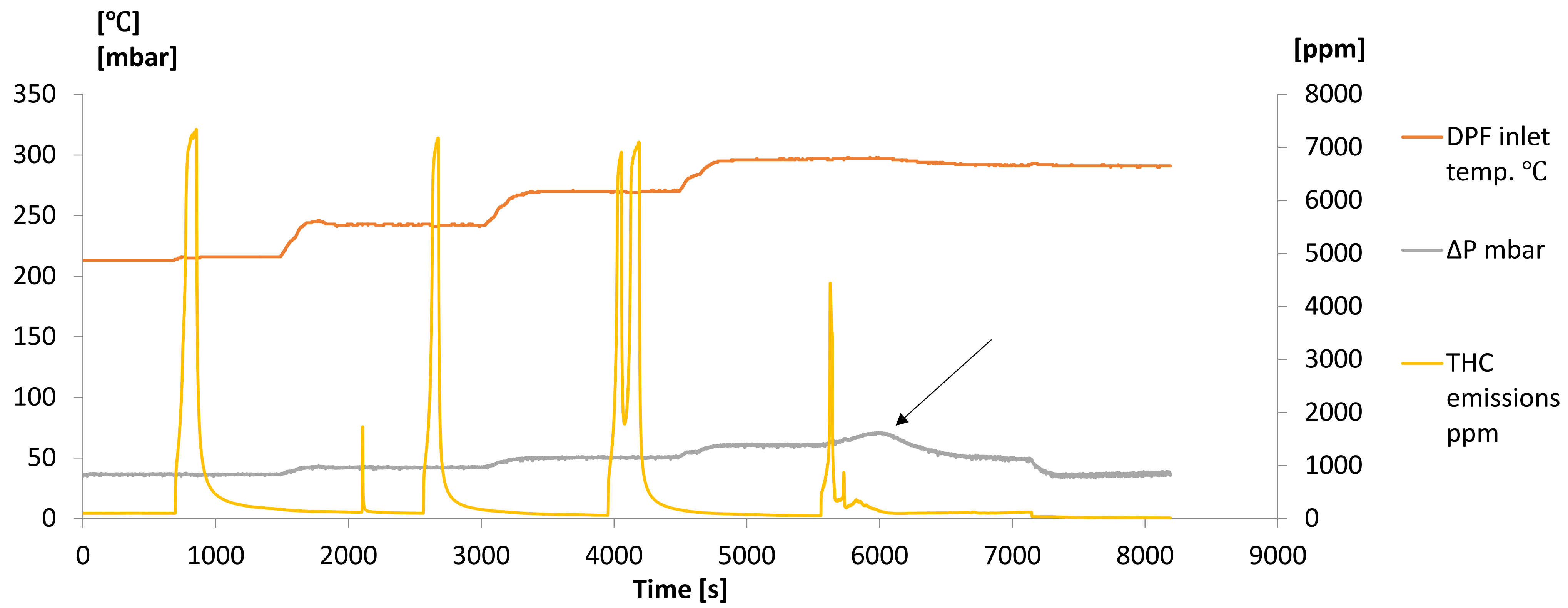
- The DPFs can be well regenerated at certain condition

Active regeneration strategy



- Combined regeneration filter system, comprising a passive component (fuel borne catalyst) and an active regeneration component (external fuel injection).

Active regeneration



DPF-3 Active regeneration

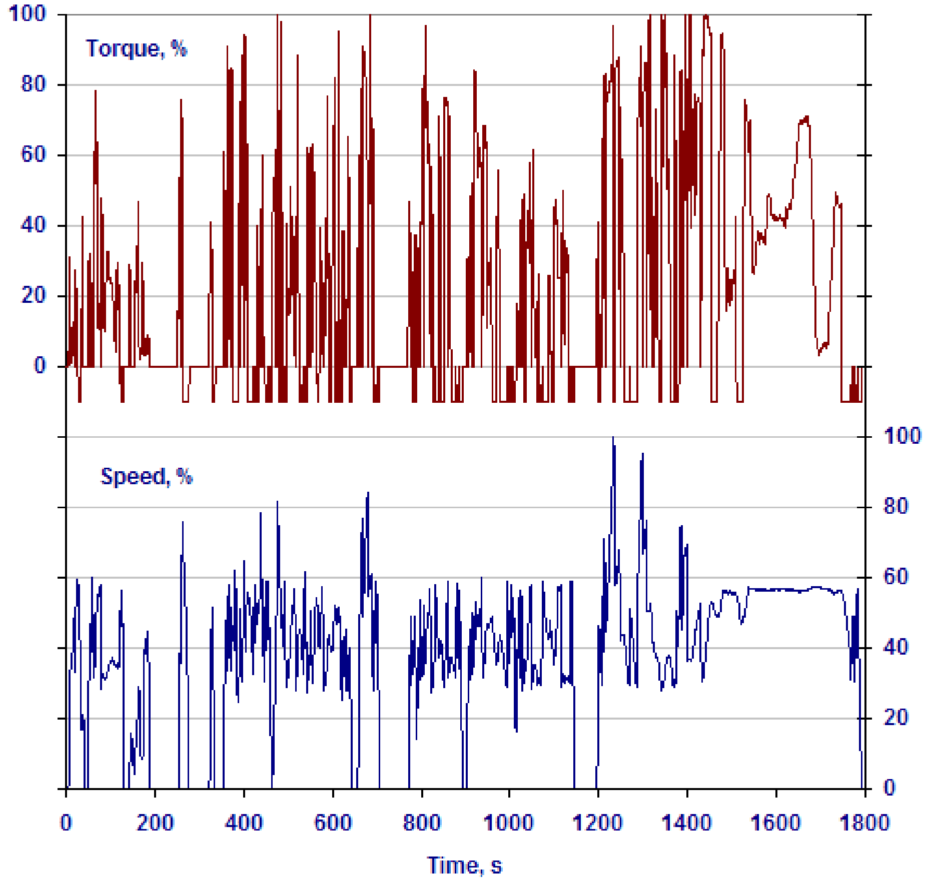
- Active regeneration in the way inject fuel with FBC into aftertreatment could be triggered when the DPF inlet temperature was above 300℃
- FBC significantly reduce the active regeneration temperature

WHTC tests

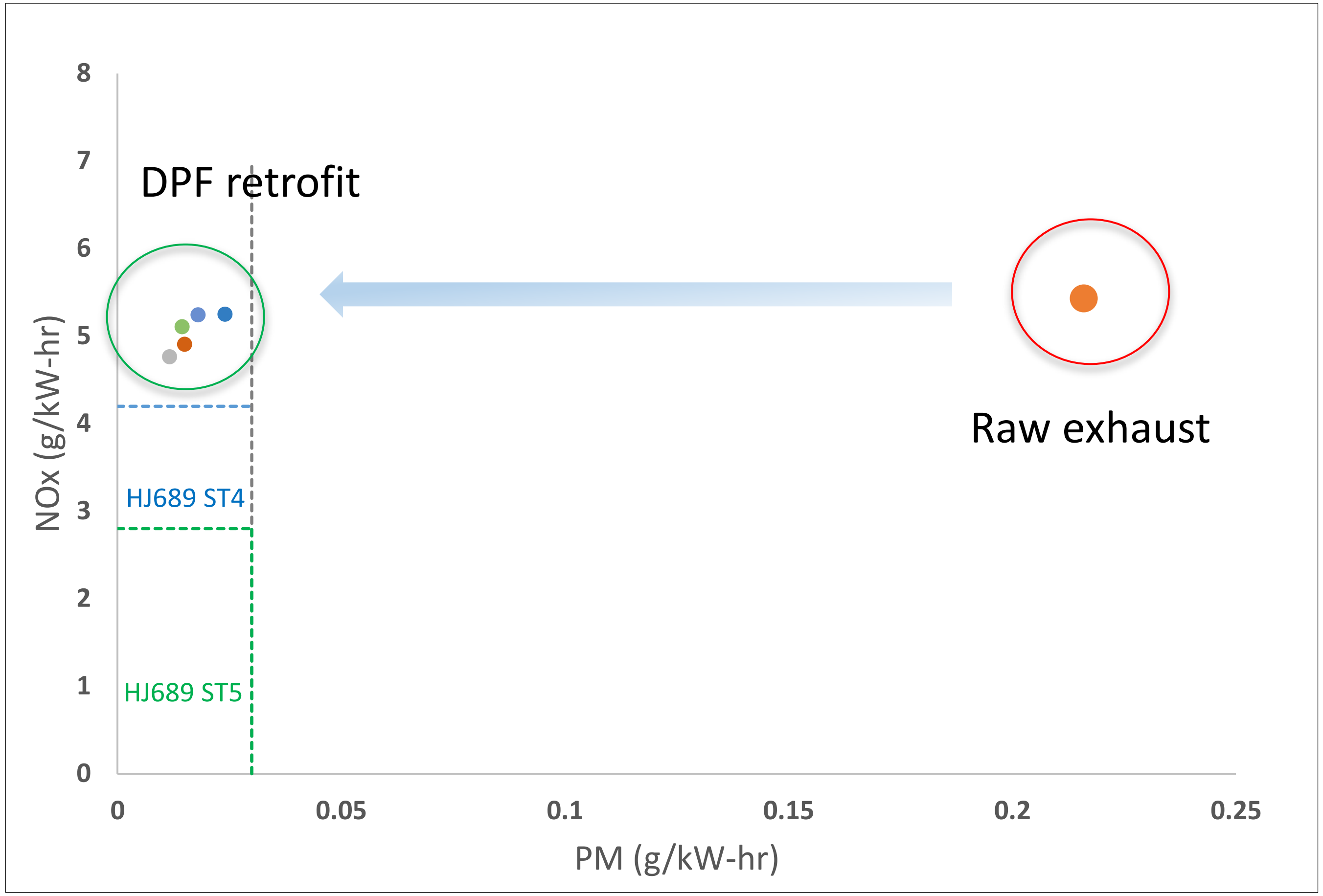
- Performing World Harmonized Transient Cycle (WHTC) testing to simulate the exhaust emission of the on-road scenarios

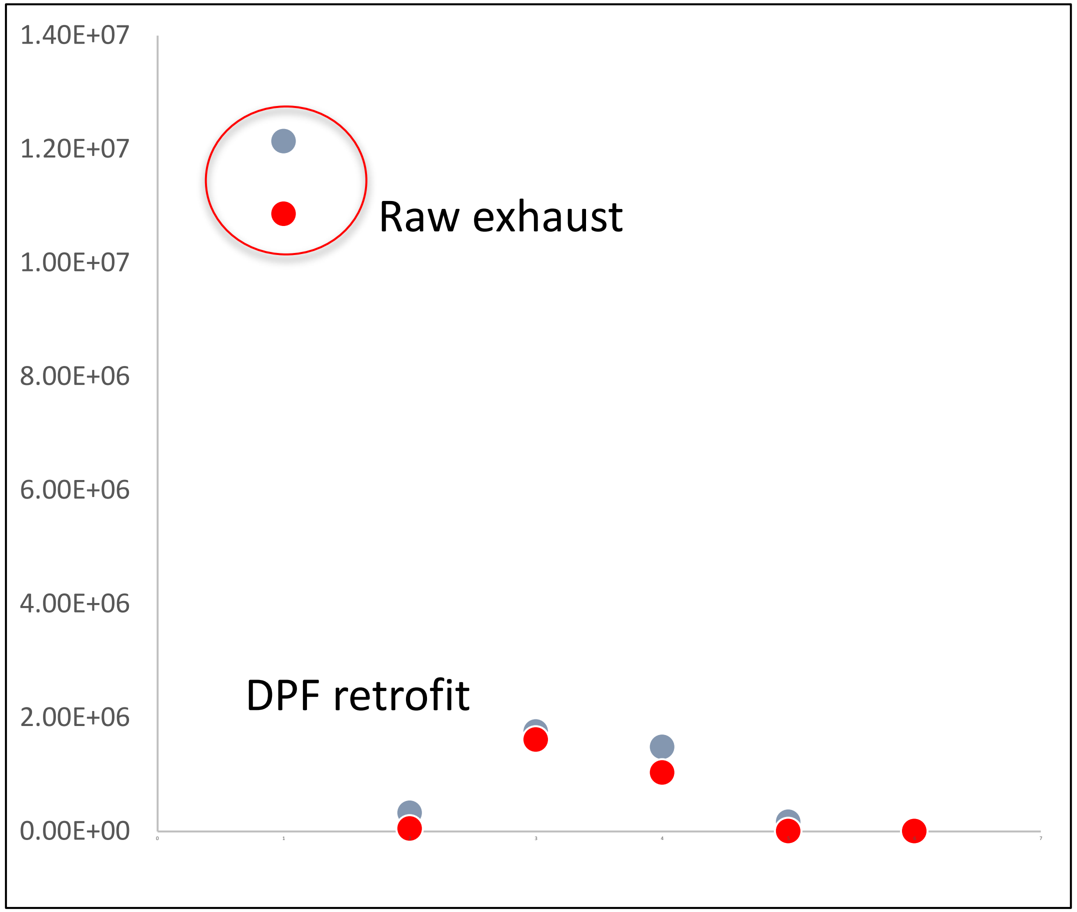
- Tests were conducted according to Chinese HJ689-2014 Limits and measurement methods for exhaust pollutants from diesel engines of urban vehicles(WHTC)

- Exhaust emission before and after DPF regeneration were measured

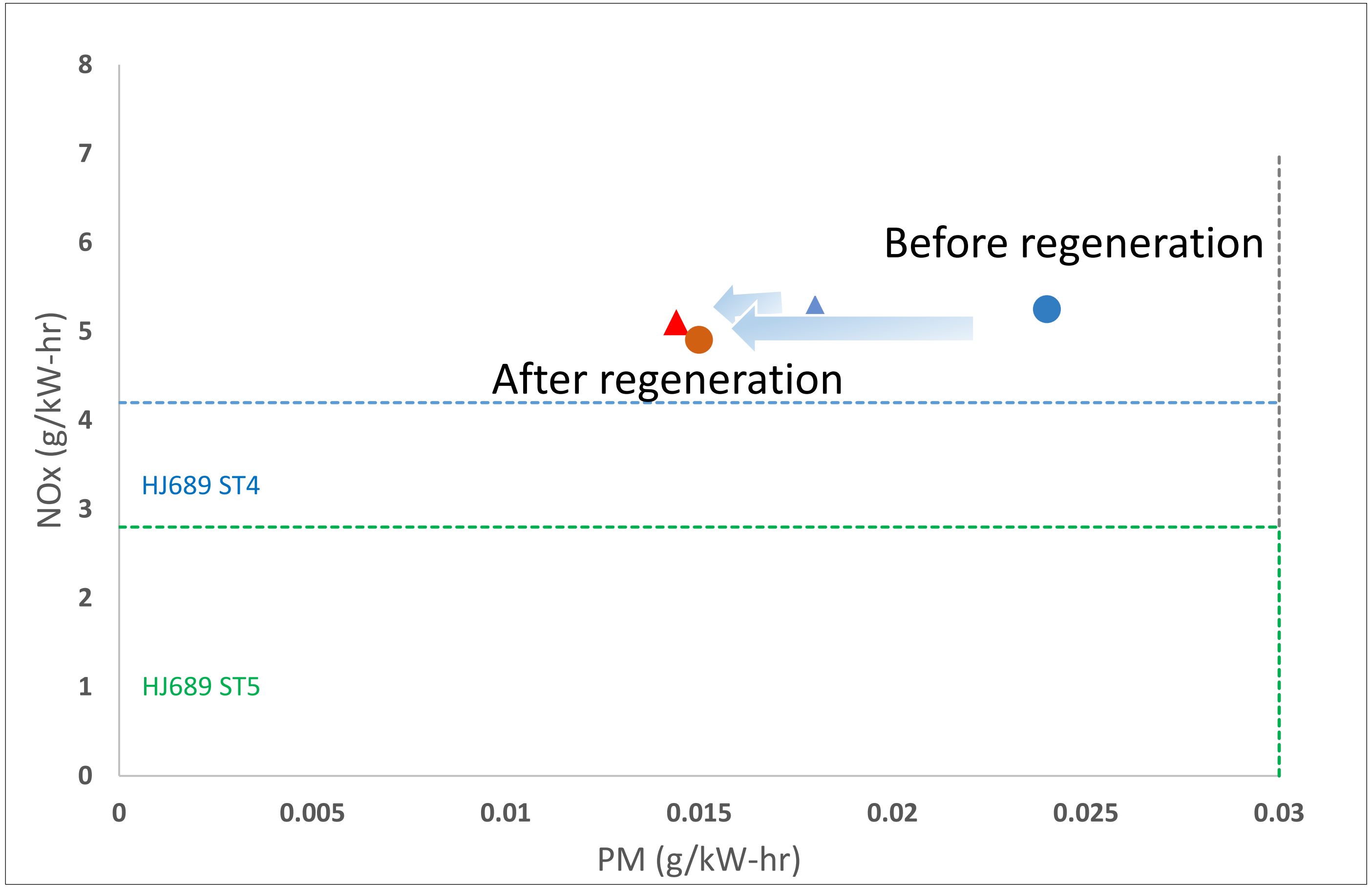


World Harmonized Transient Cycle (WHTC)





- ☐ DPFs have high efficiency in reducing PM and PN
- ☐ The DPF retro-fitted engines meet the PM requirement of Chinese Stage 4&5 legislation of urban vehicles



- The efficiency of Particulate Mass reduction following regeneration were slightly higher than the brand new due to the formation of soot cake.

Summary

- All sample DPFs have high efficiency in reducing PN.
- The DPFs can be well regenerated at certain condition.
- The efficiency of Particulate Mass reduction following regeneration were slightly higher.
- The hydrated sulfates oxidized by the coated DPF might cause of increasing of PM.
- Compare to the coated DPFs, the soot loading rate was higher in un-coated ones.
- The use of FBC (fuel bone catalyst) made a clear effect on reducing the soot ignition temperature. It helps the DPF regeneration at lower temperature.

Summary

- PGM-coated filters may currently not suitable in the Chinese retrofit market because this technology produces large amounts of sulfates and NO_2

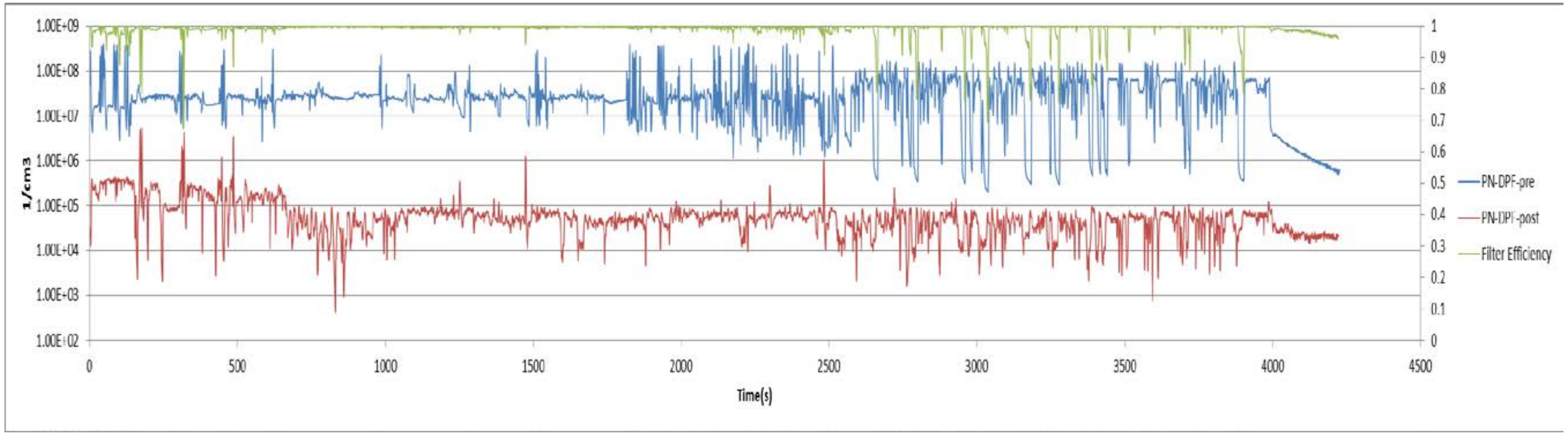
- FBC-filters have good filtration rate on both PM and PN but do not produce any sulfates nor any NO_2

Where're we

- Pilot testing in Xiamen and Nanjing of 2x10 vehicles
- Using data log to monitor the DPF operation
- Measure PN with NanoMet3
- Results show high PN filtration efficiency of DPF

DPF installation

DPF Test on Chassis Dyno.



Example of On-board PN Test Result

Real world PN Testing

What's next

- ☐ Endurance tests at pilot team
- ☐ Emission tests on the heavy duty chassis dynamometer or engine dynamometer

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Thank you!