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Assessment of retrofit devices for the Horizon 2020 Cleanest Engine and Vehicle Retrofit Prizes

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The Horizon 2020 prizes aimed at the development of retrofit and engines that would reduce pollution. The Retrofit prize had a winner, while the Engine prize not. In this paper we present the innovations that were tested at the Joint Research Centre (JRC) of the European Commission, and not awarded. One was a "condensation" aftertreatment device, two were devices inserted in the fuel supply system, and one a selective catalytic reduction (SCR) for NO_x system. The testing of the "condensation" aftertreatment device showed that it could not withstand the high exhaust gas temperatures. The results of the two fuel systems showed that they could not control efficiently the NO_x emissions. The reductions of the pollutants were negligble for the levels that the prizes were aiming. The SCR system did not achieve any significant reduction of NO_x, probably due to a malfunction of the device.

Key words: *retrofit, fuel supply innovation, SCR, Horizon 2020 prizes*

1. Introduction

Horizon 2020 competitions included two prizes: (i) the engine retrofit [1] (ii) the cleanest engine [2]. The Retrofit prize aimed at reducing the road transport pollution by spurring the development of retrofittable technology (i.e. additional devices and/or modification) applicable to Diesel engines focusing on Euro 5 vehicles (sold up to mid 2015) and Euro 6b (sold up to mid 2018), which will be on the road for many years. The purpose of the Engine prize was to stimulate the development of next generation engines and powertrain technologies using conventional fuels. This should reduce emissions of pollutants in real driving conditions to the lowest level possible in order to improve air quality in European cities, while at the same time delivering better fuel economy and lower CO_2 emissions. The assessment was done both in the laboratory and on the road requiring some of the most dangerous pollutants, NO_x and particulate matter, to be at very low levels, while limiting other pollutants and greenhouse gases. Additionally, vehicle fuel efficiency and retrofitting costs, durability, maintenance and usability, safety, drivability, and noise were considered in the prize criteria.

The innovation (engine or retrofit) had to be installed for testing purposes on a top sales C-class compact vehicle (but limited to hatchback and three volumes family car bodies). Hybrids (electric, compressed gases, hydraulic etc.), plug-in hybrids and in general systems using large energy storage capability beyond the main fuel were not admissible. A maximum volume of 50 liters of trunk space could be taken in the donor vehicle for the purpose of installing the device. For the purpose of this prize, only Diesel or gasoline and their commercial low blends were allowed.

Table 1 outlines the thresholds which had to be met prior to submitting the application. Participants conducted the tests at independent laboratories and the emissions had to be below the threshold values, before further assessment at the Joint Research Centre (JRC). Only regulated pollutants had to be presented. The same criteria were applicable as Not-To-Exceed (NTE) values for real driving tests (including altitude, use of auxiliaries testing, cold start and regenerations):

$$\text{On-road NTE limit} = \text{Laboratory limit} \times \text{CF} \qquad (1)$$

where CF is the conformity factor (= 1.2 defined in the rules) to take into account the measurement uncertainty of portable emissions measurement system (PEMS).

The prototype vehicles (with the engine or retrofit installed, activated and not) were then tested at JRC. The award criteria were based on scoring depending on how low were the emissions below the threshold (or the reduction for the retrofit devices). Details can be found in the rules of the prizes.

Table 1. Threshold values for the initial testing by the applicant

Criteria	Engine	Retrofit
NO_x (mg/km)	60	180
PM (mg/km)	1.0	4.5
$PN_{10}\times10^{11}$ (p/km)	6.0	6.0
THC (mg/km)	60	–
CO (mg/km)	400	500
Fuel consumption (FC) (dm^3/100 km)	5.0	< +10% [1]
NH_3 (mg/km)	30	–
N_2O (mg/km)	15	–
CH_2O (mg/km)	10	–

[1] compared to the baseline

The Retrofit contest was launched in April 2016 and the deadline for the submissions was June 2017 (September 2017 for the retrofitted vehicle). The evaluation was done until March 2018. The prize was awarded in April 2018. The results were published elsewhere [2–4].

The cleanest Engine contest was launched in April 2016 and the deadline for the submissions was August 2019. The evaluation was foreseen from September 2019 until March

2020. Due to the COVID-19, the evaluation was finalized in November 2020. The prize was not awarded because no prototype met the minimum thresholds of the competition. No submission incorporated a completely new engine, but only retrofitted technology.

In this paper the results of the prototype vehicles with the retrofits installed will be given, apart from the winner of the Retrofit prize, whose results were reported [3, 4]. Both JRC's and applicants' results are given, whenever available.

2. Experimental methods

2.1. Laboratory testing

The vehicles were tested at the Vehicle Emission Laboratory (VELA 2) of the European Commission Joint Research Centre (JRC), in Ispra, Italy. The climatic test cell temperature was kept at 25°C (with relative humidity 50%) or 7°C (with relative humidity of 50%) depending on the test cycle (details will follow). The dyno settings were defined in the prize rules based on the default values given in Regulation 83 using the vehicle weight. Market Diesel fuel (B7) was used for all tests for all vehicles. The 2-axle dyno was set with the appropriate dyno coefficients with the rear wheels "following" speed mode.

Measurements from the diluted gas in the full dilution tunnel with constant volume sampler (CVS) and the bags were made simultaneously. The bag results are reported here. The bag results were within 10% from those of real-time analyzers at the dilution tunnel. The gas analyzers were Horiba MEXA 7000 series with non-dispersive infrared (NDIR) analyzers for CO_2 and CO, chemiluminescence detector (CLD) for NO_x and flame ionization detector (FID) for hydrocarbons (THC). The particle number (PN) system connected at the full dilution tunnel was an AVL APC 489 with a 10 nm condensation particle counter (CPC).

Additional pollutants, including ammonia (NH_3), nitrous oxide (N_2O) and formaldehyde (CH_2O) were measured with a Fourier transform infrared (FTIR) spectrometer connected to the vehicle tailpipe, using a heated polytetrafluoroethylene sampling line (191°C). The FTIR spectrometer was the AVL Sesam including a Nicolet Antaris IGS Analyser (Thermo Electron Scientific Instruments LLC, Madison, WI, USA) with a Michelson interferometer (spectral resolution: 0.5 cm^{-1}, spectral range: 600–3500 cm^{-1}), a multipath gas cell of 2 m of optical path, a downstream sampling pump (6.5 lpm flowrate). The acquisition frequency was 1 Hz while the working pressure 860 hPa.

According to the prize rules, three cycles had to be driven in the following order:

(1) New European Driving Cycle (NEDC) with cold engine (soaked > 6 h) at 7°C,
(2) Worldwide harmonized light-duty vehicles test cycle (WLTC) with warm engine (soaked < 2 h) at 7°C,
(3) Common Artemis Driving Cycle (CADC) at 25°C (soaked > 2 h).

Due to the issues that will be described for each vehicle, this order was not always strictly followed.

2.5. On-road testing

Three routes were followed using a real-driving emissions (RDE) compliant portable emissions measurement system (PEMS) (Horiba OBS-ONE) or a portable FTIR (PEMSLAB, Certam-Addair).

The OBS measures CO_2 and CO with heated NDIR, NO_x with heated CLD and PN with a 23 nm CPC downstream of a catalytic stripper.

The portable FTIR, PEMSLAB from Certam, has a cell with an internal volume of 200 cm^3 with fixed optical path of 2 m and windows of BaF_2. The cell is operated at atmospheric pressure and heated at 180°C. Spectra are recorded by a mercury cadmium telluride (MCT) thermoelectrically (Peltier) cooled detector. The spectral range is 900–4200 cm^{-1} with a spectral resolution of 8 cm^{-1}.

Two routes (ESP and LAB) complied with the trip requirements defined in the RDE regulation were carried out in the morning with cold engine. The third route (SAC) represented hilly driving and was not RDE compliant and was conducted in the afternoon. The vehicle 12 V battery was left to charge before each test.

3. Results of Retrofit #1

3.1. General

Retrofit name: 3G exhaust system.

Owner: Galiboff Plastik Kompozit Ekstrüzyon Teknolojileri Ltd., Meric Ltd., Darıca Sanayi Sitesi, E Blok No:38, Darıca/kocaeli, Turkey

Web-site: http://www.galiboff.com/

Innovation according to the applicant: The exhaust system turns water vapor to liquid and mixes all emitted gases with water. Gases which react with water leave from the central pipe to the atmosphere as liquids. Gases that do not mix with water leave from the upper pipe, which may be connected to the intake air. This prototype upper pipe had no connection to the intake air at the prototype that was delivered to JRC.

Donor vehicle: The donor vehicle was a Seat Leon 1.9 TDI (81 kW), model year May 2004 (Euro 4), with mileage 135127 km.

3.2. Test protocol

The dyno values were: m = 1470 kg, f_0 = 7.4 N, f_2 = 0.0502 $N/(km/h)^2$. During the first NEDC test at 25°C (30/9/2019) the vehicle showed a malfunction. The car could not accelerate more than 100 km/h and the cycle was not compliant. The test campaign was suspended. The applicant was authorized to work on the car to fix the problem (7/10/2019 and 8/10/2019). The car was again installed in the cell (8/10/2019). The car was preconditioned at 120 km/h and then 3×EUDC (as foreseen by the regulation). Later that day (soak 6 h) a cold NEDC at 25°C was run. The results (Table 2) were above the threshold limits. Note that the prototype vehicle was delivered for the Engine prize, so it was assessed using the Engine limits. Nevertheless, it would have failed also the retrofit limits.

When the transfer line (i.e., the tube connecting the vehicle to the dilution tunnel) was disconnected, solid burned materials were found in the tailpipe with dimensions reaching 2.5 cm. It is probable that they originated from the filter filaments and material which fused at high temperatures. Also, the filters of the critical orifices of the CVS were inspected and were found contaminated. Due to these reasons, the campaign on the vehicle was terminated.

Table 2. Summary of results. F = Fail, P = Pass based on the Engine limits because the prototype vehicle was delivered for the Engine prize (Table 1)

Criteria	Limit	NEDC	3×EUDC	NEDC	
	Lab	25°C	Hot 25°C	25°C	
CO_2 (g/km)	–	164	140	161	
NO_x (mg/km)	60	1154	615	646	F
$PN_{10}\times10^{11}$ (p/km)	6	–	549	209	F
THC (mg/km)	–	247	166	152	F
CO (mg/km)	400	605	529	622	F
FC (dm^3/100 km)	5.0	6.3	5.4	6.2	F
NH_3 (mg/km)	30	–	–	0.3	P
N_2O (mg/km)	15	–	–	6.7	P
CH_2O (mg/km)	10	–	–	23.4	F

4. Results of Retrofit #2

4.1. General

Retrofit name: FuelWell 4D PC.

Main applicant: Katalitprylad, LLC TH "GlobalExim", Belorusskaya 26, Kiev, 04050, Ukraine.

Testing laboratory: Instytut Transportu Samochodowego (Motor Transport Institute), ul. Jagiellonska 80, 03-301, Warszawa, Poland

Web-site: www.https://fuel-well.com

Innovation according to the applicant: FuelWell is installed in the fuel system of the Diesel engine. In the first chamber selective purification of Diesel fuel from sulphur compounds and resins is carried out, by catalytic treatment with granular catalyst and saturation of fuel at the molecular level of salts of alloying metals, which in the cylinder create a dopant effect (increase compression in cylinder). In the second chamber, the fuel is subject to activation, homogenization and fine purification. Complex fuel treatment increases the completeness of its combustion, which reduces the real fuel consumption and release of harmful gases. The weight is approximately 0.85 kg.

Donor vehicle: The donor vehicle was a Peugeot 308 1.6 Blue HDi (88 kW), model year June 2017 (Euro 6b), with mileage 20177 km.

4.2. Test protocol

The tests were done with two dyno settings: m=1250 kg, f_0 = 6.8 N, f_2 = 0.046 N/(km/h)^2 to match the applicant's tests, and with the dyno values foreseen at the prize: m = 1470 kg, f_0 = 7.4 N, f_2 = 0.0502 N/(km/h)^2. Unless otherwise specified, the m = 1470 kg settings were applied.

The tests were conducted in the following order:

- 1/10/2019: NEDC cold 25°C
- 2/10/2019: NEDC cold 7°C
- 3/10/2019: NEDC cold 7°C, WLTC hot 7°C, CADC cold 25°C
- 4/10/2019: CADC cold 25°C
- 7/10/2019: 3×EUDC, NEDC cold 25°C (m = 1250 kg)
- 8/10/2019: 3×EUDC, NEDC cold 25°C (m = 1250 kg)

Tests with the retrofitted activated or not:

- 15/3/2021: WLTC hot 23°C preconditioning (activated)
- 16/3/2021: WLTC cold 23°C (activated)
- 17/3/2021: WLTC cold 23°C (activated)
- Retrofit deactivation and conditioning for 160 km.
- 24/3/2021: WLTC hot 23°C preconditioning (not-activated)
- 25/3/2021: WLTC cold 23°C (not-activated)
- Further conditioning for 150 km (not-activated)
- 7/4/2021: WLTC cold 23°C (not-activated)
- 8/4/2021: WLTC cold 23°C (not-activated)

4.3. Lab results

Table 3 summarizes the cold NEDC at 25°C results reported by the contestant, and those measured by JRC matching the settings (m = 1250 kg) and with the prize settings (1470 kg).

Based on the contestant's results, in general, the NO_x were slightly higher than the threshold, but the other pollutants below. The device showed a small to negligible improvement of the emissions.

There is relatively good agreement between reported and measured by JRC values (except PN, which was still below the threshold), so it was decided to continue with the testing, using the official dyno coefficients.

Table 3. Comparison of emissions reported by contestant and measured by JRC using the same setting for cold start NEDC at 25°C. The same cycle with the prize dyno coefficients is also given. F = Fail, P = Pass based on the Engine limits because the prototype vehicle was delivered for the Engine prize (Table 1). Lim.=Limits

Criteria	Lim.	NEDC	NEDC	NEDC	NEDC	
Inertia (kg)		1250	1250	1250	1470	
Testing lab		applic.	applic.	JRC	JRC	
Retrofit		w/o	with	with	with	
CO_2 (g/km)	–	113.5	116.9	109–110	127	
NO_x (mg/km)	60	69.0	65.8	102–130	256	F
$PN_{10}\times10^{11}$ (#/km)	6.0	–	0.09	1.8–1.9		P
THC (mg/km)	60	12.0	12.1	12–16	31	P
CO (mg/km)	400	200.9	232.3	282–368	351	P
FC (dm^3/100 km)	5	4.32	4.45	4.20	4.8	P

Table 4 summarizes the results of the official cycles. The vehicle failed NO_x and CO, and the fuel consumption was above the threshold at one test. The prototype would also have failed the Retrofit prize NO_x limits.

It should be noted that the same model but Euro 6d-temp fulfilled the Euro 6 limits at the cold and hot start WLTCs at 23°C and 10°C [5] (i.e. NO_x < 80 mg/km). On the other hand, the Euro 5b version emitted 300 mg/km (NEDC cold 7°C), 450 mg/km (WLTC hot 7°C), and 850 mg/km (CADC 25°C) NO_x [3].

Table 4. Emissions measured by JRC for the cycles prescribed in the prize rules. F = Fail, P = Pass based on the Engine limits because the prototype vehicle was delivered for the Engine prize (Table 1). Lim. = Limits

Criteria	Lim.	NEDC	WLTC	CADC	
	Lab	7°C	Hot 7°C	25°C	
CO_2 (g/km)	–	125–127	130	154–155	–
NO_x (mg/km)	60	513–519	167–220	497–808	F
$PN_{10}\times10^{11}$ (#/km)	6.0	0.6–1.0	0.8–1.2	1.5–1.6	P
THC (mg/km)	60	21–25	2-3	2	P
CO (mg/km)	400	685–708	68-84	88–89	F
FC (dm^3/100 km)	5	4.8–4.9	4.95	5.9	F
NH_3 (mg/km)	30	0.5	41.0	47.5	F
N_2O (mg/km)	15	10.8	5.2	4.0	P
CH_2O (mg/km)	10	16.9	0.8	1.3	F

The WLTC results with the retrofit activated or not are summarized in Table 5, plotted also in Fig. 1. There is no significant reduction of the emissions. Any reduction is within the experimental uncertainty and the repeatability of the vehicle.

Table 5. Emissions measured by JRC for the cycles prescribed in the prize rules. F = Fail, P = Pass based on the Engine limits because the prototype vehicle was delivered for the Engine prize (Table 1). Lim. = Limits

Criteria	Lim.	WLTC	WLTC	Diff	
	Lab	23°C	23°C	–	
Retrofit		Not-active	Active	–	
CO_2 (g/km)	–	131.5	134.4	+2%	–
NO_x (mg/km)	180	455	432	–5%	F
$PN_{10}\times10^{11}$ (#/km)	6.0	1.76	1.58	–10%	P
THC (mg/km)	–	0.5	0.5	–	P
CO (mg/km)	500	122	84	–31%	F
FC (dm^3/100 km)	+10%	–	–	+2.2%	P

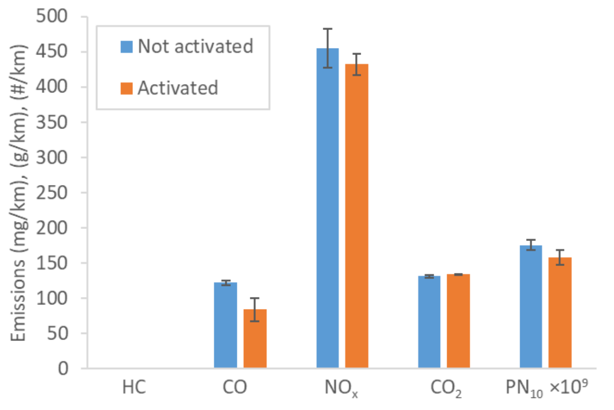

Fig. 1. Comparison of cold WLTC at 23°C emissions with the retrofitted activated or not. Error bars show max-min of 2–3 repetitions

4.4. RDE results

The on-road tests were conducted with a PEMS (Horiba OBS-ONE) for two trips and a portable FTIR (Certam-AddAir) for another two trips.

ESP and LAB were RDE compliant tests, while SAC was an altitude test. The vehicle did not pass the NO_x limit in any of the driven routes, and also the fuel consumption was higher than the threshold (Table 6). Similar conclusions would be drawn comparing with the Retrofit prize limits.

It should be added that the Euro 6d-temp version of the specific model fulfilled the Euro 6 on-road NO_x limits (emissions around 80 mg/km) [5].

Table 6. On-road emissions. F = Fail, P = Pass based on the Engine limits because the prototype vehicle was delivered for the Engine prize (Table 1). Lim. = Limits

Criteria	Lim.	ESP	SAC	LAB	SAC	
	RDE	PEMS	PEMS	FTIR	FTIR	
$T_{amb,mean}$ (°C)		14	19	14	12	
$Altitude_{max}$ (m)		300	1080	400	1080	
CO_2 (g/km)	–	148	138	132	122	
NO_x (mg/km)	72	372	357	378	178	F
$PN_{23}\times10^{11}$ (#/km)	7.2	2.5	1.7	1.8	3.9	P
CO (mg/km)	480	720	153	93	119	F
FC (dm^3/100 km)	6.0	5.4	5.1	4.9	4.6	P
NH_3 (mg/km)	36	–	–	15	1.0	P
N_2O (mg/km)	18	–	–	1.9	3.7	P
CH_2O (mg/km)	12	–	–	4.1	2.2	P

5. Results of Retrofit #3

5.1. General

Retrofit name: E.R.De.I.D.E. (Emissions Reduction Device In Diesel Engines).

Main applicant: Ve.S.T.A. s.r.l., via Burago, Ornago, Italy.

Testing laboratory: M.T.M. srl and BRC srl, part of the Westport Group Fuel Systems, with laboratories in Cherasco (Cuneo), Strada Provinciale 58, no. 11, Italy.

Web-site: www.vesta-corporate.com

Innovation according to the applicant: ERDeIDE (Emission Reduction in Diesel Engines) is a technological evolution of an earlier prototype engineered by Ve.S.T.A. srl, called Droptek. ERDeIDE is a static device to be installed downstream of the low pressure pump and before the high pressure injection systems, and it is powered by the vehicle battery at 12 V: ERDeIDE is inserted into the fuel supply circuit and applies a combination of physical effects (predetermined temperature and magnetic field) to the fuel. The applicant proposes that the combination equilibrium of the parameters, applied for at least some time, influence, with a medium-lasting effect, the molecular magnetic moment of hydrocarbons, their conformations, and angular and torsional tensions. The method is considered to affect especially the aromatic compounds. The weight is approximately 2.5 kg.

Donor vehicle: Peugeot 308 1.6 HDI Euro 5b Diesel, with engine capacity of 1560 cm^3 and a power output of 68 kW, 6 gears manual transmission, exhaust gas recirculation, Diesel oxidation catalyst and particulate filter. Model year Feb 2015, with mileage 58300 km (at JRC).

5.2. Test protocol

The car was driven to JRC with full tank with market fuel. All tests were conducted with the fuel in the tank. The dyno settings of the testing laboratory (MTM, BRC) were: m = 1360 kg, f_0 = 7.1 N, f_2 = 0.0481 $N/(km/h)^2$. The dyno settings of JRC were: m = 1250 kg, f_0 = 6.8 N, f_2 = 0.0460 $N/(km/h)^2$. The sequence of the tests conducted is presented below.

- 18/12/2017: NEDC cold 7°C, WLTC hot 7°C (with retrofit)
- 19/12/2017: NEDC cold 7°C, WLTC hot 7°C (without retrofit)
- 21/12/2017: NEDC cold 7°C (with retrofit)

The 12V battery was fully charged at the beginning of the day (cold NEDC). The first cold NEDC with the retrofit on the 18^{th} had high emissions, probably because it was the first test after many weeks parked outside, so it was repeated on the 21^{st}. The first test of the 18^{th} was not considered in the analysis below. Due to the high NO_x emissions it was decided not to test the CADC.

5.3. Results

The JRC and the ERDeIDE reported results are not directly comparable because different dyno coefficients were applied. Nonetheless, the trends for the effectiveness of the retrofit should be comparable.

The JRC results showed a slight increase of the CO_2 with the retrofit (2 g/km), while the applicant's results showed a slight decrease (Fig. 2). The differences of the CO_2 emissions are < 2 g/km for both complete test cycles (NEDC and WLTC) (Fig. 2) and their urban parts (UDC and Low part of WLTC respectively) (figure not shown). The small differences fall within the experimental uncertainty and the repeatability of the measurements and differences in the gear shift strategy at the two labs. Thus the

CO_2 penalty or benefit cannot be considered to be substantial with the present data.

The JRC results showed a slight increase of the NO_x emissions, while the applicant's results showed a slight decrease when the retrofit was activated (Fig. 3). However, the changes were within experimental uncertainties in both cases. Similar conclusions can be drawn for both the complete cycles and their urban parts. The emission levels were much higher than 180 mg/km (threshold value) for both the JRC and delivered results for both the complete cycles and their urban parts.

The PN_{10} emissions slightly decreased with the activation of the retrofit (Fig. 4), however the decrease is within the experimental uncertainty. For example, the PN emissions of the first NEDC conducted at JRC without preconditioning with the retrofit were higher than without the retrofit (data not shown).

The N_2O emissions were low and practically unaffected by the retrofit (Fig. 5). The NH_3 emissions were very low and at the detection limit of the instrument.

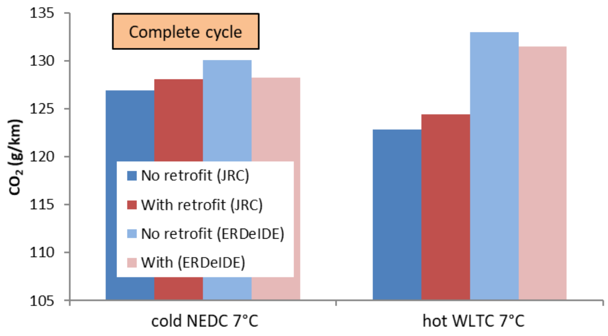

Fig. 2. CO_2 results for the complete cycles

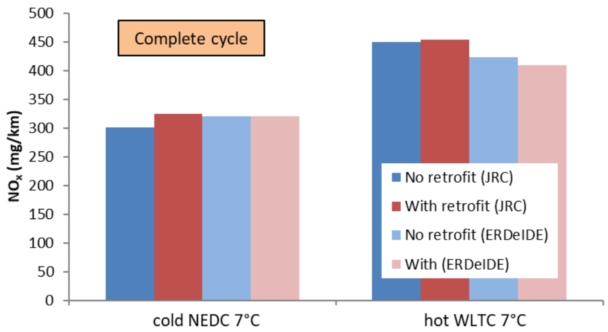

Fig. 3. NO_x results for the complete cycles

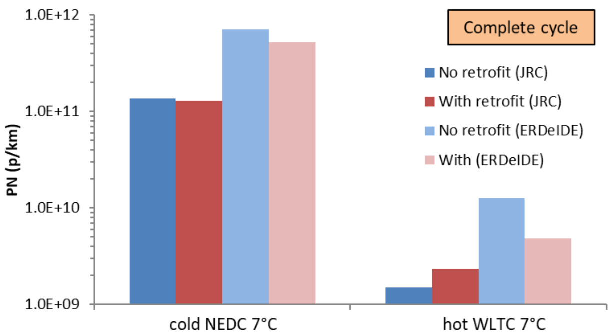

Fig. 4. PN results for the complete cycles

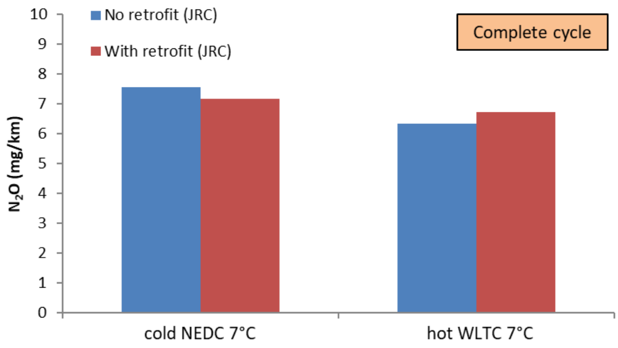

Fig. 5. N_2O results for the complete cycles

The reported (and verified by JRC) NO_x emissions of the car (Table 7) were above the thresholds (see Table 1), thus the retrofit does not fulfil the requirements of the rules of contest. Comparison of with and without retrofit did not show any significant improvement for the pollutants of interest for this competition. The retrofit was not further evaluated.

Table 7. Emissions as reported by ERDeIDE for the cycles prescribed in the prize rules. F = Fail, P = Pass. Lim. = Limits

Criteria	Lim.	NEDC	WLTC	CADC	
	Lab	7°C	Hot 7°C	25°C	
CO_2 (g/km)	–	128.3	131.5	151.4	–
NO_x (mg/km)	180	320	410	819	F
PM (mg/km)	4.5	0.51	0.14	0.22	P
$PN_{10}\times10^{11}$ (#/km)	6.0	5.2	0.05	1.5	P
CO (mg/km)	500	746	50	58	–
FC (dm^3/100 km)	+10%	–1.4%	–1.1%	+0.5%	P

6. Results of Retrofit #4

6.1. General

Retrofit name: Dr. Pley

Main applicant: Dr. Pley GmbH, Regnitzstraße 18b, D-96052, Bamberg, Germany

Testing laboratory: FAKT GmbH, Grüntenstraße 3–5 D-87751 Heimertingen, Germany

Web-site: www.dr-pley.com

Innovation according to the applicant: It is a Selective Catalytic Reduction (SCR) system with an electronic control unit that controls all actors and sensors that are required for the SCR system. Different parameters can be used (e.g. NO_x sensor signals, engine parameters, etc.) for the Diesel Exhaust Fluid (DEF) supply to the SCR system. A new SCR with a much lower light-off-temperature than what available in the market has been developed. Using these new SCR catalysts in combination with a DEF hydrolysis reactor, the ammonia injection temperature can be lowered to 130°C. Based on the measured NO_x, the device adjusts the operational parameters. The weight is approximately 15 kg (plus DEF).

Donor vehicle: Audi A3 Sportback 2.0 TDI with 110 kW power and 1968 cm^3 engine displacement. Automatic transmission, exhaust gas recirculation, Diesel oxidation catalyst and particulate filter. Model year Sept 2013 (Euro 5b), with mileage 80000 km (at JRC).

6.2. Test protocol

The dyno settings of both the testing laboratory (FAKT) and JRC were: m = 1470 kg, f_0 = 7.4 N, f_2 = 0.0502 $N/(km/h)^2$. Many tests were conducted, but due to the issues described below only some indicative results will be presented.

Due to issues at FAKT or different vehicle conditioning, the only tests close to the rules (and comparable with JRC's are those with the retrofit). The first JRC results were not in good agreement with the applicant's results. After an on-site inspection of the system (29/11/2017) the contestant found that a marten had cut the purge air pipe as well as parts of the insulation of the NH_3 transfer pipe. Due to lack of purge air, a sealing was damaged by overheating. This led to a leakage of NH_3 out of the hydrolysis reactor. However, even with damaged insulation of the transfer pipe, there was not deposit inside the transfer pipe. The contestant replaced the broken pipe and quick-fixed the broken sealing with high temperature silicone (repair 1). A few more tests were repeated.

This intervention did not improve the results, so it was decided to permit the contestant to take the car (8/1/2018) and repair it on his own premises (repair 2). The investigation showed that the leakage which was fixed on-site with silicone did not work. There was a lack of purge air resulting in a blockage of the ammonia transfer pipe and a release of DEF at the rupture of the purge air pipe. Analysis of stored device data showed that the operation of the SCR system was prevented by the retrofit control unit due to the detected failure of the purge air supply. The DEF hydrolysis reactor was replaced at Dr. Pley's premises in the end.

The tests were repeated at the beginning of January. The results after this repair did not show any improvement. According to the contestant it happened probably due to a bug in the software. The software was fixed on-site (repair 3). All SCR system components were checked by the contestant and there was no problem or leakage. The DEF consumption was in the expected range as well. Only one "official" test was conducted (NEDC cold at 7°C) and there was no difference from the previous so the rest tests were not conducted. An overview of the NO_x results in the laboratory and on the road are summarized in Fig. 6 and Fig. 7 respectively.

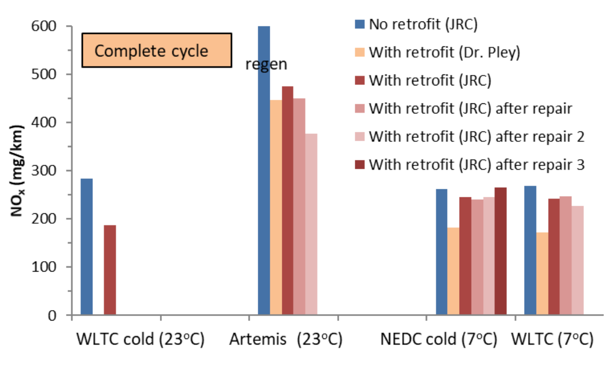

Fig. 6. NO_x results for the complete cycles. "Regen" means that regeneration took place

Table 8 summarizes the results with the retrofit installed, as reported by the applicant. Table 9 gives the same tests as measured at JRC. Although the differences were not big, the results were below and above the NO_x threshold of 180 mg/km at the two laboratories for many cycles. Based on the JRC results and the not so clear reduction of the emissions, the retrofit was not further evaluated.

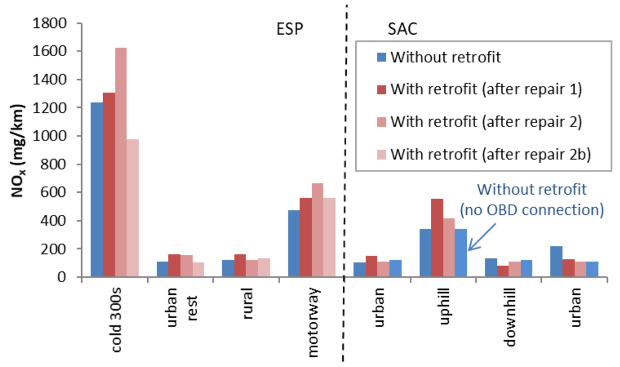

Fig. 7. NO_x results for the on-road tests

Table 8. Summary of retrofit results (as reported by Dr. Pley). F = Fail, P = Pass based on the Retrofit limits because the prototype vehicle was delivered for the Retrofit prize (Table 1). For the lab tests the average of the three cycles was considered as pass/fail criterion. Lim. = Limits

Criteria	Lim.	NEDC	WLTC	CADC	RDE	
	Lab	7°C	Hot 7°C	25°C	–	
NO_x (mg/km)	180	183	172	447	88	F
$PN_{23}\times10^{11}$ (#/km)	6.0	0.3	0.5	0.0	0.2	P
CO (mg/km)	500	113	122	10	10	P
FC (dm^3/100 km)	10%	+22%	–1%	+3%	–	P

Table 9. Summary of retrofit results (as measured at JRC). F = Fail, P = Pass based on the Retrofit limits because the prototype vehicle was delivered for the Retrofit prize (Table 1). For the lab tests the average of the three cycles was considered as pass/fail criterion. Lim. = Limits

Criteria	Lim.	NEDC	WLTC	CADC	RDE	
	Lab	7°C	Hot 7°C	25°C	–	
NO_x (mg/km)	180	246	243	476	179	F
$PN_{10}\times10^{11}$ (#/km)	6	0.4	0.5	0.1	–	P
CO (mg/km)	500	179	25	10	16	P
FC (dm^3/100 km)	10%	+0.1%	+6.7%	–	+9%	P

6. Conclusions

The Horizon prize for clean future vehicles called for innovations (engines, aftertreatment, and retrofit devices) that would result in very low tailpipe emissions and low fuel consumption. Popular devices that claim benefits on fuel economy and exhaust emissions include devices that turn water into fuel, fuel line devices that heat, magnetize, ionize irradiate or add metals, and mixture enhancers that improve the air-fuel mix prior to combustion. So far there is no strong scientific evidence on their efficiency. On the other hand, NO_x abatement devices have a strong potential [6, 7].

This paper summarized the JRC results of the submitted vehicles for the prizes. The first innovation was an aftertreatment device based on exhaust gas condensation. The concept has been used for e.g. army applications to recover the water from the exhaust gas [8]. In our tests the emissions remained very high and the testing stopped due to contamination issues of the laboratory facilities. The specific aftertreatment device, in addition to backpressure issues, did not use appropriate material to withstand high exhaust gas temperatures. The second innovation, a fuel purification system, did not result in meeting the threshold emission levels, especially for NO_x. The reactions of the fuel with the catalyst of the device are not clear, but if any, there was no obvious effect. The third innovation, a fuel magnetic device, also did not achieve the NO_x threshold emission levels. The concept of using magnetic field to reduce emissions has been reported in the literature [9, 10]. If this is happening and how the emissions are affected is not clear, but at our testing the results were not promising. A system that applied voltage at a copper coil, [11], similar to the fuel magnetic device of our study, concluded that it was possible to notice a particulate reduction. The explanation was that the copper leached in the fuel catalytically aided the combustion, but the effect was noticeable only when the fuel was in the tank for some time. The testing at JRC showed that the two fuel systems had very small reduction potential of the emissions to be meaningful for circulation of vehicles in cities. The fourth innovation was a Selective Catalytic Reduction (SCR) for NO_x system. The measurements at JRC did not show the expected NO_x reduction potential [3, 12], probably due to some issues of the device at the prototype vehicle. The system, along with others, is tested under the "Testing Retrofit Technologies" project of DG-GROW of the European Commission [13].

Concluding the results of this study showed a limited potential of the fuel line retrofit devices. Urea (ammonia) based systems, which seem the only promising technologies [14] need case by case assessment [15]. The durability of such systems should also be assessed [16].

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Nomenclature

CADC	common Artemis driving cycle
CF	conformity factor
CLD	chemiluminescence detector
CVS	constant volume sampler
DEF	diesel exhaust fluid
ESP	RDE compliant route
EUDC	extra urban driving cycle
FC	fuel consumption
FID	flame ionization detector
FTIR	Fourier transform infrared
JRC	Joint Research Centre
LAB	RDE compliant route
MCT	mercury cadmium telluride
NDIR	non-dispersive infrared
NEDC	new European driving cycle
NTE	not-to-exceed
PEMS	portable emissions measurement system
PM	particulate matter mass
PN	particle number
RDE	real driving emissions
SAC	RDE non-compliant route
SCR	selective catalytic reduction for NO_x
UDC	urban driving cycle
VELA	vehicle emission laboratory
WLTC	worldwide harmonized light-duty vehicles test cycle

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