Development of a 12 Volts Electrical Heated Catalyst as a clean and affordable solution for Brazilian market.

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ABSTRACT

This paper evaluates the efficiency of a 12 Volts Electrical Heated Catalyst (EHC) as a local clean and affordable solution to match Brazilian emission challenges, as an alternative to existing standard technological solution of increasing after treatment loading.

Electrical Heated catalyst is already an existing solution for European market with 48 Volts, ensuring up to 6kW heating power, which is the minimum power needed to match the European target. Taking advantage of different climate condition from Europe, the Brazilian market is the first where a 2kW heating power through 12 Volts Electrical Heated Catalyst should be applied for 3 main reasons:

- Main challenge of Brazilian Emission target is related to NMOG control during cold phase especially using pure Ethanol could be directly improved by a faster catalyst light-off.
- Brazilian climate condition is -5ºC as lowest boundary temperature condition whereas European lowest temperature boundary is -30°C.
- Brazilian market is still mainly using standard powertrains technologies avoiding 48 Volts electrification, thus most of the local vehicle only have a 12 Volts battery available on-board, whereas most of European vehicle already have 48 Volts available.

AVL South America has developed a R&D project together with ITA & ITEMM and RENAULT through a Brazilian government funding program called FINEP to assess the effectiveness of a 12 Volts Electrical Heated Catalyst in order to improve emission level of a 1.0-liter PFI Flex-Fuel low-cost engine on pure ethanol usage, which is the most challenging fuel for meeting future phases of PROCONVE L8, Brazilian Emissions Standard for Light Vehicles Phase8.

Emissions tests confirmed the potential up to 46% reduction NMOG during cold phase, resulting in 30% reduction for complete FTP and RDE cycles, thus confirmed the reduction from baseline BIN80 to BIN50 applying 12 Volts EHC with same catalyst and engine calibration.

Such emission reduction would request to increase 50 gr/ft3 catalyst loading to achieve same result (estimated additional cost of 100Euros).

Further investigations are ongoing to improve efficiency of the system up to 67% NMOG emission reduction during cold phase as expected by theorical studies. [1]

Electrical balance of the system is a key point in this study to turn the system compatible with the existing battery in the vehicle as lowest additional cost depends on the reference. To a standard PL8 solution (increasing after-treatment cost), EHC is challenging it as a more cost-effective solution.

INTRODUCTION

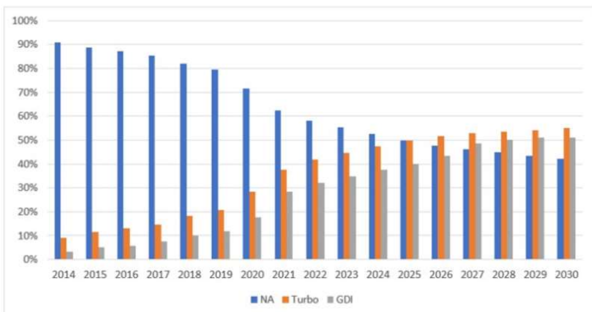
The definition of the vehicle after-treatment system is no longer solely guided by increasingly stringent emissions legislations and on-board diagnostic (OBD) system requirements. The right cost of ownership over the product life is a major competitive advantage, which can only be achieved through optimized integration of the after-treatment system with the powertrain definition in early stages of development. In a cost sensitive market like Brazil, such integration is even more decisive, especially for the automaker's A- and B-segment vehicles, which are the top sellers and generally equipped with a PFI (Port Fuel Injection, also known as Indirect Injection) flex fuel 1.0L engine, even though in recent years the market has observed the introduction of TGDI (Turbocharged Gasoline Direct Injection) flex fuel 1.0L engine in these segment vehicles. The forecast provided by [2] is that TGDI engines will increase their share in the Brazilian market, overcoming PFI engines in 2028, as shown in Figure 1. This high market share for TGDI engines will be mainly leveraged by A- and B- segment vehicles, likely to be equipped with a TGDI flex fuel 1.0L engine. Such low engine displacement TGDI technology will continuously increase its share due to ROTA

2030, Brazilian automotive program based on fuel efficiency, safety and R&D (Research and Development). In Brazil most of the engines are flex-fuel, which is a technology that allows the engine to run on either gasoline or ethanol, or in any blend in-between.

LV shares by segment

Segment	2001	2005	2010	2015	2016	2017	2018	2019
Mini	1.1	7.0	7.3	10.7	9.6	9.8	11.1	11.9
Small	66.0	63.9	56.0	45.2	44.2	41.0	41.3	39.8
Lower Med.	13.7	11.8	14.6	15.4	14.7	15.3	12.1	11.4
Medium	3.7	0.8	0.8	1.2	0.9	0.9	0.8	0.7
SUV	3.6	5.3	7.6	14.0	16.2	19.1	20.6	22.2
Pickup	7.1	7.1	9.3	10.5	11.9	11.5	11.9	12.0
Other	4.8	4.1	4.5	2.9	2.5	2.4	2.1	2.0
Total LVs	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

Table 1. Light vehicles (LV) shares by segment in Brazil [1]. Mini (A), Small (B) segments.



Source: IHS Markit VPaC: Vehicle Performance and Compliance – September 2019

Figure 1. Market share increase forecast for TGDI engines in the Brazilian market [3].

The future phase of pollutant emission control for light vehicles in Brazil, namely PROCONVE L8 or shortly PL8, will be implemented, in 2025 as a first step with more stringent targets for upcoming steps in 2027 and upfront.

These upcoming phases will require emission reduction technologies compatible with low-cost Brazilian market context. This paper evaluates the efficiency of a 12 Volts Electrical Heated Catalyst as a local clean and affordable solution to match Brazilian emission challenges, as an alternative to existing standard technological solution of increasing after treatment loading.

Electrical Heated catalyst is already an existing solution for European market with 48 Volts, ensuring up to 6kW heating power, which is the minimum power needed to match the European target. Taking advantage of different climate condition from Europe, the Brazilian market is the first where a 2kW heating power through 12 Volts Electrical Heated Catalyst should be applied for 3 main reasons:

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AVL South America has developed a R&D project together with ITA & ITEMM and RENAULT through a Brazilian government funding program called FINEP to measure the efficiency of a 12 Volts Electrical Heated Catalyst to improve emission level of a 1.0 liter PFI low cost engine called using pure Ethanol.

BRAZILIAN EMISSION LEGISLATION

Historically, the pollutant emission control for light vehicles in Brazil has always been based on the legislation applied in the USA. It presents several adaptations, both in terms of implementation time, procedures and limits, mainly due to specificities, such as higher ethanol content in gasoline [4].

The main pollutant control challenge for PL8 is related to NMOG (Non-Methane Organic Gases), which besides NMHC also includes the organic gases ethanol and aldehydes. Specific NMOG calculation for PL7 and PL8 considers photochemical reactivity adjustment coefficients to account for different ozone formation potential between gasoline and ethanol fuels.

CO (Carbon Monoxide) and HCHO (aldehydes) are further reduced for PL8, and PM (Particulate Matter) is now regulated for GDI (Gasoline Direct Injection) engines only.

Besides more stringent emission limits presented above, PL8 also introduces the concept of a single emission limit at the corporate level, regardless of the vehicle category. This allows the automaker to draw up strategies according to its portfolio to meet the standard. It also establishes the generation and use of emission credits.

RDE (Real Driving Emission), currently in monitoring phase, will be part of PL8 legislation with different CF (Conformity Factor) for each step:

- CF=2 for PL8 step1 in 2025.
- CF=1.5 for PL8 step2 in 2027.

For RDE testing, only CO, NOx, THC (Total Hydrocarbons) and CO_2 (Carbon Dioxide) will be measured.

Table 2 summarizes the exhaust and evaporative emissions limits for passenger vehicles for Brazilian (PL6, PL7, PL8), American (Tier 3) and European (Euro 6) legislations. It is important to note that even with similar levels of NMOG + NOx between PL7 and US Tier 3 Bin125 (as for PL8, Bin is related to emission level; in this case 125 refers to NMOG + NOx = 125 mg / mi), these standards are not directly comparable in relation to technological solutions due to different fuels. While the Brazilian standard uses E22, E61 and E100 as reference fuels, the American standard adopts E10. The number refers to the percentage of ethanol in volume that is mixed with gasoline. NMOG + NOx is the most critical limit to be met for PL7 and PL8. This is mainly due to ethanol, which has the hydroxyl functional group (-OH), in addition to the low vapor pressure that makes it difficult to burn in cold conditions.

					Exhaust					Evaporative			
	Legislation	Level	Date	Cycle	NMOG+NOx (mg/km)*	PM (mg/km)	CO (mg/km)	HCHO (mg/km)	RDE	D+HS** (number of tests / h per test)	D+HS** (g/test)	D+HS** (g/total)	Refueling Onboard (mg/l)
Brazil	PL6	-	2014-2022	FTP-75	130	-	1300	20	No	1/2	1,5	1,5	-
	PL7	-	2022-2025	FTP-75	80	6	1000	15	Monitor	2/24	0,5	1	50
	PL8	80	2025-	FTP-75	80	6	1000	15	Yes	2/24	0,5	1	50
	PL8	70	2025-	FTP-75	70	4	600	10	Yes	2/24	0,5	1	50
	PL8	60	2025-	FTP-75	60	4	600	10	Yes	2/24	0,5	1	50
	PL8	50	2025-	FTP-75	50	4	600	10	Yes	2/24	0,5	1	50
	PL8	40	2025-	FTP-75	40	4	500	10	Yes	2/24	0,5	1	50
	PL8	30	2025-	FTP-75	30	3	500	8	Yes	2/24	0,5	1	50
	PL8	20	2025-	FTP-75	20	2	400	8	Yes	2/24	0,5	1	50
	PL8	0	2025-	FTP-75	0	0	0	0	Yes	2/24	0,5	1	50
US	Tier 3	Bin 160	2017-2025	FTP-75	99,4	1,9	2609,8	2,5	No	3/24	0,3	0,9	53
	Tier 3	Bin 125	2017-2025	FTP-75	77,7	1,9	1304,9	2,5	No	3/24	0,3	0,9	53
	Tier 3	Bin 70	2017-2025	FTP-75	43,5	1,9	1056,3	2,5	No	3/24	0,3	0,9	53
	Tier 3	Bin 50	2017-2025	FTP-75	31,1	1,9	1056,3	2,5	No	3/24	0,3	0,9	53
	Tier 3	Bin 30	2017-2025	FTP-75	18,6	1,9	621,4	2,5	No	3/24	0,3	0,9	53
	Tier 3	Bin 20	2017-2025	FTP-75	12,4	1,9	621,4	2,5	No	3/24	0,3	0,9	53
	Tier 3	Bin 0	2017-2025	FTP-75	0	0	0	0	No	3/24	0,3	0,9	53
EU	Euro 6	-	2014-2025	WLTC	138	4,5	1000	-	Yes	1/48	2	2	-

* For PL6 and Euro 6 NMOG + NOx is estimated from NMHC and NOx individual limits
Obs: NMHC = NMOG for comparison purpose
** Diurnal + Hot Soak (D+HS) test has specificities between Brazil, US and EU standards.
Obs: limits are presented in this format for comparison purpose only.

Table 2. Light vehicle exhaust and evaporative emissions limits for Brazilian, US and EU legislations.

Figure 2 shows the evolution of corporate limits over time for the US Tier 3 and PL8, which establishes a gradual reduction every 2 years, with values to be reviewed according to global technologies and international experiences in force at the time.

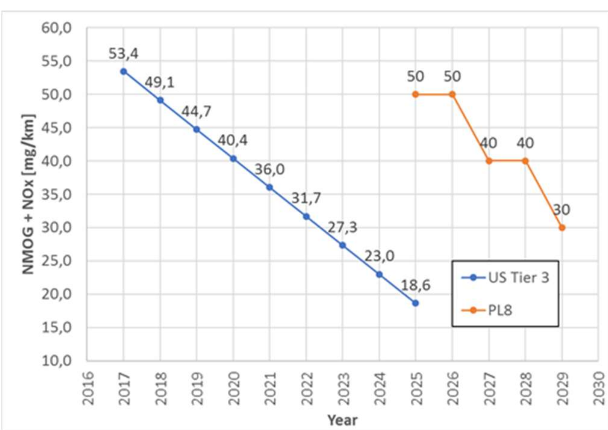

Figure 2. Emissions corporate level, considering NMOG + NOX, for US Tier 3 and PL8.

AFTER TREATMENT TECHNICAL SOLUTIONS

For gasoline engine TWC (Three-Way Catalyst) is the standard after-treatment system for controlling emissions. It receives this name due to its capability of controlling THC, CO and NOx. Main parameters and components are described for better understanding the process of selecting a TWC. The catalyst position in the exhaust is very important for emission control. More stringent THC and CO emissions require CC (Close-Coupled) catalyst, which is integrated to the exhaust manifold to allow it to faster achieve operating temperature for maximum conversion. UF (Under-Floor) catalysts are used as buffer for further emission reduction. TWC itself is composed of substrate, a cylinder with honeycomb structure that is defined by its material, volume, CSPI (Cells Per Square Inch), thickness between cells. Such substrate is impregnated with PGM (Platinum Group Metals), commonly palladium (Pd) and rhodium (Rh), which will be responsible for the catalytic conversions. Then a metallic housing is bounded to the substrate through a mantle that has several functions, as sealing, thermal insulation, fixation and mechanical protection against impact. A heat shield provides extra thermal insulation to keep catalyst at the proper operating temperature.

The fundamental disadvantage of conventional TWC is that it requires exhaust heat produced by combustion by products to achieve operational temperature. Meanwhile it can only partially reduce emission on cold phase, which is generally responsible for more than 80% of total emissions over cycle. As countermeasure some technologies were developed to faster warm-up the catalyst, such as SAI (Secondary Air Injection), which injects air in the exhaust to have post-combustion (extra fuel is needed), and EHC (Electrically Heated Catalyst), which utilizes electrical power for heating.

The three-way catalyst is a component widely used to control exhaust emissions from gasoline engines. It is a catalyst due to its properties, which increases the speed of a chemical reaction, participates in it, but is not consumed as a reagent or product. And it is so called three-way for being able to convert 3 pollutants that are regulated, directly or indirectly, by emissions legislations: HC, CO and NOx.

Catalytic agents are precious metals that are part of the PGM group, composed by ruthenium (Ru), rhodium (Rh), palladium (Pd), osmium (Os), iridium (Ir) and platinum (Pt). Automotive applications, however, mainly use Pt, Pd and Rh due to their remarkable resistance to corrosion and oxidation at high temperatures.

Currently most automotive applications have reduced or eliminated the use of Pt, replacing it by Pd for the oxidation of HC and CO. The reduction of NOx, in turn, is performed by Rh. The global chemical reactions are shown by Equations 1, 2 and 3.

$$HC + O_2 \rightarrow CO_2 + H_2O$$

(1)

$$CO + {}^{1}/_{2}\,O_2 \rightarrow CO_2$$

(2)

$$NO_x + CO \rightarrow CO_2 + {}^{1}/_{2}\,N_2$$

(3)

This means that HC, CO and NOx are controlled through the three-way catalyst, which at its maximum efficiency consumes the above-mentioned pollutants (chemical reaction reagents) to produce CO_2, H_2O (water) and N_2 (nitrogen), as illustrated in Figure 3. The substrate is generally honeycomb shaped and is defined by CPSI and the wall thickness of adjacent cells. PGM is impregnated in each cell to maximize the useful area for catalytic reactions.

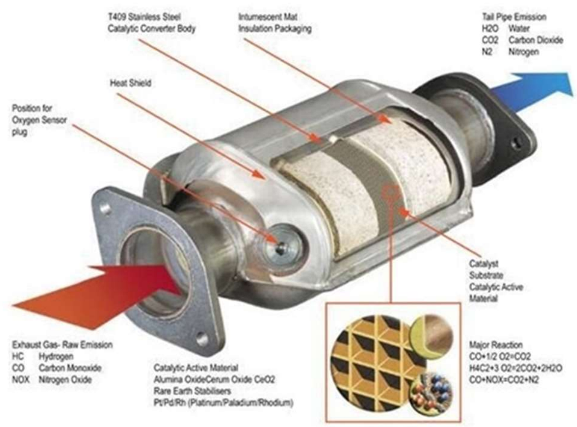

Figure 3. Three-way catalyst working principle and main components.

For the catalytic conversion to be maximized, it is necessary that the catalyst operates at an appropriate temperature and that the air-fuel mixture is controlled in a narrow band around stoichiometric ratio. Figure 4 shows the impact of catalyst aging on the light-off temperature, at which the catalyst presents 50% conversion efficiency, in this case to CO. Catalyst aging can occur due to different phenomena, such as, for example, a mechanical impact that detaches the mantle between substrate and encapsulation or the agglutination of PGM by thermal stress, thus reducing the useful area. Catalyst aging requires longer time and higher temperatures to reach the light-off temperature.

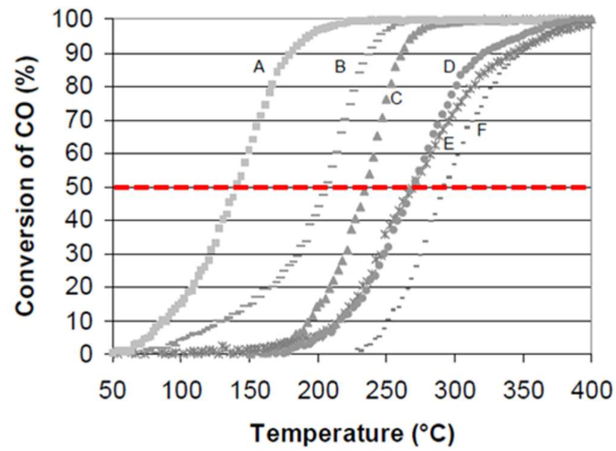

Figure 4. Comparison of the light-off curves of CO after the reductive and oxidative ageings: A) H_2 (Hydrogen)/800°C/3h-aged; B) air/800°C/3h-aged; C) H_2/1000°C/3h-aged; D) H_2/1200°C/3h-aged; E) air/1000°C/3h-aged, and F) air/1200°C/3h-aged; lean reaction conditions; adapted from [5].

Figure 5 shows the conversion efficiency of HC, CO and NOx as function of air-fuel ratio, as well as the operating range for optimum conversion efficiency of the 3 gases. Such range is typically between $\lambda = 1 \pm 2\%$.

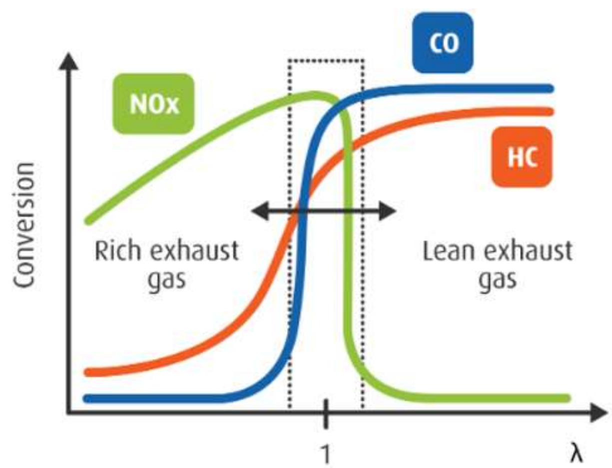

Figure 5. Characteristic curves of HC, CO and NOx conversion as function of λ [6].

12 VOLTS ELECTRICAL HEATED CATALYST

Vehicles powered with Internal Combustion Engine (ICE), as only tractive force or as in a hybrid powertrain, will likely need to have an EHC to meet more stringent emissions. This happens, for example, because catalyst is always below its light-off temperature during a cold-start and engine warm-up. And even after light-off is reached exhaust temperature could drop causing TWC to operate out of its optimum range, e.g., during a long deceleration or when the engine is off due to start-stop system. EHC associated with ECU control functions allows efficient TWC thermal management to have as soon as possible, under different conditions, TWC at its optimum temperature to convert pollutants. The additional costs for EHC can be more than offset. The greater efficiency of systems consisting of a close-coupled TWC with an attached EHC allows the volume and PGM loading to be substantially reduced [7]. Figure 6 shows an example of EHC available in market.

Figure 6. Electrically Heated Catalyst.

Available 12 Volts battery results in a 2kW heating power that should increase the catalyst temperature +200°C during cold phase and reduce -67% HC emission by shortening its light off time.

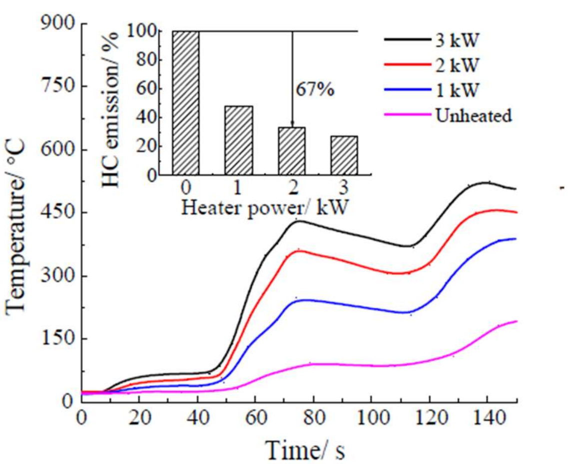

Figure 7. Catalyst temperature vs heating power

Emission tests have been performed with RENAULT SANDERO (PL6 emission level) and KWID (PL7 emission level) vehicle both equipped with a 1.0-liter PFI Flex Fuel engine using a 12V EHC installed at the front face of the catalyst.

EHC control strategy has been optimized at AVL South America to define optimum heating time and power before and after the engine start, considering the EHC temperature limit indicated by fabricant.

Figure 8. EHC installed in the catalyst.

FTP CONDITIONS TESTING

Back-to-back emission tests have confirmed potential reduction up to 46% NMHC between EHC ON and OFF condition during 1st phase of FTP cycle using pure ethanol:

Phase Results	[Bag]	Phase 1
CO2	[g/km]	137,12
CO	[mg/km]	3038,17
NOX	[mg/km]	7,81
THC	[mg/km]	508,59
CH4	[mg/km]	137,81
NMHC	[mg/km]	374,86
NMHC+NOX	[mg/km]	382,67

Table 3. FTP results Sandero EHC OFF (1st phase)

Phase Results	[Bag]	Phase 1
CO2	[g/km]	138,06
CO	[mg/km]	2520,21
NOX	[mg/km]	5,18
THC	[mg/km]	388,55
CH4	[mg/km]	163,08
NMHC	[mg/km]	230,30
NMHC+NOX	[mg/km]	235,48

Table 4. FTP results Sandero EHC ON (1st phase)

Phase Results	[Bag]	Phase 1
CO2	[g/km]	117.29
CO	[mg/km]	563.40
NOX	[mg/km]	11.22
THC	[mg/km]	193.77
NMHC	[mg/km]	134.93
NMHC+NOX	[mg/km]	146.15

Table 5. FTP results Kwid EHC OFF (1st phase)

Phase Results	[Bag]	Phase 1
CO2	[g/km]	120.00
CO	[mg/km]	517.98
NOX	[mg/km]	9.46
THC	[mg/km]	120.14
NMHC	[mg/km]	72.91
NMHC+NOX	[mg/km]	82.37

Table 6. FTP results Kwid EHC ON (1st phase)

Vehicle	Sandero		Kwid	
EHC	OFF	ON	OFF	ON
NMHC (mg/km)	375	230	135	73
NMHC + NOX (mg/km)	382	235	146	82
	-39%		-46%	

Table 7. Emission results comparison EHC ON vs OFF (FTP)

NMHC + NOX emission reduction is directly linked to catalyst light off reduced time due to +200ºC catalyst temperature during cold phase.

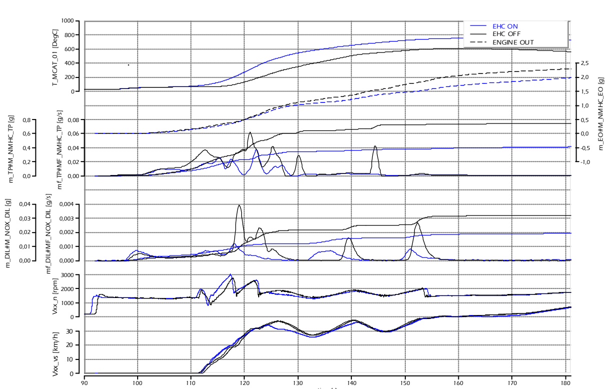

Figure 9. Catalyst temperature & emission during FTP cold phase

By employing the EHC, NMHC + NOX tailpipe emissions are considerably reduced due to the improved light-off.

RDE CONDITIONS TESTING

Back-to-back comparison under Brazilian RDE non-extended condition using E100 (15°C) has confirmed 30% NMHC + NOX emission reduction:

- EHC OFF = 41mg/km
- EHC ON = 29mg/km

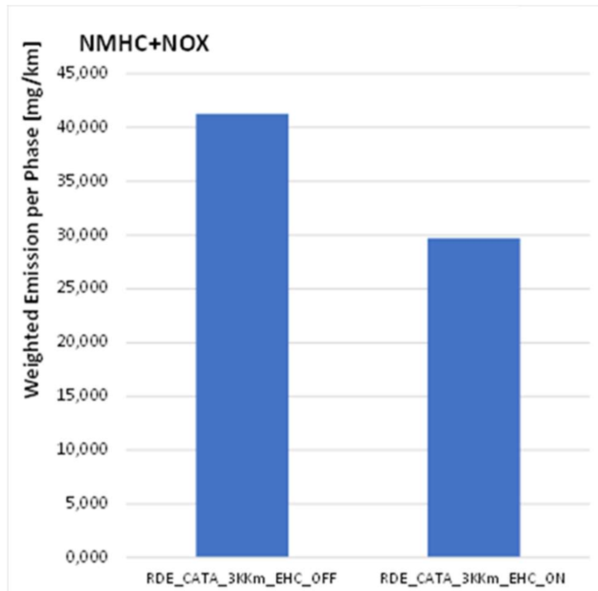

Figure 10. NMHC + NOX results EHC ON vs OFF (Complete Brazilian RDE cycle - non extended)

ELECTRICAL BALANCE AND BATTERY DURABILITY IMPACT

EHC ON increases electrical consumption +3% of battery state of charge compared to EHC OFF baseline configuration during FTP tests using E100, which is compensated by alternator charging in almost 8 minutes:

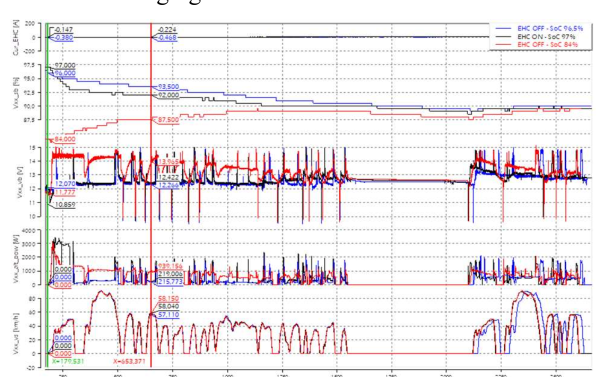

Figure 11. Battery state of charge comparison during FTP

EHC 12V system is increasing less than 8 minutes the time for the battery to recover the electrical energy invested to reduce light off catalyst time.

Fuel consumption impact would need more statistics to be evaluated, as the estimated gap is below measurement dispersion (+0.5%).

Based on real electrical consumption demand of the system, battery durability impact has been compared EHC OFF vs. OFF using 10 batteries of each group in battery durability test bench, simulating 1000 driving cycles:

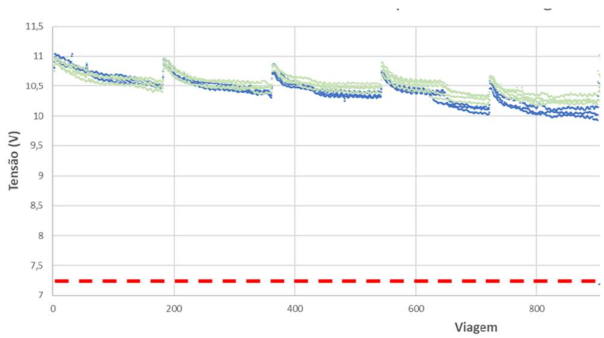

Figure 12. Battery tension after each durability cycle EHC OFF (green) vs EHC ON (blue).

EHC ON configuration should impact 14% the battery durability compared to baseline without EHC (or EHC OFF).

A Battery Management System (BMS) smart strategy should reduce below 7% this gap by keeping the battery around 90% State of Charge regulation, while the durability comparison has been made considering a worst-case situation where no regulation is made (Battery is charging from lower state of charge value thus impact durability).

SUMMARY, CONCLUSION AND FUTURE PERSPECTIVE

Emissions tests confirmed 46% reduction NMOG (NMHC+NOX) during cold phase of FTP75 by using a 12 Volts EHC generating 2kW heating reducing light off time catalyst, resulting in 31% reduction for complete FTP cycle.

Considering a baseline result = 80mg/km (PL8 BIN80 level), the application of 12V EHC should result in PL8 BIN50 with same catalyst and engine calibration, as the EHC is acting as an after-treatment device.

Back-to-back comparison under Brazilian RDE condition (15°C) has confirmed 30% NMOG (NMHC+NOX) emission reduction, thus confirmed the reduction from baseline BIN80 to BIN50 applying EHC with same catalyst and engine calibration.

Such emission reduction would request to increase 50 gr/ft3 catalyst loading to achieve same result (estimated additional cost of 100Euros).

Same 12V EHC system is being tested for TGDI engine to measure its efficiency without influence of fuel heating system.

Further investigations are ongoing to improve efficiency of the system up to 67% NMOG emission reduction during cold phase as expected by theorical studies, that should lead up to 50% NMOG emission reduction as global FTP result thus should achieve PL8 BIN 40 from a PL8 BIN80 baseline.

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ACKNOWLEDGMENTS

The author would like to acknowledge the contributions from the powertrain engineering team/AVL South America and key people of the industry to this paper. Helpful and insightful discussions on the potential technological packages and the cost analysis methodology were invaluable for the outcome of this work.

DEFINITIONS/ABBREVIATIONS

A- Segment (Vehicle): Also known as city car or mini compact; smallest category of vehicles.

AT: Automatic Transmission

B- Segment (Vehicle): Also known supermini or subcompact; next larger category of vehicle when compared to A- segment vehicle.

BMS: Battery Management System

BRL: Brazilian currency, real

CC: Close-Coupled

CF: Conformity Factor for RDE

CO: Carbon Monoxide

CO_2: Carbon Dioxide

CV: Catalyst Volume

ECU: Engine Control Unit

EGR: Exhaust Gas Recirculation

EHC: Electrically Heated Catalyst

EPA: Environmental Protection Agency

EU: European Union

Exx: gasoline with xx percent of ethanol in volume

Flex Fuel: technology that allows the engine to run on either gasoline or ethanol, or in any blend in-between

FTP-75: Federal Test Procedure Number 75

GDI: Gasoline Direct Injection

H_2: Hydrogen

H_2O: Water

HC: Hydrocarbons

HCHO: Aldehydes

HEGO: Heated Exhaust Gas Oxygen sensor

ICE: Internal Combustion Engine

Ir: Iridium

LV: Light Vehicle

MT: Manual Transmission

N_2: Nitrogen

NMHC: Non-Methane Hydrocarbons

NMOG: Non-Methane Organic Gases

NOx: Nitrogen Oxides

OSC: Oxygen Storage Capacity

OBD: On-Board Diagnostic

OBD-Br2+: On-Board Diagnostic Brazil Phase 2+

OBD-Br3: On-Board Diagnostic Brazil Phase 3

OH: Hydroxyl Functional Group

ORVR: Onboard Refueling Vapor Recovery

Os: Osmium

Pd: Palladium

PFI: Port Fuel Injection

PGM: Platinum Group Metals

PL8 Level 50: Level is related to emission level; in this case 50 refers to NMOG + NOx = 50 mg / km

PM: Particulate Matter

PROCONVE: Motor Vehicles Air Pollution Control Program in Brazil

PROCONVE L6, PL6: Brazilian Emissions Standard for Light Vehicles Phase 6

PROCONVE L7, PL7: Brazilian Emissions Standard for Light Vehicles Phase 7

PROCONVE L8, PL8: Brazilian Emissions Standard for Light Vehicles Phase 8

Pt: Platinum

RDE: Real Driving Emission

R&D: Research and Development

Rh: Rhodium

RIA: Regulatory Impact Analysis

ROTA 2030: Brazilian automotive program based on fuel efficiency, safety and Research and Development

Ru: Ruthenium

SAI: Secondary Air Injection

SHED: Sealed Housing for Evaporative Determination

SVR: Swept Volume Ratio

TGDI: Turbocharged Gasoline Direct Injection

THC: Total Hydrocarbons

TRL: Technological Readiness Level

TSP: Thermal Shock Protection

TWC: Three-Way Catalyst

UEGO: Universal Exhaust Gas Oxygen sensor

UF: Under-Floor

USA: United States of America

USD: US Dollars

US Tier 3: United States National Vehicle Emissions and Fuel Standards Phase 3

US Tier 3 Bin125: Bin is related to emission level; in this case 125 refers to NMOG + NOx = 125 mg / mi

Vd: Engine Displacement

VVT: Variable Valve Timing