

Performance Assessment of a 12-Volt Electrical Heated Catalyst as a Clean Solution for the Brazilian Market.

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ABSTRACT

This paper evaluates the efficiency and relevance of a 12-Volt Electrical Heated Catalyst (EHC) in a 1.0L turbocharged GDI engine for serial production, as a local and clean solution to address Brazilian emission challenges. It serves as an alternative to existing standard technological solutions aimed at meeting PL8 Tab 2B emissions requirements.

The Electrical Heated Catalyst is already an established solution in the European market, operating at 48 Volts and providing up to 6kW of heating power, which is the minimum required to meet European emission targets. However, due to differences in climate conditions compared to Europe, the Brazilian market presents an opportunity to implement a 12-Volt EHC with lower heating power as a more suitable alternative.

This approach is justified by three key factors. First, the primary challenge of Brazilian emission targets lies in NMOG control during the cold phase, particularly when using pure ethanol, which can be significantly improved by a faster catalyst light-off. Second, Brazil's lowest boundary temperature is -5°C , considerably higher than Europe's -30°C , reducing the heating demand. Finally, the Brazilian market predominantly relies on standard powertrain technologies without 48-Volt electrification, meaning most local vehicles are equipped only with a 12-Volt battery, whereas many European vehicles already integrate 48-Volt systems.

The proposed system includes a 12-Volt heater installed upstream of a close-coupled catalytic converter connected to a 12-Volt battery.

The test matrix includes FTP75 and RDE tests to assess emissions under different power levels, operating times, fuel types (gasoline and ethanol), and fresh versus aged catalytic converters.

Emission tests confirmed a potential reduction of up to 44% in NMOG emissions during the cold phase, leading to an overall 40% reduction over the complete FTP75 and RDE cycles.

The electrical balance of the system is a key aspect of this study to ensure compatibility with the existing 12-Volt battery in the vehicle while minimizing additional costs. Compared to a standard PL8 solution, which increases after-treatment costs, the EHC presents itself as a more cost-effective alternative.

INTRODUCTION

The design of vehicle emissions control system is no longer driven exclusively by increasingly stringent emissions regulations and On-Board Diagnostics (OBD) requirements. Today, achieving an optimal total cost of ownership throughout the vehicle's lifecycle has become a key differentiator in competitive automotive markets. In cost-sensitive markets such as Brazil, this integration becomes even more critical, particularly for entry level segment vehicles, which dominate sales volumes. Traditionally powered by 1.0L Port Fuel Injection (PFI) flex-fuel engines—also known as indirect injection—these models have recently begun to adopt Turbocharged Gasoline Direct Injection (TGDI) flex-fuel engines [1].

Market forecasts indicate that TGDI engines will surpass PFI engines in market share by 2028, driven largely by their adoption in compact entry segment vehicles. This trend is strongly supported by the ROTA 2030 program, a Brazilian government initiative focused on enhancing vehicle energy efficiency, safety, and promoting technological innovation through R&D. The preference for small-displacement TGDI engines is influenced by their superior fuel economy and

performance, particularly under the flex-fuel technology widely used in Brazil.

Flex-fuel technology enables vehicles to operate on gasoline, ethanol, or any mixture of the two, offering versatility but also introducing complexity in terms of emission control. Ethanol combustion generates different exhaust gas compositions and thermal characteristics compared to gasoline, affecting catalyst light-off behavior and aging rates. Additionally, the use of direct injection in TGDI requires more advanced after-treatment strategies, due to its complexity.

Consequently, the integration of these powertrain technologies with efficient, cost-effective emissions control systems—especially under the constraints of volatile Platinum Group Metal (PGM) prices used in catalytic converters—is essential for maintaining compliance and profitability.

BRAZILIAN EMISSIONS REQUIREMENTS

Starting in 2025, in Brazil, the emission requirement for passenger vehicles is PL8, considering tailpipe emissions measured over the FTP-75 driving cycle, in which the regulated pollutants are:

- NMOG: Non-Methane Organic Gases, which includes NMHC and the organic gases ethanol and aldehydes.
- NOx: Nitrogen oxides.
- CO: Carbon Monoxide.

The PL8 regulation also establishes the concept of “BIN,” which refers to the combined total of NMOG and NOx emissions, with results required to meet the limits set in Table 1. The PL8 standard further outlines a progressive tightening of emission limits for 2027 and 2029. For 2025, the maximum allowable sum of NMOG + NOx is 50 mg/km, corresponding to BIN50. In 2027, the regulation will require BIN40, and by 2029, BIN30 [3].

PL8 also introduces the concept of corporate average emissions compliance, allowing manufacturers to weight the emission results of individual models by their respective sales volumes. Consequently, a high-volume model must typically be certified with a lower BIN value to ensure that the overall fleet average remains within the limits established by current legislation.

In addition to tailpipe emissions, the PL8 regulation also requires compliance with Real

Driving Emissions (RDE) standards, with a conformity factor (CF) of 2. This means that a vehicle certified under PL8 must emit less than twice the certified laboratory value when tested under RDE conditions. Starting in 2027, this conformity factor will be reduced to 1.5. The RDE test is conducted on public roads and covers a broader range of operating conditions—such as ambient temperature, engine speed, and load—compared to the FTP75 emissions certification cycle.

Year	PROCONVE	RDE	OBD	NMOG + NOx	CO	Durability
				g/km	g/km	
2025	PL8 BIN50	CF=2	OBD Br3	0.050	0.6	160kkm
2027	PL8 BIN40	CF=1.5	OBD Br3	0.040	0.5	160kkm
2029	PL8 BIN30	CF=1.5	OBD Br3	0.030	0.5	160kkm

Table 1. Emissions limits to Brazilian PL8.

Another aspect of regulatory evolution in the PL8 standard, scheduled for 2028, is the revision of the MIR (Maximum Incremental Reactivity) factor. This factor assesses the composition of NMOG emissions and is expected to increase the stringency of emission results.

EMISSION CONTROL IN PASSENGER VEHICLES

Considering emission regulation constraints, RDE requirements, OBD compliance, cold-start ethanol combustion control, and the commitment to drivability, emission control has become one of the major challenges for the automotive industry both in Brazil and worldwide.

In general, there are two main areas of focus for reducing and controlling emissions in a conventional internal combustion engine (ICE) passenger vehicle: minimizing pollutant generation at the engine source (base emissions) or treating the exhaust gases using a catalytic converter installed in the vehicle’s exhaust system [2].

The reduction of base emissions is achieved by precisely controlling the internal combustion engine, optimizing combustion in a stable and efficient manner through adjustments to parameters such as:

- Fuel injection – adjustment of the quantity injected and, in engines equipped with direct fuel injection, the distribution of the injected amount into multiple injections throughout the intake phase of the engine.
- Ignition timing – immediately after engine start and during the first seconds of operation, the ignition timing can be

adjusted not only to ensure combustion stability but also to transfer thermal energy to the catalyst so that it reaches its operating temperature as quickly as possible.

The effectiveness of adjusting these parameters can be verified through test results, and these parameters are especially important during the first seconds of the cycle, when the system has not yet warmed up and the catalyst has not reached a sufficient temperature to convert the pollutant gases.

Especially when operating with ethanol, the balance between emission reduction control and drivability can be complex, given the high sensitivity of alcohol-based fuel to stoichiometry. This can easily cause combustion instability, which in turn affects customer experience (drivability) and leads to an increase in base emissions.

As previously mentioned, another method of emissions control involves converting the gases through the use of a catalyst.

For gasoline engines, the Three-Way Catalyst (TWC) is the standard after-treatment system used to control emissions. Its name reflects its ability to simultaneously reduce total hydrocarbons (THC), carbon monoxide (CO), and nitrogen oxides (NOx).

The positioning of the catalyst in the exhaust system plays a critical role in its effectiveness. Stricter THC and CO emission standards require the use of a Close-Coupled (CC) catalyst, which is integrated directly into the exhaust manifold. This configuration enables faster warm-up and quicker activation.

The TWC consists of a substrate, typically a cylindrical structure with a honeycomb design. Its main characteristics include material, volume, Cells Per Square Inch (CPSI), and wall thickness. The substrate is coated with Platinum Group Metals (PGMs)—mainly palladium (Pd) and rhodium (Rh)—which serve as the active catalytic agents.

One major limitation of conventional TWCs is their reliance on exhaust heat to reach effective operating temperature. During the cold phase—responsible for over 80% of total emissions in a test cycle—the TWC’s performance is significantly reduced. To address this issue, technologies such as Secondary Air Injection (SAI) and Electrically Heated Catalysts (EHC) have been developed.

The content presented summarizes the methodology for emissions control in passenger vehicles and highlights the limitations and weaknesses of the system during the initial phase of the emissions cycle. At this stage, the engine requires combustion stability for proper operation, which results in fuel-rich air-fuel ratios and restricted ignition timing retardation (which could otherwise promote earlier catalyst heating), especially when operating with ethanol. This is compounded by the low conversion efficiency of the gases due to the catalyst’s low temperature.

As mentioned, 80% of emissions originate from this phase, making it crucial to achieve rapid catalyst activation to enable effective gas conversion.

Figure 1 illustrates the classic emission behavior of an internal combustion engine, showing the baseline emissions profile (blue line, HC pre) and the tailpipe emissions profile (orange line, HC post). Additionally, the engine speed profile is represented by the brown line.

It can be observed that during the initial acceleration there is the highest peak of emissions generated by the engine and also measured at the tailpipe, clearly indicating that at this moment the catalyst is unable to convert the gases.

The separation between the HC pre profile (blue line) and the HC pos profile (orange line) highlights the catalyst’s start of conversion activity, showing that the HC pos emissions are substantially lower than those generated by the engine.

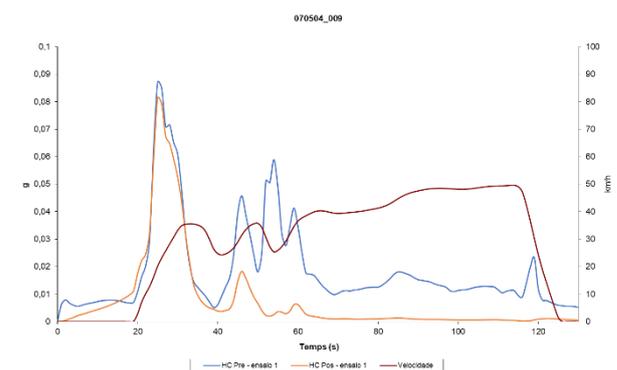


Figure 1. Emission and emission control profiles during the FTP75 cycle within the first 130 seconds.

12 VOLTS ELECTRICAL HEATED CATALYST

Given the limitations of internal combustion engines and the challenge of heating the catalyst to operational temperature, an electrically heated catalyst (EHC) is a viable and cost-effective

solution for application in light vehicles. The external energy input accelerates the catalyst warm-up, enabling it to reach optimal operating conditions sooner and thus promote earlier conversion of exhaust gases [4].

An electrically heated catalyst (EHC) features a heating element mounted on the inlet face of the monolith, powered by the vehicle's electrical system. In this study, the original 12-Volt vehicle system supplies power to the heating element, enabling energy transfer.

Figure 2 shows the adapted heating element integrated into the system, where the positive electrode is visible at the center. The ground electrode is established through the catalyst housing.



Figure 2. EHC heating element mounted on the catalyst.

Figure 3 shows the catalyst equipped with temperature sensors and gas sampling ports for modal analysis of emission results [5].

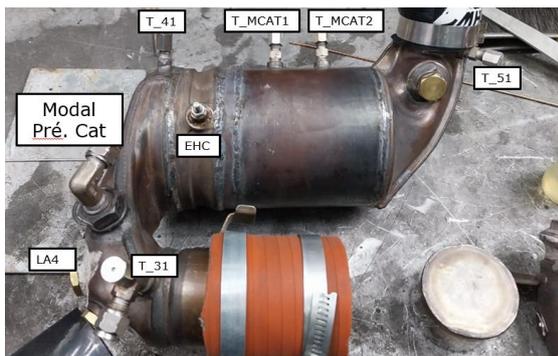


Figure 3. Catalyst instrumentation.

Depending on the power applied to the EHC heating element, different catalyst temperature profiles can be achieved. Figure 4 shows the expected emissions results alongside the catalyst temperature profile.

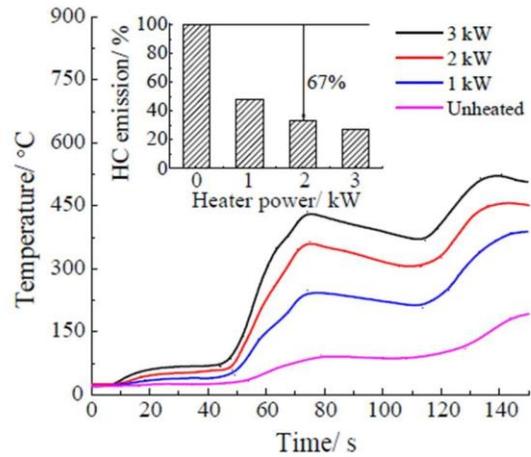


Figure 4. Catalyst temperature vs heating power.

TEST MATRIX

For the execution of the study in question, a Renault Kwid vehicle equipped with a 1.0L GDI flex engine and a 6-speed automatic transmission was used. This vehicle originally complies with PL7 standards.

To obtain reliable results, a test matrix was proposed considering both FTP75 certification cycles and RDE (Real Driving Emissions) tests.

For the purpose of this study, the RDE cycles were shortened to 5 minutes, based on the assumption that the greatest impact of the EHC occurs during the initial minutes. RDE tests were conducted at temperatures of 23°C and cold conditions at 15°C.

Tests were carried out using E22 (certification gasoline) and E100 (pure ethanol). Although the primary objective is emissions control with E100, tests with E22 were also performed to provide a comprehensive understanding of the system's behavior across all operating conditions.

Before each test, the vehicle's battery was recharged to start all tests with a State of Charge (SOC) at 100%.

The testing campaign was also duplicated using both fresh catalysts (0 km) and aged catalysts (equivalent to 160,000 km).

Finally, the test campaign was conducted following the sequence below:

- Baseline tests – vehicle without modifications to determine reference results.

- 100A 45s – current control at 100A with heating applied for 45 seconds, starting at engine start.
- 100A 90s – current control at 100A with heating applied for 90 seconds, starting at engine start.
- 160A (2kW) 90s – current control at 160A with heating applied for 90 seconds, starting at engine start.

Accounting for the configuration combinations and confirmation repetitions, a total of 56 tests were performed. Table 2 summarizes the test matrix and its combinations.

		Baseline	45s 100A	90s 100A	90s 160A (2kW)
E22	cata 3k	FTP75	FTP75	FTP75	FTP75
	cata 160k	FTP75	FTP75	FTP75	FTP75
		RDE23°C	RDE23°C	RDE23°C	RDE23°C
		RDE15°C	RDE15°C	RDE15°C	RDE15°C
E100	cata 3k	FTP75	FTP75	FTP75	FTP75
	cata 160k	FTP75	FTP75	FTP75	FTP75
		RDE23°C	RDE23°C	RDE23°C	RDE23°C
		RDE15°C	RDE15°C	RDE15°C	RDE15°C

Table 2. Test execution matrix.

The following results compare the weighted emissions using the baseline emissions as reference. The values obtained with the different configurations represent the percentage relative to the baseline result.

To minimize variability, only the NMHC results were considered for the comparative analysis. This choice is justified by the EHC’s significant impact during the catalyst warm-up phase at the beginning of the cycles.

In Figure 5 below, we can observe the expected NMHC emissions reduction of 43% by applying 2 kW for 90 seconds, only when the energy required to heat the catalyst comes from an external source (spare battery). In the vehicle, no calibration changes were made to optimize the system’s operation, which makes clear that the 160A current consumption—comparing the 90s 160A configuration using the vehicle’s original battery and an external battery (the rightmost blue bars on the graph)—has a significant impact. An analysis of engine parameters during the test shows that the electrical system compensates for the current drawn by the EHC by increasing power demand from the alternator, which consequently increases the load on the engine.

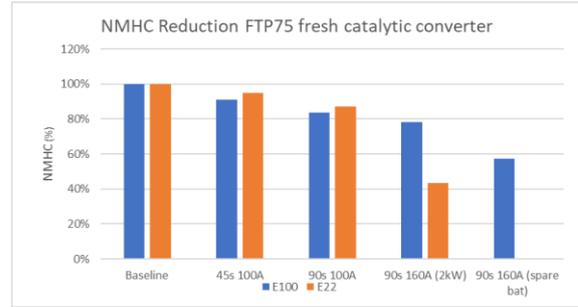


Figure 5. NMHC reduction in the FTP75 cycle for different EHC configurations, fresh catalyst.

Figure 6 below shows the temperature profiles corresponding to the different tests performed. It is important to note that the thermocouple positions follow the sequence shown in Figure 2, which are:

- T_41 – temperature of the gas entering the catalyst.
- T_MCAT_01 – temperature at one-third of the monolith length.
- T_MCAT_02 – temperature at two-thirds of the monolith length.

The test identification follows the color code:

- Baseline
- 45s 100A
- 90s 100A
- 90s 160A (2kW)
- 90s 160A (2kW) spare battery

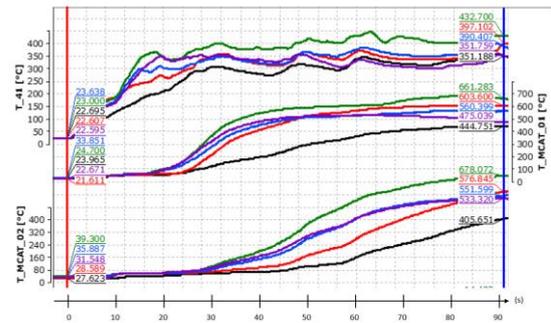


Figure 6. Catalyst temperature profile during the first 90 seconds of the FTP75 cycle.

We can observe a rather interesting behavior where the 90s 160A spare battery configuration would be expected to provide the best performance; however, in reality, the use of the vehicle’s onboard battery forces the engine to increase its load to meet the power demand of the alternator. This results in higher thermal load being transferred to the exhaust system, indicating that a combined approach of EHC use and engine calibration adjustments may be the optimal solution.

process might need to be suspended to prevent a critical failure that could immobilize the vehicle. Without the EHC system operating, emission behavior would differ significantly, potentially leading to compliance issues.

SUMMARY, CONCLUSION AND FUTURE PERSPECTIVE

Emission testing demonstrated that using a 12-volt Electrically Heated Catalyst (EHC) delivering 2 kW of power significantly shortens catalyst light-off time, achieving a 43% reduction in NMHC emissions during the FTP-75 cycle. Without modifying the engine calibration or catalyst design, this reinforces the EHC's role as an effective post-treatment device.

Testing under Brazil's Real Driving Emissions (RDE) protocol at 23°C and 15°C confirmed a 40% reduction in NMHC emissions, further supporting the opportunity to reduce the BIN level using the same catalytic converter.

The EHC can considerably reduce the light-off time of the catalytic converter activation time.

However, the impact on the electrical system must be carefully considered to avoid rapid degradation of the 12-Volt battery, immobilizing failures, and potential compliance issues regarding emissions regulations.

In the future, the application of EHC appears to be a powerful tool for emissions control, especially in hybrid systems with large battery capacities and in Range Extender applications.

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DEFINITIONS/ABBREVIATIONS

CC: Close-Coupled
CF: Conformity Factor for RDE
CO: Carbon Monoxide
CO₂: Carbon Dioxide
CPSI: Cells Per Square Inch
EHC: Electrically Heated Catalyst
FTP-75: Federal Test Procedure Number 75
GDI: Gasoline Direct Injection
HC: Hydrocarbons
ICE: Internal Combustion Engine
NMHC: Non-Methane Hydrocarbons
NMOG: Non-Methane Organic Gases
NOx: Nitrogen Oxides
OBD: On-Board Diagnostic
OH: Hydroxyl Functional Group
Pd: Palladium
PFI: Port Fuel Injection
PGM: Platinum Group Metals
PL8 BIN50: Level is related to emission level; in this case 50 refers to NMOG + NOx = 50 mg / km

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

Pt: Platinum

RDE: Real Driving Emission

R&D: Research and Development

Rh: Rhodium

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

SAI: Secondary Air Injection

TGDI: Turbocharged Gasoline Direct Injection

THC: Total Hydrocarbons

TWC: Three-Way Catalyst