XXIII Simpósio Internacional de Engenharia Automotiva
SIMEA 2015

Blucher Engineering Proceedings
Setembro de 2015, Número 1, Volume 2

Simpósio Internacional de Engenharia Automotiva
SIMEA 2015

PAP198

Strategy for NMHC reduction in PFI flex fuel engines

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ABSTRACT

The vehicular emission of non-methane organic gases and compounds (NMOG) plays an important role in the formation of ozone and its contribution to the "photochemical smog" and therefore has been one of the main focuses of automotive development, in order to minimize its environmental impact.

Some countries in Europe and the USA already control the NMOG emission, mainly composed of non-methane hydrocarbons (NMHC), aldehydes, ketones, and non-burned ethanol (EtOH). In Brazil, where the high scale flex fuel market is in series production since 2003, currently 0.05 g/km of NMHC are allowed for passenger cars (based on the ongoing PROCONVE legislation, L6 stage). The deduction of the non-burned ethanol fraction is also allowed [1] [2] [10].

In order to support the NMHC reduction and minimize the impact of flex fuel engines on the environment, this study presents some engine calibration options at different PFI vehicles, considering the usage of the heated cold start system based on heated fuel rail.

INTRODUCTION

The reduction of Hydrocarbon emission (HC) in internal combustion engines is a primary objective in ongoing engine research and developments in the mobility business. Technological efforts in the automotive industry aim the minimum impact to the environment and the compliance with emission legislation and the emission limits introduced in the USA, in Europe or even in Brazilian flex fuel market, the focus of this study [12].

Since the end of 70´s a successful history of bio-fuel usage is worldwide recognized in Brazil. The demand for a large scale use of hydrous ethanol has increased since 2003, with the launch of the first flex fuel vehicle in the market. Nowadays more around 90% of the new vehicles in the Brazilian market are flex fuel. These vehicles can operate with any portion between E22 and E100. Every gas station has at least two possibilities: E100 and E22-E27 (the government can adjust the portion of ethanol in gasoline according to the ethanol production and the oil price) [12].

This specific market and bio alternative has brought along several benefits for the society and for the environment. However, a different aspect must be considered regarding the emission of pollutants, mainly towards of NMHC and aldehyde, which could impact the public health [1] [2] [3]

The current IBAMA regulation 54/04 [[4]] allows the discount of the non-burned ethanol, which is derived from the NMHC.

But in other countries, the same topic is handled in a different way. The North American Legislation controls NMOG emission of the vehicles belonging to the Tier 2 program [5]. The European Directive 70/220/EEC [6] established in 2009 limits for the NMHC emission (without the deduction of non-burned ethanol), either from passenger cars or light-duty transport vehicles equipped with Otto cycle engines.

Previous studies have already compared the emission of organic compounds from flex-fuel vehicles according to different regulations. In all cases it was described that the ethanol content present in fuel has a direct effect in the NMHC levels, depending on the calculation rules defined by the legislation [3].

Since the release of PROCONVE L6, the adoption of NMOG limits for the next stage (L7) is being discussed and evaluated. Another possibility would be the non-deduction of the non-burned ethanol fraction (refer to the Table 1 for more information about the evolution of PROCONVE in Brazil) [1] [2] [7] [9].

Table 1 – Reference of PROCONVE for passenger cars and light commercial Vehicles (≤1700 kg) in g/km

Model Year	Stage	CO	NMHC	NMOG	NO_X
2007+	L4	2.0	0.16	n/a	0.25
2009+	L5	2.0	0.05	n/a	0.12
2014+	L6	1.3	0.05	n/a	0.08
?	L7	?	?	?	?

After the market release of the first heated cold start system in 2009, new possibilities to improve the cold start ability of flex fuel vehicles have been settled. By heating the ethanol instead of injecting gasoline to enable cold starts, additional functionalities could be developed and optimized, such as improvement of vehicle drive ability, fuel content identification, as well the possibility for reducing the emission of gases, all of them combined with a proper calibration during the development phase [11].

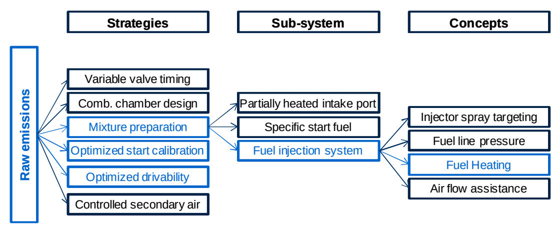

Figure 1 – Strategies and concepts for NMHC reduction

Many strategies were already investigated in the engine calibration field aiming to support the reduction of overall emitted hydrocarbons. The best results so far were achieved through the combination of several strategies [8][13].

In this paper will be presented the results obtained by using the fuel heating system (in order to reduce the droplet size and improve the fuel evaporation) together with the optimization of start and warm-up calibration parameters, during the FTP-75 cycle [9].

1. THEORY

1.1. The FTP-75 cycle

A famous test procedure for emission certification and part of the fuel economy testing of light-duty vehicles in the USA is the Federal Test Procedure 75 (FTP-75). This procedure is a variant of the EPA Urban Dynamometer Driving Schedule (UDDS) and divided in three phases. Between phase 2 and phase 3 the engine is stopped for 10 minutes (hot soak from minimum 540 seconds to a maximum of 660 seconds). The phase 3 is a repetition of phase 1, but in hot environment [8].

Below a brief description of each phase:

- Phase 1: Cold start transient phase, between 20 and 30ºC, from start until 505 seconds;

- Phase 2: Stabilized phase, from 506 up to 1372 seconds;

- Phase 3: Hot start transient phase, from start until 505 seconds.

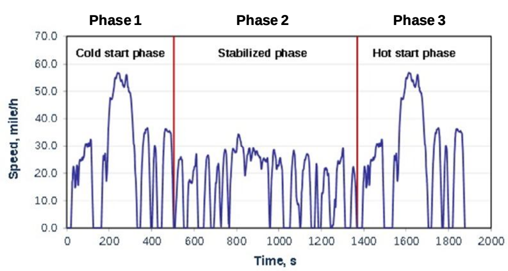

Figure 2 – US EPA Urban Dynamometer Driving Schedule (FTP-75)

In Brazil the FTP-75 was the base for the test standard NBR6601 [9].

1.2. Vehicle data

To evaluate the proposed work, different vehicles were prepared as part of the verification phase. Since the focus was on the Brazilian PFI market, three different vehicles equipped with the FLEXSTART™ System and 1.0, 1.6 and 2.0 liter engines (please refer to Table 2) were evaluated at the same experimental conditions.

Table 2 – Vehicle Data

	Vehicle 1	Vehicle 2	Vehicle 3
Engine	1.0L 12V PFI	1.6L 16V PFI	2.0L 16V PFI
Cold Start System	Heated Fuel Rail	Heated Fuel Rail	Heated Fuel Rail
Fuel used	E100	E100	E100
Emission cycle	FTP-75, Phase 1	FTP-75, Phase 1	FTP-75, Phase 1
Compression Ratio	~11.8	~12.5	~10.0

1.3. Scope - NMHC Emission reduction

The reduction of hydrocarbons emissions in internal combustion engines is a primary target at most of engine research.

Due to the particular usage of flex fuel in Brazil, the scope of this present study has focus on NMHC reduction with E100.

The results are related with the absolute NMHC content, i.e., considering also the non-burned ethanol (please refer to Table 3 for more information).

1.4. Calibration and fuel heating as optimization tool

Based on theory and simulation, a sort of calibration guideline was composed to support new developments, especially during the vehicle calibration phase.

As described before, the optimal results to reduce the emission of hydrocarbons can be obtained combining different strategies.

The base for the proposed calibration guideline, aiming better combustion efficiency and less environment impacts, can be resumed by the following application parameters:

- Heat up and control the ethanol temperature between 70 and 100ºC (by activating the cold start system based on heated fuel rail)
- Sustain the fuel heating support up to an engine coolant water

temperature threshold (around 80ºC)

- Adjust the main start parameters (e.g. fuel flow)
- Optimize the warm-up parameters (e.g. fuel flow, engine speed and transient factors at specific conditions)
- Adjust the catalyst light-off strategy

The effectiveness of each parameter is completely dependent on the engine characteristics. For example, the adjustment of the catalyst light-off strategy may not bring any advantage in some applications.

1.5. Step-by-step guideline

Combining the cold start system based on heated fuel rail and the calibration expertise, the following steps were evaluated:

- Step 1 – Determine the pre-heating and post-heating time

The pre-heating and the post-heating time definition is very important to get the maximum potential of the heated fuel rail system. The purpose is to keep the fuel heated during the time where most of the HC emission can be measured (from the baseline).

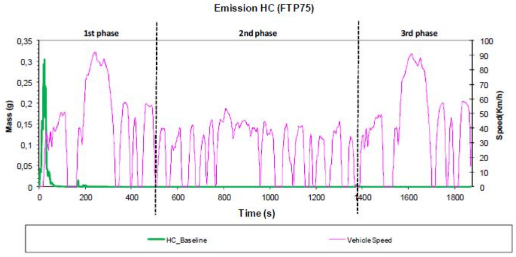

Figure 3 – Amount of HC emitted during FTP-75

The Figure 3 shows a measurement of the vehicle speed in comparison with the HC emissions. With a zoom on it (Figure 4) is possible to observe that the major amount of HC is emitted during the first phase of the FTP-75.

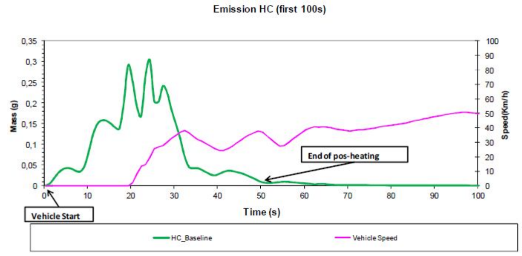

Figure 4 – Amount of HC emitted during the first 100 seconds

In the experiment shown in the Figures above the heating system was activated during 50 seconds after the engine start, keeping the same target temperature from pre-heating. Nevertheless the heating operation can be held at any calibrated temperature (up to the ethanol vaporization temperature), during any necessary time, depending on the engine and catalyst properties.

- Step 2 – Start optimization with the heated fuel rail system

The start optimization was based on start-factor change, stepwise, together with fuel heating temperature setup (between 70 ºC to 100ºC).
Depending on the engine, an increased start-factor can result also in a reduced start time, leading to a smaller injection area. The direct effect is less amount of fuel compared to the same vehicle, but without activating the cold start system based on heated rail. By this reason, an increased start-factor can lead to a better emission result.

- Step 3 – Post-start and warm-up optimization with heated fuel rail system

The pos-start optimization experiments were based on decreasing or increasing the post-start-factor, together with best start configuration (starting with the best results from Step 2).

The emission reduction ratio result is normally lower than the previous step, since the HC-emission is higher at the beginning of Phase 1.

- Step 4 – Transient optimization with the heated fuel rail system

The transient optimization tests were based on decreasing the series production transient factor from 10% to 50%, in steps of 10%, together with the best result from Step 3.
Decreasing the factor from 30 to 50%, a general emission reduction rate around 35-40% was obtained (mainly for NMHC and non-burned ethanol discount).

- Step 5 – Heating Temperature optimization

The heating temperature optimization tests were based on decreasing the fuel heating temperature from 100 ºC to 70ºC, during pre and post-heating. These temperatures were optimized together with best configuration from Step 4.
Due to the energy balance optimization, each engine has shown a specific and optimal heating temperature, which results in the best emission reduction factor.
The temperature optimization brought around 45% of NMHC reduction. The other gases and compounds kept the same emission reduction rate (in comparison with the optimization from Step 4).

2. RESULTS

The target results for the experiments had the PROCONVE L6 as reference (since the L7 is not yet released).

According to the theory and the experiments, the maximum HC and NMHC reduction was achieved up to 200s after the engine start (still inside the Phase 1 of FTP-75).

The Table 3 shows the overall results after measurements of the exhausted gases.

Table 3 – Emission reduction obtained observing the main components of exhausted gases

	HC	NMHC	EtOH
1.0L Engine	15%	14%	44%
1.6L Engine	44%	48%	50%
2.0L Engine	31%	29%	26%

Since the main purpose was to evaluated the NMHC reduction in comparison with the baseline (without heating the ethanol), the Figure 5 shows the results with the different vehicles, without deducting the non-burned ethanol.

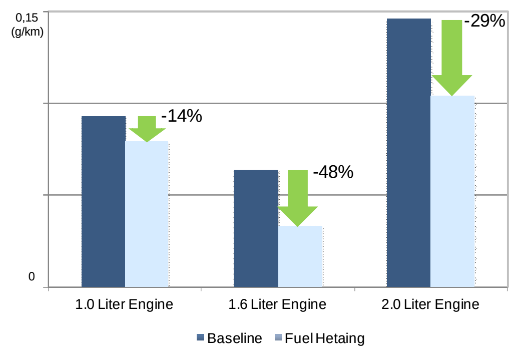

Figure 5 – NMHC delta reduction (Baseline vs Fuel Heating)

The best result was 48% of NMHC reduction, with the 1.6 liter engine, also the one with the highest compression ratio.

The following figures show the results obtained for each vehicle, during the complete Phase 1 and also a zoom in the first 140 seconds.

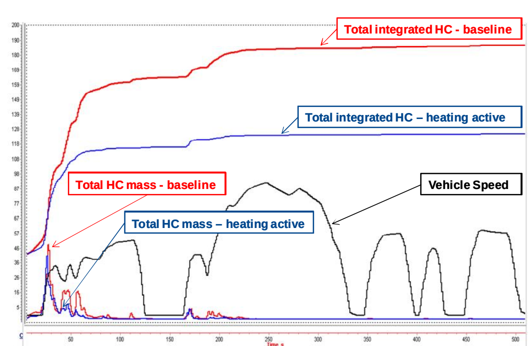

Figure 6 – HC emissions with 1.0L engine (Phase 1)

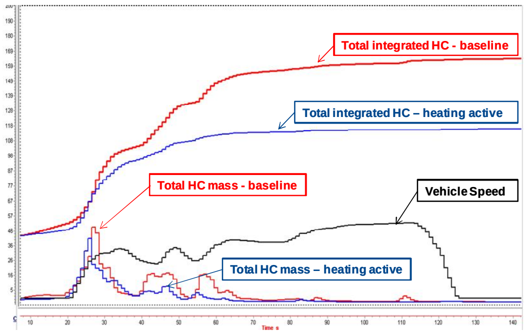

Figure 7 – Zoom on Figure 6 (HC emissions with 1.0L engine during the first 140 seconds)

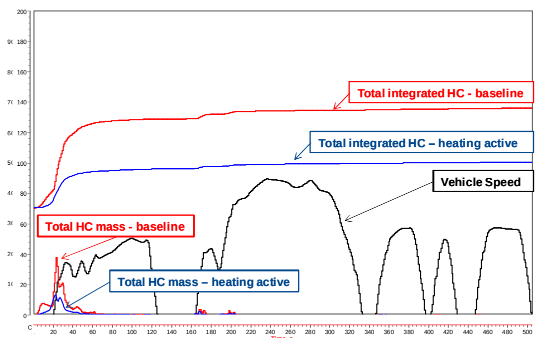

Figure 8 – HC emissions with 1.6L engine (Phase 1)

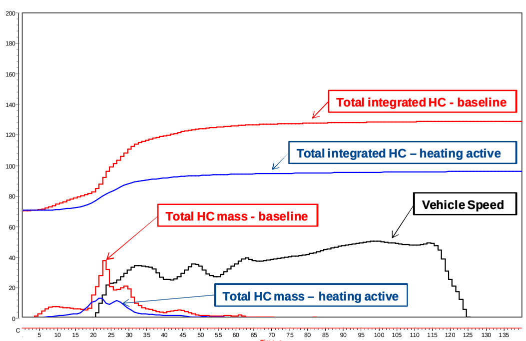

Figure 9 – Zoom on Figure 8 (HC emissions with 1.6L engine during the first 140 seconds)

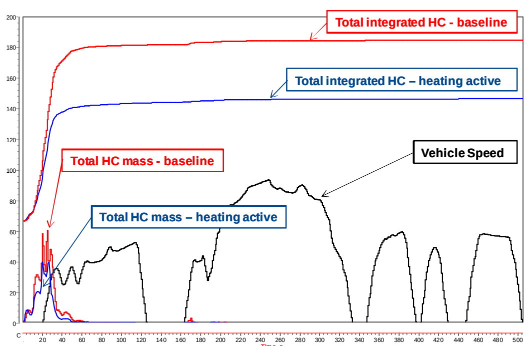

Figure 10 – HC emissions with 2.0L engine (Phase 1)

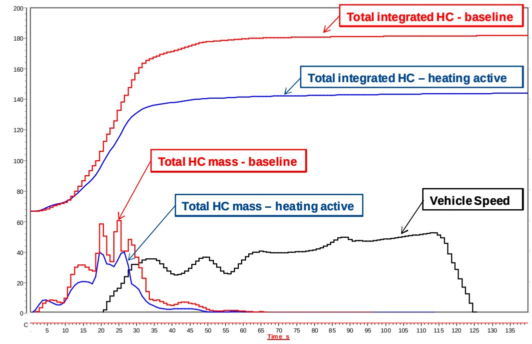

Figure 11 – Zoom on Figure 10 (HC emissions with 2.0L engine during the first 140 seconds)

Looking closer to the short period after start (up to 140 seconds), the benefits of using the colds start system with the heated fuel rail are even more representative (please refer to Figure 7, Figure 9 and Figure 11).

Depending on the application, an improvement on the drivability performance could be achieved using the heated ethanol during the cold phase.

3. CONCLUSION

By heating the ethanol during the FTP-75 cycle, especially during the Phase 1, less fuel volume is necessary to be injected in comparison with the same verification done without heating. Combined with other calibration strategies, which are dependent of the engine characteristics, the direct effect and benefit to the environment is an expressive reduction of hydrocarbon emission, including the NMHC (up to 48% reduction).

The effectiveness of the presented method was also impressive when using the cold start system with heated fuel rail. Even comparing three engines with different technical characteristics, it is possible to observe consistent improvements on HC emissions.

Another important benefit observed during this study is the drivability improvement when the cold start system with heated rail was active, leading to a potential effort reduction in the cold phase calibration.

Focusing on the reduction of hydrocarbons emissions, during the present work a calibration guideline for a flex fuel vehicle equipped with the FLEXSTART™ System was described.

It is also important to mention that the proposed strategy contributes to after-treatment gases reduction, and thus may also impact on catalytic load. Therefore, depending on the engine characteristics and the fuel blend, a catalyst load reduction could also be evaluated. The effective results must be further investigated.

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DEFINITIONS/ABBREVIATIONS

ABNT	Associação Brasileira de Normas Técnicas
NBR6601	Light road vehicles — Determination of hydrocarbon, carbon monoxide, nitrogen oxide, carbon dioxide and particulate material on exhaust gas (from Brazilian Legislation)
EtOH	Non-burned ethanol
E100	Hydrous ethanol
E22	Gasoline fuel in Brazil, which can contains from 22 to 27% of ethanol in the mixture
ECU	Engine Control Unit
Flex fuel	Term used to describe vehicles that can run with either gasoline (E22), hydrous ethanol (E100) or in any proportion between E22 and E100
FLEXSTART™	System that uses fuel heating to help the cold start of Flex-Fuel vehicles
FS or FSS	FLEXSTART™ System
FTP-75	USA Federal Test Procedure #75
HC	Hydrocarbon emission
IBAMA	Instituto Brasileiro de Meio Ambiente e dos Recursos Naturais
L6	PROCONVE Legislation, 6th release
NMHC	Non-Methane Hydrocarbons
NMOG	Non-Methane Organic Gases
PROCONVE	Programa de Controle de Poluição do Ar por Veículos Automotores
PFI	Port Fuel Injection technology for gasoline engines
UDDS	EPA Urban Dynamometer Driving Schedule