Real Driving and Bench Emissions from EURO VI Engine using Different Blends of Renewables and Diesel Fuel

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ABSTRACT

In January/2022, came into force in Brazil the PROCONVE P8 emission limits, equivalent to EURO VI, that includes Real Driving Emissions (RDE) and new engine test cycles for heavy-duty vehicles emission homologation. There are not many articles showing emission results of EURO VI engines using high content of renewable fuels. For engines until phase EURO V, some publications state that an increase of FAME (Fatty Acid Methyl Ester) content in commercial diesel could reduce PM (Particulate Matter) emissions, contributing to air quality improvement. On the other hand, there are works indicating that NOx emission increases with the use of FAME. This paper shows RDE results of a EURO VI truck and bench emission results of a EURO VI engine, using different fuel blends of FAME, HVO (Hydrotreated Vegetable Oil) and Brazilian S10 diesel, without considering fuel effects on the durability of the aftertreatment systems. A European B7 emission homologation fuel was used as reference fuel. Results showed no statistical difference for PM and the other regulated pollutants, suggesting that for the EURO VI vehicle and engine tested, the emissions are more influenced by the engine and aftertreatment system technology than the fuel/biofuel blends.

INTRODUCTION

There is a worldwide trend to reduce vehicle pollution with regulations that define even more restrictive emissions limits. New legislations establish complementary procedures for measurements in traffic, more representative of vehicles real average use, when compared to the bench emission tests carried out on laboratory. In Europe, real driving emissions measurement (RDE) is currently used as one of the requirements of UN ECE Regulation R49.06 (EURO VI) [1] for vehicle approval, in addition to bench tests. Regarding heavy duty vehicles of the Diesel cycle, Brazil has historically followed the European Directives in its Motor Vehicles Air Pollution Control Program (PROCONVE).

CONAMA (Brazilian National Council for the Environment) approved, on November 16, 2018, the PROCONVE P8 phase, which apply to emission homologation of new vehicle models, as of January 1, 2022, and for all models from January 2023 onwards. CONAMA Resolution 490/2018 [2], which regulates the subject, establishes significant reductions in vehicular emissions from Diesel engines, with limits for nitrogen oxides (NOx), hydrocarbons (HC), carbon monoxide (CO), mass of particulate matter (PM) and particle number (PN). Chapter VII of this resolution also establishes, from the beginning of the PROCONVE P8 phase, the maximum limits for proving emissions during the vehicle's useful life (In-Service Conformity - ISC), measured through tests in real traffic (RDE).

There is also a global trend towards a reduction in carbon intensity in the energy matrix, which, in the case of Brazil, is reflected in increasing levels of biofuels in the automotive segment. Regarding the adoption of renewable fuels in the heavy-duty vehicles, FAME began to be used in Brazil in 2005, as an optional blend of 2 % by volume in commercial diesel fuel (B2) [3]. As of 2008, this mixture became mandatory throughout the country and increased to 3 %. Since then, there have been consecutive increases up to 10 % (B10) in 2018. In this year, further increases of 1 % per year till 2023 were forecasted, when 15 % blends would be reached [4]. Levels of up to 13 % were practiced in 2021, but some market reasons forced the blend back to 10 %, currently in force. There is still the possibility to reach 15 % (B15) in 2023. On the other hand, Europe has limited the biodiesel content in diesel to 7 % by volume (B7) and is promoting the use of HVO (Hydrotreated Vegetable Oil). Due to operational issues associated with stability, fuel filterability and durability of the emission aftertreatment system components in EURO VI engines, further increases in FAME content are being questioned by vehicle manufacturers [5].

In this context, some studies associate the use of higher levels of FAME in diesel fuel, with lower particulate matter emissions, thus improving air quality [6-8]. Nevertheless, some publications report an increase in NOx emissions with the use of higher levels of FAME blended in diesel fuel, in various engine/aftertreatment system technologies [6, 7, 9, 10].

Considering this scenario, the present work evaluated the impact of FAME and HVO addition in the S10 diesel fuel, regarding the vehicle emissions, by means of RDE tests, using a PEMS (Portable Emissions Measurement System), and dynamometric bench tests, both with EURO VI engines (equivalent to PROCONVE P8). Three formulations of S10 diesel with different contents of soybean FAME (BX) and HVO (RX), B15, R15 and B7 R8, were tested. A European diesel B7, EURO VI homologation fuel, was used as a refence.

METHODOLOGIES

TESTED FUELS - A total of three different formulations of Brazilian S10 diesel fuel containing biocomponents (B15, B7 R8 and R15) were prepared to compare their performances regarding the emissions of pollutants, by means of tests in EURO VI vehicle and engine. The regulation UN ECE R49.06 [1] adopts a European B7 diesel fuel as emission approval standard for EURO VI phase, which has also been used as a reference fuel for the tests. Table 1 shows a summary of the physicochemical characterization of the reference and the three formulated fuels, described below:

- B15: blend of ULSD with 15 % by volume of FAME;
- R15: blend of ULSD with 15 % by volume of HVO;
- B7 R8: blend of ULSD with 7 % by volume of FAME and 8 % by volume of HVO.

Table 1. Fuel properties and limits.

Property	Test Method ASTM/EN	Limits	B7 ref.	R15	B7 R8	B15
FAME Content, % v/v	EN14078	7.0/15 máx.	6.5	0.0	7.0	14.9
Flash Point, ºC	D93	38 mín.	96.5	66.0	66.0	65.5
Sulfur, mg/kg	D5453	10 máx.	2.0 (D2622)	3.9	4.5	5.4
Density at 20 °C, kg/m^3	D4052	815-850 !	830.2	836.3	843.4	851.6
Cetane Number	D613	48 mín.	57.6	57.3	54.4	52.7
T95, °C	D86	370 máx.	343.6	360.0	358.7	357.5

! ANP Resolution nº 50/2013: 815 - 853 kg/m^3 at 20ºC (diesel fuel plus FAME).

A volume of 1000 L of each fuel was formulated for RDE and engine bench emission tests in stationary and transient cycles (WHSC – World Harmonized Stationary Cycle and WHTC – World Harmonized Transient Cycle). All blended fuels were suitable for performing the emissions tests.

REAL DRIVING EMISSIONS TEST (RDE)

Test Vehicle – it was used a new 4x2 EURO VI truck, year/model 2020, category N_3, specified to operate with GVW (Gross Vehicle Weight) of 18 t. This truck, imported from Europe, is equipped with a 6.9 L, 290 hp engine and an ATS (After Treatment System) consisting of a Diesel Oxidation Catalyst (DOC), a Diesel Particulate Filter (DPF), a Selective Catalytic Reduction catalyst (SCR) and an Ammonia Slip Catalyst (ASC).

According to manufacturer information, for Brazilian market, this 290 hp engine will be applied in a 24 t 6x2 configuration vehicle. For this reason, the tests were performed with a load of 16 t, compatible with the Brazilian application of 24 t, since the R49 standard requires the tests to be carried out with a load between 50 % and 60 % of the maximum load allowed for the vehicle. For this purpose, concrete ballasts were added to the truck's body, as shown in Figure 1.

Figure 1 - Weights added to the truck’s body.

The break-in of the vehicle and after-treatment system was carried out with 16 t load, simultaneously with investigations to define and validate possible routes for the RDE tests. City, rural and highway sections for the RDE route were evaluated, according to the percentages established by the R49 standard.

The mileage accumulation was carried out on the Anchieta and Imigrantes highways in the state of São Paulo, with a total of two hours of engine operation on uphill sections suitable for reaching exhaust gases temperatures of above 450 °C at the DOC (Diesel Oxidation Catalyst) inlet, for system break-in. Figures 2 and 3 show, respectively, the temperature data at the DOC's entrance (obtained directly from the vehicle's original temperature sensor, from the system's closed loop control, as well as from OBD - On Board Diagnostics data), and the accumulated time with temperatures above 450°C.

Refilling of the truck with European reference diesel B7 and ARLA 32 (Automotive Liquid Reducing Agent - 32.5 % urea) was performed at the beginning of each RDE test. Thus, it was possible to make a preliminary evaluation of fuel and ARLA consumptions, comparing with predicted values and verifying the effective operation of the engine and SCR (Selective Catalytic Reduction).

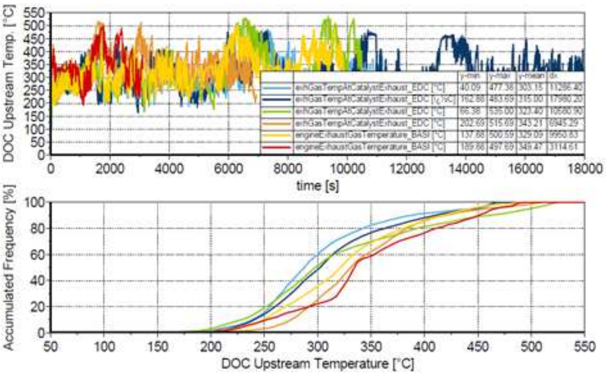

Figure 2 - DOC upstream temperatures, upper curves: over time, lower curves: cumulative frequency.

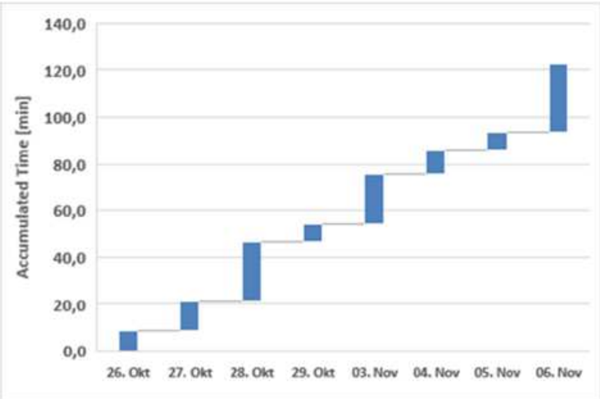

Figure 3 - Daily accumulated operating time with DOC upstream temperatures higher than 450 °C.

Portable PEMS Emissions Analyzer - The Horiba PEMS (Portable Emissions Measurement System) OBS-ONE model was used and installed on the truck's body, behind the cab, as shown in Figure 4.

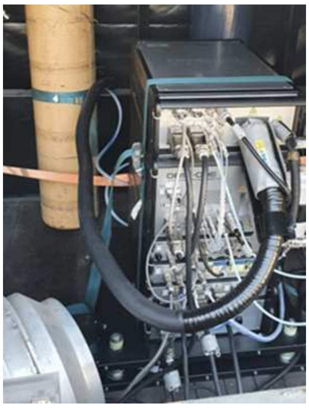

Figure 4 - PEMS OBS-ONE installed on the truck's body.

To protect the measurement equipment against rain, wind and direct sunlight, a closed cabin was assembled on the truck's body, as shown in Figure 5.

Figure 5 - Cabin for PEMS protection in the truck.

A diesel-powered electric generator was used to provide the necessary power to the OBS-ONE and its accessories. A battery pack was also used as auxiliary power system for the equipment. During the first tests it was noticed that the generator exhaust, located close to the PEMS, was causing interference in the measurements. Thus, the generator and its exhaust system were relocated to the back of the truck's body, seeking to eliminate its influence on the measurements of the PEMS NOx sensor. Figures 6 and 7 show, respectively, the new location of the generator and details of its exhaust.

Figure 6 - Generator installed on the back of truck's body.

Figure 7 - Generator engine exhaust outlet toward the back of the truck.

Figure 8 shows the PEMS instrumented piping, installed at the vehicle exhaust outlet, which includes the heated line, for leading the gases to the analyzers, the temperature sensor, and the gas flow meter.

Figure 8 – PEMS exhaust gas instrumented collecting pipe.

Test Route Definition - Several studies and preliminary tests were conducted to define three routes that met the requirements of the UN Regulation ECE R49.06 [1] to perform the RDE tests according to the EURO VI stage, level C. One of these routes was selected for testing, as shown in Figure 9. The average travel time on this path was two hours and seven minutes, covering approximately 142 kilometers.

The percentages of the city, rural and highway stretches were within the limits, respectively, of 20, 25 and 55 % (± 5 %) required by the R49 standard for this vehicle category (N_3). The vehicle operation met the requirements for city driving at speeds between 0 and 50 km/h, rural driving at speeds between 50 and 75 km/h, and highway driving at speeds above 75 km/h. The operating sequence in these sections was also obeyed. There are no requirements regarding average speed values. The work done on the route attains the requirement of at least five times the work done in a WHTC bench emissions cycle (20.2 kWh), averaging 114 kWh on the selected route.

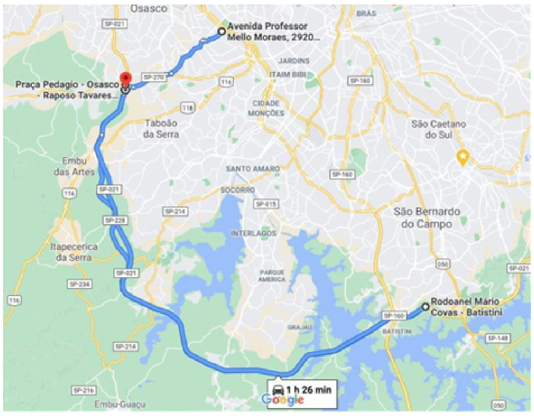

Figure 9 - Route used in the RDE tests.

Test Sequence and Fuel Change Procedure - The following sequence of tests was performed:

- three tests with the reference fuel (B7 EU);
- three tests with R15 fuel;
- three tests with B7 R8 fuel;
- three tests with B15 fuel and
- two tests with the reference fuel (B7 EU).

The following fuel change procedure was used to minimize the risk of cross-contamination:

a) drain the remaining volume of fuel in the vehicle's tank from the previous test, including the dead volume, if any, and drain the fuel filter, replacing it with a new one;

b) fill up the tank with approximately 25 L (between 15 and 20 % of the tank capacity) and fill the new filter with the next fuel in the test sequence. Pump manually through the priming pump to eliminate air in the system (1 L);

c) start the engine, discarding the return fuel line to the tank for at least five minutes (volume discarded depending on the truck model, between 10 and 12 L);

d) perform sampling of this fuel on its return (disconnected from the tank) and determine its density;

e) repeat this step until the measured density matches the density obtained in the characterization of this fuel (at the same temperature) thus ensuring that the lines and tank are filled with 100 % of the fuel to be tested, with minimal contamination. A fuel density tolerance of ± 0.5 kg/m³ between the measured value and the reference value was adopted.

ENGINE BENCH EMISSIONS TEST

Test Engine - An imported 12.4 L, 520 hp EURO VI engine was used, with EGR (Exhaust Gas Recirculation) and after-treatment system containing oxidation catalyst (DOC), particulate matter filter (DPF), NOx selective catalyst reduction (SCR) and an ammonia abatement catalyst (ASC). In Brazil, this engine will equip heavy vehicles with a GCW (Gross Combination Weight) of 74 t. Figure 10 shows the test engine mounted on the test bench.

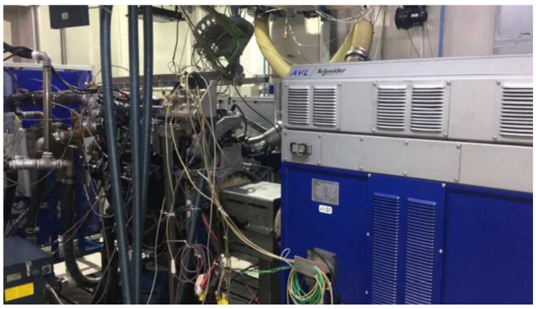

Figure 10 – Test engine mounted on the test bench.

Test Sequence and Fuel Change Procedure - The following sequence of tests was adopted:

- two WHTC and two WHSC with the reference fuel (B7 EU);
- three WHTC and three WHSC with R15 fuel;

- three WHTC and three WHSC with B7 R8 fuel;
- three WHTC and three WHSC with B15 fuel, and
- two WHTC and two WHSC again with reference fuel (B7 EU).

For each fuel, the WHTC emission tests were run without cold start (WHTC hot/hot), after performing the full load curve (FLC), and on the sequence the WHSC tests were performed.

Before starting any new WHTC (hot/hot) set, the engine was preconditioned, running at full load for 10 minutes at 1500 rpm. Prior to a new WHTC set, a 10-minute soaking period was also included. This soaking is also repeated between the WHTC (hot/hot) two phases, according to this test cycle pattern. The preconditioning for the WHSC tests followed Regulation UN ECE R49.06 [1] and were carried out before each new repetition.

The following fuel change procedure was used to eliminate the possibility of cross-contamination:

a) draining of the fuel contained in the tank that supplies the dynamometric cell;

b) washing of the bottom of this tank with 10 to 15 L of new fuel, and subsequent draining;

c) draining of the fuel line that connects the tank to the test bench, including the gravimetric scale and fuel temperature conditioner;

d) draining of the line that connects the temperature scale/conditioner, including the pressure conditioning module to the engine. This drainage was carried out by collecting an approximate volume of 30 L (around five times the volume of the line) in a drum for disposal, from the return line of the engine's fuel supply system;

e) replacement of fuel filters (bench and engine);

f) engine operation at full load at 1500 rpm for five minutes (for consumption of approximately six liters of fuel), with continuous monitoring of fuel temperature and density, measured by the test cell fuel consumption device, using the Coriolis principle;

g) sampling of fuel and measurement of its temperature and density, using a densimeter, to verify the effective fuel replacement, by comparison with the reference density of each fuel.

DATA PROCESSING - In this work, only the tailpipe emissions are being considered. A statistical evaluation of the results was performed using the analysis of variance technique (ANOVA), with a confidence interval of 95 % ($p=0.05$).

The basic premises for the analysis were:

- in some of the RDE tests, the emissions results for carbon monoxide (CO) and methane (CH_4) presented negative values, since they are very low and close to the equipment's lower limit of measurement. As there is no indication in the standard for heavy-duty vehicles on how to treat these results, the recommendation of the standard for light duty-vehicles was followed, equating the negative final results to zero [11];
- non-methane hydrocarbon (NMHC) emissions were calculated from the difference between the results of total hydrocarbons (THC) and CH_4, already corrected according to the criteria of the R49 standard and considering negative values as equal to zero.

It should be noted that, in the case of RDE tests, since the particulate matter is not legislated, the focus of the analysis was the NOx, while, in the bench tests, it was NOx, PM (particulate matter) and PN (particle number). Historically, hydrocarbons (HC) and CO emissions from Diesel engines are well below the legislated limits and do not present problems, which was also confirmed with the results obtained in the present work.

To verify the repeatability behavior of fuels, vehicle and engine throughout the tests, the reference fuel B7 EU was tested in two moments, before and after the other fuels. The results of both steps (before and after the formulated fuels) were considered in a single dataset for statistical calculations.

RESULTS AND DISCUSSION

REAL DRIVING EMISSIONS (RDE) – The results are presented through comparative graphs between the fuels. The data were normalized by assigning a value of 100 % to the European reference B7 fuel (B7 EU). These graphs also contain the confidence intervals of 1.96 times the standard deviation obtained with each fuel.

Figures 11 and 12 show the comparative emissions of NOx and the corresponding Conformity Factors (CF) for the different fuels in the RDE tests. The CF is the parameter effectively used to compare the results of pollutants with the legal limits. In EURO VI phase this limit is 1.5 for all legislated pollutants. Although the absolute results of emissions are not included in this article, it is worth mentioning that, in the tests carried out, with all fuels, the CF of NOx was always below the legal limit.

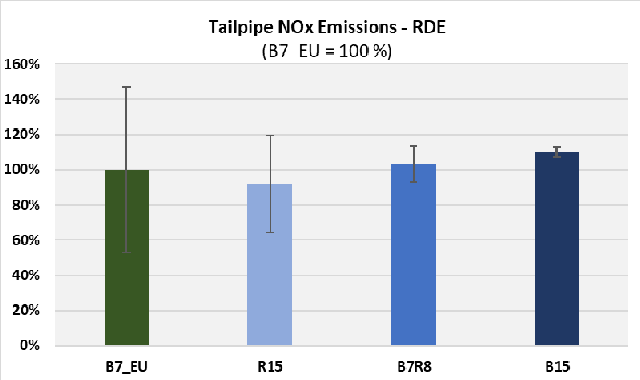

Figure 11. Tailpipe NOx Emissions – RDE.

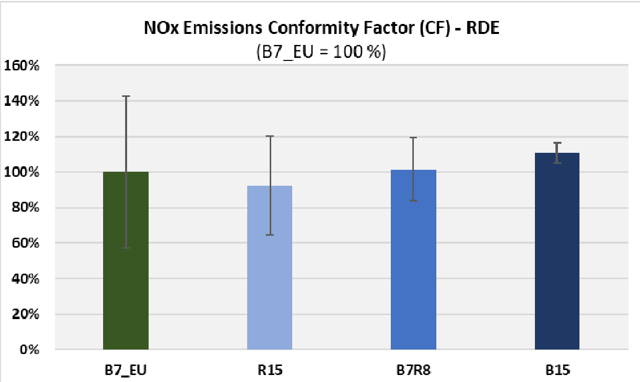

Figure 12. NOx Emissions Conformity Factor – RDE.

Regarding the comparison of emitted NOx and CF between the different fuels, the analysis revealed that:

- there were no statistically significant differences between the NOx results obtained with the use of the reference fuel at the beginning and at the end of the tests. In this way, the trials results with the reference were considered as a single set of data for further statistical analyses, as indicated in the section on data treatment;
- there were no statistically significant differences between the NOx results for all fuels tested;
- there were no statistically significant differences between the CF results for all fuels tested, showing, as expected, the same trend for NOx.

ENGINE BENCH EMISSIONS RESULTS – The NOx, PM and PN tailpipe emissions results, obtained at the engine bench, are presented for the stationary cycle WHSC in Figures 13 to 15 and for the transient cycle WHTC in Figures 16 to 18. As in the RDE tests, the data were normalized by assigning a value of 100 % to the European reference B7 fuel (B7 EU). These graphs also contain the confidence intervals of 1.96 times the standard deviation obtained with each fuel. Although the absolute results of emissions are not included in this article, they were also analyzed in terms of meeting the EURO VI limits.

WHSC Stationary Cycle – Figure 13 shows the tailpipe NOx comparative results between the different fuels in the WHSC cycle. Note that the confidence intervals calculated for the different fuels overlap, suggesting that there is no statistically significant difference between the results obtained, which was confirmed by ANOVA. All fuels met the maximum EURO VI phase (PROCONVE P8) limit of 400 mg/kWh for the NOx.

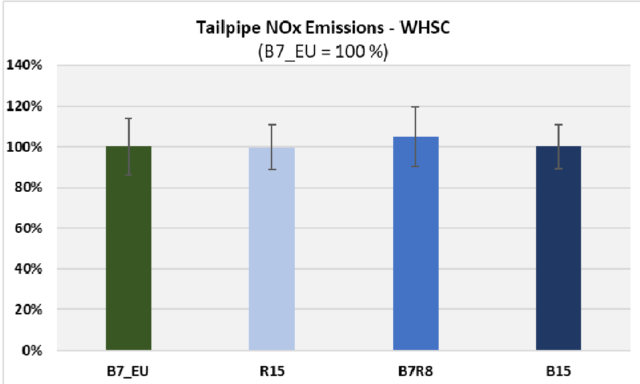

Figure 13. Tailpipe NOx Emissions – WHSC.

Figure 14 shows the comparison of PM (particulate matter) emissions in the WHSC cycle. Interposition of confidence intervals is observed, suggesting that there is no statistically significant difference between the results obtained, which was also confirmed by ANOVA. All fuels easily met the maximum limit established for the EURO VI phase (PROCONVE P8), of 10 mg/kWh.

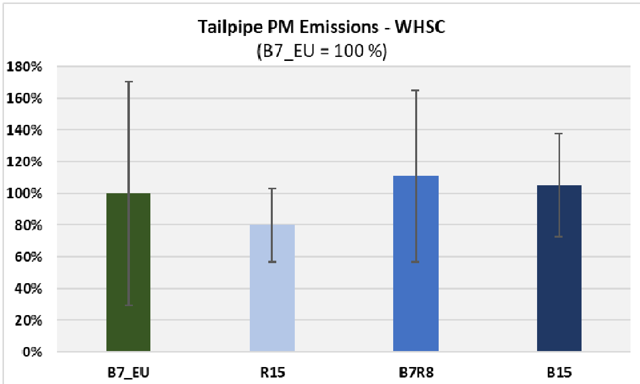

Figure 14. Tailpipe PM (particulate matter) Emissions – WHSC.

Figure 15 shows the comparison of PN (particle number) emissions. All fuels were also within the limits, staying at least two orders of magnitude below the maximum legislated limit (8.00E+11 #/kWh) for the WHSC cycle.

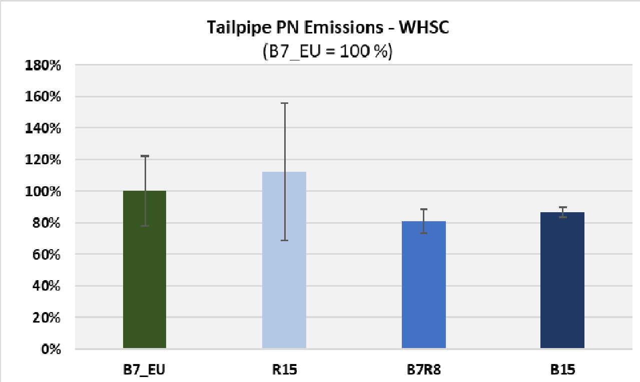

Figure 15. Tailpipe PN (particle number) Emissions – WHSC.

WHTC Transient Cycle – As for the WHTC transient cycle, it should be noted that the tests were performed in the hot/hot condition (without cold start). Although the absolute results of emissions are not included in this article, it is worth mentioning that, as a reference, the results were also analyzed regarding compliance with the EURO VI limits, defined for the cold/hot condition (with cold start).

Regarding NOx emissions in the WHTC cycle, all fuels were below the maximum limit of 460 mg/kWh of the EURO VI phase (PROCONVE P8), presenting similar performances, as can be seen in Figure 16. Clearly, the confidence intervals calculated for the different fuels overlap, suggesting that there is no statistically significant difference between the results obtained, which was confirmed by ANOVA.

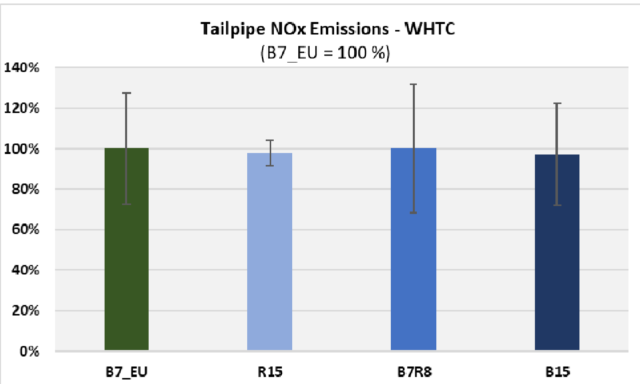

Figure 16. Tailpipe NOx Emissions – WHTC.

Regarding PM (particulate matter) emissions in the WHTC transient cycle, as in the WHSC stationary cycle, all fuels also presented results well below the maximum limit established for the EURO VI phase (PROCONVE P8), of 10 mg/kWh, and did not show any statistically significant difference in relation to the B7 reference fuel (Figure 17).

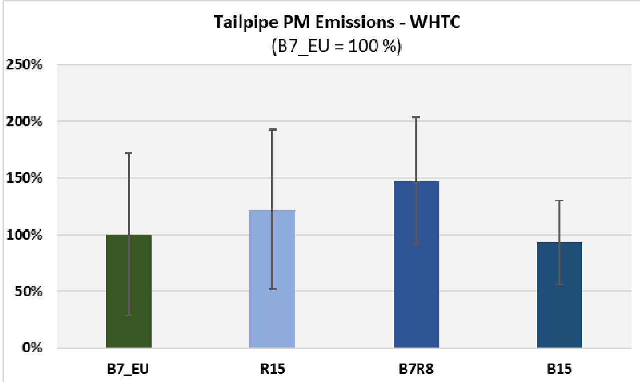

Figure 17. Tailpipe PM (particulate matter) Emissions – WHTC.

Figure 18 shows the comparisons of PN (particle number) emissions in the WHTC transient cycle. As in the WHSC stationary cycle, all fuels were within the limits with ease, staying at least two orders of magnitude below the maximum legislated limit (6.00E+11 #/kWh) for the WHTC cycle.

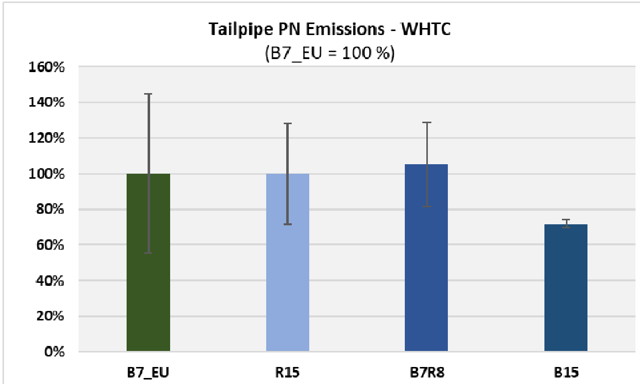

Figure 18. Tailpipe PN (particle number) Emissions – WHTC.

In general, considering the intrinsic measurements variations and the calculated confidence intervals, of 1.96 times the standard deviation, the results show similar NOx, PM and PN emissions performances between the different fuels, in the stationary (WHSC) and transient (WHTC) cycles, which was confirmed by the analysis of variance (ANOVA).

CONCLUSIONS

In this work, RDE tests and dynamometric bench tests were carried out to evaluate the impact of FAME and HVO diesel blends on the emissions of a vehicle and an engine, both EURO VI (equivalent to PROCONVE P8). It is worth noting that, in the case of RDE tests, the focus of the analysis was the NOx, while, in the bench tests, it was NOx, PM (particulate matter) and PN (particle number).

Three experimental fuels were evaluated, formulated from mixtures of S10 diesel, produced with national oils, with FAME and HVO: R15 (S10 diesel with 15 % HVO by volume); B7 R8 (S10 diesel with 7 % by volume of biodiesel and 8 % by volume of HVO) and B15 (S10 diesel with 15 % by volume of FAME). A European B7 diesel (B7 EU), emission approval standard, was adopted as the reference fuel for the work.

REAL DRIVING EMISSIONS - The evaluation of the NOx results of the RDE tests, carried out with the different fuels in an 18 t, 4 x 2 truck, year/model 2020, equipped with a 6.9 L, 290 hp EURO VI engine, revealed that:

- all fuels evaluated showed emissions within the EURO VI limits;
- there were no statistically significant differences between the tested fuels.

ENGINE BENCH – For the dynamometric bench emissions tests, a 12.4 L, 520 hp EURO VI engine was used. The tests in stationary (WHSC) and transient (WHTC) cycles with the different fuels revealed that:

- all fuels, regardless of the cycle tested, presented emissions within the limits required by the EURO VI phase for NOx, PM and PN;
- PN emissions obtained for all fuels remained at least two orders of magnitude below the legislated limits for both cycles;
- there were no statistically significant differences between all tested fuels in terms of NOx and PM emissions. In the case of PN, this analysis is not applicable due to the very low values found.

As mentioned in the introduction, for engines technologies up to EURO V, some publications report variations in NOx and PM emissions as a function of the increase in the FAME content in diesel fuel [6-10]. However, this work did not find statistically significant differences in NOx, PM and PN emissions for the R15, B7 R8, B15 and B7 EU fuels, in the bench and RDE tests performed with a EURO VI engine and vehicle. This result suggests that emissions are more influenced by engine and after-treatment technologies than by the fuel, which is consistent with references [10, 12].

REFERENCES

[1] Economic Commission for Europe of the United Nations (UN/ECE) -- Regulation Nº 49.06. Uniform provisions concerning the measures to be taken against the emission of gaseous and particulate pollutants from compression-ignition engines and positive ignition engines for use in vehicles. Revision 6. Geneva, 2013. 1 (unece.org)

[2] Brazil, Conselho Nacional do Meio Ambiente (Brazilian National Council for the Environment) – CONAMA. Resolution # 490 de 16.11.2018. https://www.legisweb.com.br/legislacao/?id=369514.

[3] Brazil, Governo Federal (Federal Government). Law # 11.097, January 13, 2005. Diário Oficial da União, Brasília, DF, January 14, 2005. http://www.planalto.gov.br/ccivil_03/_Ato2004-2006/2005/Lei/L11097.htm.

[4] Brazil, Conselho Nacional de Política Energética (National Energy Policy Council) - CNPE. Resolution # 16/2018. https://www.legisweb.com.br/legislacao/?id=369098.

[5] European Automobile Manufacturers' Association - ACEA. ACEA Position Paper - Revision of the Fuel Quality Directive (FQD), March, 2022. Position paper – Revision of the Fuel Quality Directive (FQD) - ACEA - European Automobile Manufacturers' Association.

[6] U.S. EPA. A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions (No. EPA420-P-02–001), 2002.

[7] U.S. EPA. Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis (No. EPA420 R-10-006), 2010.

[8] Empresa de Pesquisa Energética (Energy Research Company) – epe. Technical Note: Impacto na saúde humana pelo uso de biocombustíveis na Região Metropolitana de São Paulo, February, 2021. https://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-570/NT-EPE-DPG-SDB-2020-01_NT_Impacto_saude_uso_bios.pdf.

[9] Hoekman, S. K. & Robbins, C. Review of the effects of biodiesel on NOx emissions. Fuel Processing Technology, 96, 237–249, 2012. https://doi.org/10.1016/j.fuproc.2011.12.036.

[10] O'Malley J. & Searle S. Air Quality Impacts of Biodiesel in the United States. International Council on Clean Transportation – ICCT, 2021.

[11] Associação Brasileira de Normas Técnicas (Brazilian Association of Technical Standards) – ABNT. ABNT NBR 17011 - Veículos rodoviários automotores leves — Determinação de gases orgânicos não metano, hidrocarbonetos, monóxido de carbono, óxidos de nitrogênio e dióxido de carbono no gás de escapamento em tráfego real, March 18, 2022.

[12] Gomes, H. O., Melo, T.C.C., Silva, Moreira, M. F. Effect of ultra-low sulfur diesel quality on exhaust emission in EURO VI diesel engine. XXVII Simpósio Internacional de Engenharia Automotiva. SIMEA 2019, August, 2019.