Fuel saving through low viscosity lubricants: experimental validation challenges

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ABSTRACT

Increasing the efficiency of internal combustion engines, and the consequent reduction in fuel consumption of vehicles equipped with this technology, is a relevant strategy for mitigating greenhouse gas emissions. The experimental evaluation of new technologies represents greater challenges, since in most cases, the fuel saving effect is within test uncertainties. This article experimentally compares the use of low-viscosity lubricants in a passenger car, in emissions test cycles and proposes numerical compensations to mitigate the effect of test experimental variations using instantaneous values of the car speed and battery voltage. The vehicle fuel consumption was experimentally determined by carbon balance method. The measurement uncertainties are minimized considering the tests were performed in an OEM certified emissions laboratory, with tailpipe gases collected by constant volume sampling (CVS) system. On the FTP75 cycle, the use of 5W20 brought 3.5% fuel savings and 6.8% with the 0W16 in comparison to the reference 5W40 oil. Pollutant emissions did not show significant variation.

INTRODUCTION

Recent and continuous concern regarding greenhouse gases (GHG) emissions pushes vehicle powertrain efficiency. Conventional internal combustion engines, constructed with alternative mechanisms, dissipate a significant amount of fuel energy through friction to work. This mechanical friction is significantly affected by lubricant properties and, both lower viscosity lubricants and friction modifier (FM) additives are used to reduce engine friction.

Lubricant viscosity effect is more pronounced in hydrodynamic regime, but low viscosity lubricant could lead to higher friction in boundary regime, caused by increase of asperity contact. The use of FM significantly reduces or even annuls potentially higher asperity friction with low viscosity lubricants, more pronounced in lower engine speeds, according to Taylor et al. [1]. Vaitkunaite et al. [2] investigated the benefits of molybdenum dialkyldithiocarbamate (MoDTC) additive as FM in a floating liner in a fired engine test bench and confirmed the friction force reduction with the increase of FM concentration, mainly close to piston bottom dead center (BDC) where boundary lubricant regime is more pronounced. Skjoedt et al. [3] measured the effect of lubricant viscosity and FM on fuel economy of a 2.5 L gasoline engine in two dyno conditions: low engine speed / high load and high engine speed / low load. The lubricant viscosity reduction from 10W40 to 5W20 resulted in 1.0 to 5.5% fuel economy improvement, with higher values in low boundary regimes (high speed and low load). On the other hand, the MoDTC FM resulted in higher fuel economy in high boundary regimes (low speed / high load), with fuel economy improvement from 0.9 to 2.6%. Organic FM presented lower, about half of MoDTC, impact on fuel economy. Dubey et al. [4] compared Molybdenum inorganic FM (MoDTC) with organic FM and observed better tribological performance of MoDTC, with thicker protective tribo-film and higher friction reduction in boundary lubrication regime. Cui et al. [5] observed a 2.7% reduction in fuel consumption in FTP75 cycle in a vehicle equipped with a 1.4 L turbocharged engine when replacing the 15W40 by a 0W20 lubricant. Lee and Zhmud [6] achieved up to 4% fuel economy in NEDC with the replacement of a 15W40 by a 0W20 lubricant.

MATERIALS AND METHODS

ENGINE LUBRICANTS – Three low viscosity fully formulated proposals were characterized and compared with baseline oil 5W40, see Table 1. The 0W20 and 5W20 proposals have the same API (American Petroleum Institute) classification of the baseline 5W40. Only the 0W16 proposal has molybdenum (Mo) as friction modifier (FM) and higher API than the considered lubricants. Additionally, an experimental graphene-based additive was added on the 5W20 oil in a concentration of 0.1% of graphene. See details in Tomanik et al. [7].

Table 1. Main characteristics of tested oils.

	API	KV40	KV10	FM	Mo	GNP
		mm^2/s			ppm	wt%
5W40	SN	81.75	13.52	No	-	-
5W20	SN	45.04	8.15	No	-	-
5W20 + GNP	-	49.26	8.74	No	-	0.1
0W20	SN	45.79	8.78	No	-	-
0W16	SP	29.62	6.51	Yes	900	-

The lubricants viscosity behavior with temperature is shown in Figure 1. The increase in viscosity in low temperatures significantly impacts fuel economy during cold phase, as already observed by Roberts, Brooks and Shipway [8], with clear advantage of 0W16. Brazilian homologation standards consider cold start above 10°C in Real Drive Emissions (RDE) of NBR 17011 [9] and between 20 and 30°C in emissions tests of NBR 6601 [10]. The 0W20 and 5W20 viscosities are very similar above +10°C with expected similar impact in fuel consumption, and 0W20 was not tested in vehicle.

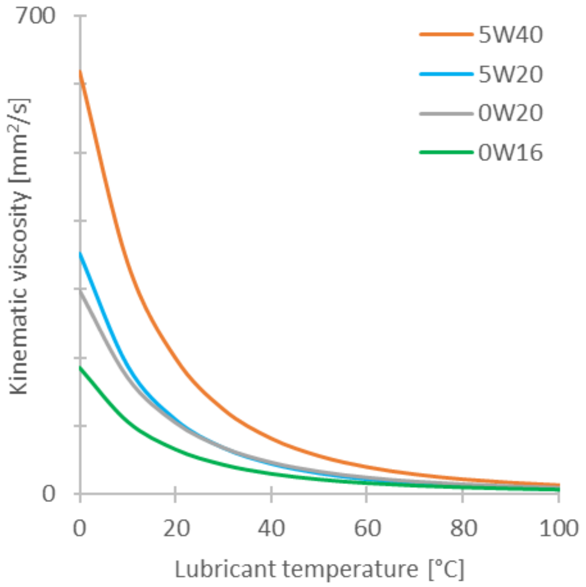

Figure 1. Lubricants' viscosity behavior with temperature.

EXPERIMENTAL TESTS IN VEHICLE – A large SUV equipped with flex fuel spark ignition engine was used to measure fuel consumption with Brazilian reference gasoline (E22) in the combined cycle (NBR 7024) [11]. The tailpipe pollutant emissions were measured according to NBR 6601 [10]. See vehicle characteristics in Table 2.

Table 2. Main characteristics of tested vehicle.

Vehicle category	Large SUV
Engine	1.4 l, 4 cyl., turbo, direct injection
Engine oil pump	Variable
Engine start-stop	Disabled
Transmission	Aut., 6 speed, torque converter

The baseline 5W40 engine lubricant was compared with 5W20, 5W20+GNP with graphene additive and 0W16 low viscosity proposals. To avoid lubricant contamination the lubricant change was performed in two steps. First the oil was drained, a new lubricant filter installed, and the engine was flushed by 10 min in idle with new lubricant. In the second step the lubricant was drained, the lubricant filter changed, and the engine filled with new lubricant of same sample. After this procedure the vehicle was sent to the emissions laboratory.

The vehicle fuel consumption was experimentally determined by carbon balance method. The measurement uncertainties are minimized considering the tests were performed in an OEM certified emissions laboratory equipped with a single 48 inches dyno roll, which assures a single tire contact point and better repeatability, with tailpipe gases collected by a constant volume sampling (CVS) system. Two tests were performed for each lubricant sample. The test repeatability was improved keeping the same: vehicle, fuel, driver and test cell. The start-stop function was disabled by the vehicle infotainment to avoid its influence on different tests. The vehicle 12V lead acid-enhanced flooded battery (EFB) recharging is performed with a smart alternator by a strategy based on battery monitoring system (BMS). Test variability was compensated regarding vehicle speed and battery voltage, recorded through the tests. These data were input in a 1-D simulation model of this vehicle to calculate test compensation factors following the procedure detailed by Rovai and Tomanik [12].

The engine speed and brake mean effective pressure (BMEP) was calculated by the 1-D simulation model through in-cycle performed tests considering vehicle inertia, drag coefficients, transmission efficiency map and transmission control unit (TCU) shifting strategy. The engine friction mean effective pressure ($FMEP_{base}$) was determined with baseline 5W40 lubricant at steady temperature conditions in a motoring procedure performed in an active dyno bench. The engine FMEP with low viscosity lubricant proposals ($FMEP_{prop}$) were calculated by Equation 1, according to Rovai et al. [13]. The 5W20+GNP viscosity was not measured, and assuming the GNP has no significant impact on lubricant viscosity, the calculated FMEP was the same for 5W20 and 5W20+GNP.

$$\frac{FMEP_{prop}}{FMEP_{base}} = \left(\frac{Kv_{prop}}{Kv_{base}}\right)^{i} \qquad (Eq.1)$$

$FMEP_{prop}$ = lubricant proposal FMEP [bar],

$FMEP_{base}$ = baseline lubricant (5W40) FMEP [bar],

Kv_{prop} = lubricant proposal kinematic viscosity [mm^2/s],

Kv_{base} = lubricant baseline kinematic viscosity [mm^2/s].

RESULTS AND DISCUSSION

FUEL CONSUMPTION RESULTS – The fuel consumption results measured in vehicle according to NBR 7024 [11], were plotted in Figure 2 in FTP75, Figure 3 in Highway and in Figure 4 in Combined cycle. The range of the percentual fuel economy improvement (FEI) of each proposed lubricant related to baseline 5W40 were calculated by the difference between extremes best and worst result of each proposal against baseline. The average values were pointed at the middle of the plotted bars.

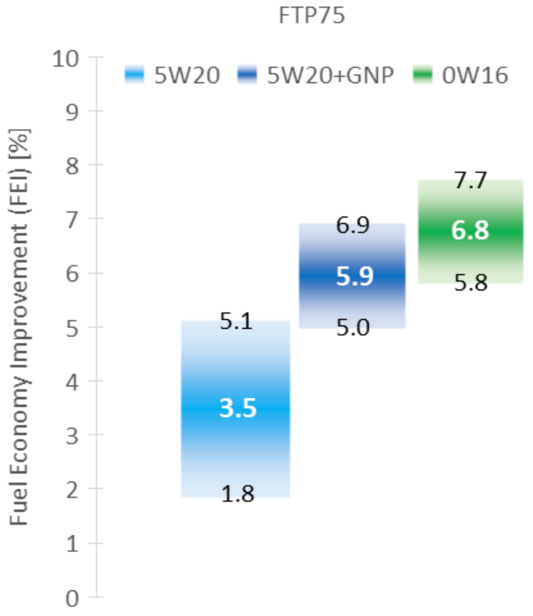

Figure 2. Test results in FTP75 cycle.

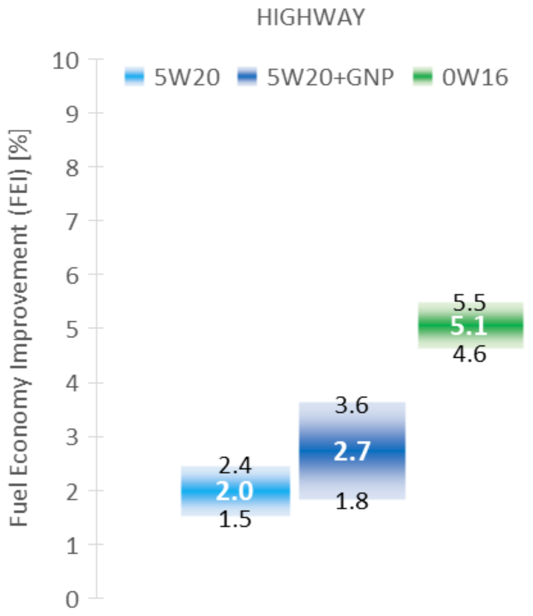

Figure 3. Test results in Highway cycle.

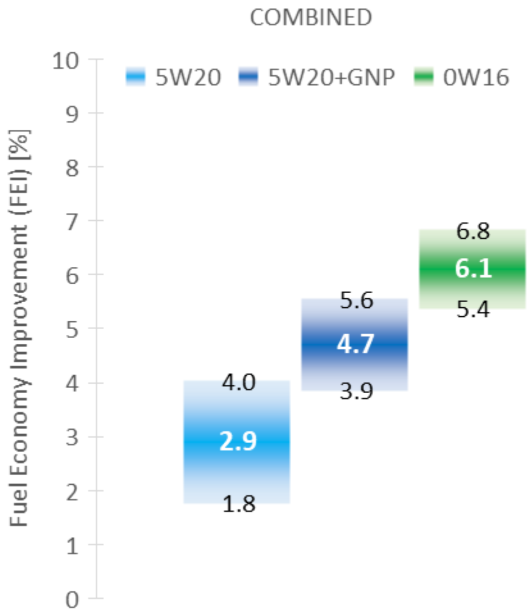

Figure 4. Test results in Combined cycle.

The highest dispersion of 1.7% was observed in FTP75 with 5W20. The dispersion of the other results was close to or below 1%. The 5W20 improvements on fuel economy were enhanced by 5W20+GNP and 0W16 in any test conditions. These results confirm the low viscosity and FM additives impact on the fuel economy. Measuring dispersion sometimes overlaps FEI of two close lubricant proposals but with a clear tendency of advantage of tested oils of average values.

Lubricant viscosity impact on FEI is represented by 5W20 compared to 5W40. The advantage of 0W16 is the sum of low viscosity and FM effects.

The GNP additive improvement can be emphasized comparing 5W20 and 5W20+GNP, with more significant fuel economy variation in lower engine speeds, observed in urban use, showing the positive impact of GNP reducing the asperity contact in boundary lubrication regime. Even though, significant fuel economy was measured in highway cycle with GNP.

Higher FEI were observed in FTP75, an urban cycle, which runs in lower vehicle speed and load. The highway cycle represents road use at higher speeds. The average baseline FMEP over IMEP ratio, with IMEP calculated by the sum of BMEP and FMEP, in Table 3, points engine friction is more pronounced in FTP75 cycle, what explains the better results measured in this test cycle. In Table 3 the friction ratio in highway cycle is little higher than the half ratio in FTP75.

Table 3. Average baseline FMEP over IMEP ratio.

	$FMEP_{base}$ / $IMEP_{base}$ [%]
FTP75	10.0
HIGHWAY	5.5
COMBINED	7.2

Tomanik et al. [14] proposed a calculated fuel economy improvement (FEI_{calc}) based on engine FMEP reduction with a low viscosity lubricant over engine IMEP (Equation 2).

$$FEI_{calc} = \frac{FMEP_{base} - FMEP_{prop}}{IMEP_{base}} \qquad (Eq.2)$$

FEI_{calc} = calculated fuel economy improvement [%],

$FMEP_{prop}$ = lubricant proposal FMEP [bar],

$FMEP_{base}$ = baseline lubricant (5W40) FMEP [bar],

$IMEP_{base}$ = baseline lubricant indicated mean effective pressure, calculated by the sum of brake mean effective pressure and friction mean effective pressure [bar].

The fuel economy improvement was calculated (FEI_{calc}) for two proposed low viscosities, see Table 4. The expected FEI resulted the same for 5W20 and 5W20+GNP because the GNP impact on lubricants was not measured and supposed to be negligible due to its low concentration.

Table 4. Calculated fuel economy improvement (FEI).

	FEI_{calc} [%]	
	5W20 or 5W20+GNP	**0W16**
FTP75	5.3	7.1
HIGHWAY	2.3	3.7
COMBINED	3.4	5.0

The FEI deviation of experimental measurements and calculated values is determined by Equation 3, with positive values for a conservative calculation, higher experimental results than expected by calculated FEI, and vice versa.

$$FEI_{dev} = FEI_{meas} - FEI_{calc} \qquad (Eq.3)$$

FEI_{dev} = fuel economy improvement deviation [%],

FEI_{meas} = average measured fuel economy improvement [%],

FEI_{calc} = calculated fuel economy improvement [%].

The FEI measured deviation (FEI_{dev}) was calculated for the three tested oils with the results in Table 5. The FEI_{dev} resulted in negative values for 5W20, pointing to higher expectations from this calculation method. The FEI_{dev} became positive, switching to conservative values, for both samples with additives, showing the potential of the additives on fuel economy improvement. The FEI_{calc} method resulted in higher FEI for lubricant viscosity and conservative values for FM additives.

Table 5. Fuel economy improvement (FEI) deviation.

	FEI_{dev} [%]		
	5W20	**5W20+GNP**	**0W16**
FTP75	-1.8	+0.6	-0.3
HIGHWAY	-0.3	+0.4	+1.4
COMBINED	-0.5	+1.3	+1.1

POLLUTANT EMISSIONS – Tailpipe pollutant emissions were measured following NBR 6601 [10]. The percentual variations of average values of two FTP75 emissions tests with each lubricant are shown in Table 6.

Table 6. Tailpipe pollutant emissions in FTP75.

	NMOG [%]	**NOx [%]**	**NMOG+NOx [%]**	**CO [%]**
5W40	Ref	Ref	Ref	Ref
5W20	+1.7	+32.8	+14.9	+0.2
5W20 + GNP	+5.7	-26.9	-8.1	+19.8
0W16	-1.3	-35.0	-15.6	+17.9

Reference tests with 5W40 presented tailpipe NMOG+NOx emissions below 50% of PL7 legal limits, and CO emissions around 10% of Brazilian PROCONVE L7 legal limits (PL7) [15]. The small NMOG variations are an indicative that no significant impact of low viscosity lubricants on lubricant consumption was observed in the tests performed. The NOx emissions variations can be considered normal, as NOx emissions are less stable than NMOG, besides they were balanced by the regulated sum of NMOG+NOx. Even the 19.8% variation of CO emissions with 5W20+GNP keeps the absolute values very far from maximum limit. The particulate number (PM) was measured at 5W20+GNP, and the values were within usual measurements for this application, which discards any GNP effect on PM.

LUBRICANT FUEL DILLUTION – Lubricant fuel dilution is an important concern, especially considering flex fuel vehicles running on ethanol in low usage conditions, not rarely observed in Brazilian fleet. The cold start and warm up conditions demand fuel enrichment to stabilize combustion against fuel deposition on the intake system, and part of this fuel dilutes lubricant. In low usage cycles the lubricant could not reach temperature to evaporate the fuel diluted in lubricant which contributes to reduce lubricant viscosity. In this condition the blow-by system becomes less efficient to separate lubricant from blow-by flow, increasing lubricant consumption and emissions. Additionally, the lower lubricant viscosity could lead to poor engine lubrication compromising durability. According to Taylor et al. [1] and Costa, Cousseau and Souza [16].

ENGINE WEAR AND DURABILITY – According to Lee and Zhmud [6], the ultralow viscosity lubricants can expose engine parts beyond the limits with higher wear and lower durability consequences, more pronounced in low engine speeds and high loads. Blanco-Rodríguez et al. [17] observes that lower lubricant viscosity contributes to reduce frictional losses in hydrodynamic regime but could imply in higher engine wear in mixed and boundary lubrication regimes by higher asperity friction. Zhang et al. [18] observed the lower viscosity advantages in fuel economy, mostly observed in higher engine speeds, can be neutralized by asperity friction in lower engine speeds.

The FM content in tested 0W16, that should protect engine against excessive wear, but the extreme conditions were not visited along emissions tests. Despite the tested engine is equipped with a variable oil pump and it is already validated with 0W20, and no abnormal engine noise or malfunction were noticed during tests, the release of a 0W16 demands engineering development, e.g. durability tests.

CONCLUSIONS

The potential of low viscosity lubricants and FM additives was confirmed by experimental vehicle test in-cycle. The lubricant viscosity reduction from 5W40 to 5W20 resulted in 1.8 to 4.0% FEI in combined cycle. The addition of GNP additive enhanced the FEI of 5W20 to 3.9 to 5.6%. The 0W16 lubricant with Mo additive as FM resulted in 5.4 to 6.8% FEI in combined cycle.

The FEI results were more pronounced in FTP75 than in Highway cycle, confirming the higher engine friction impact on fuel economy in urban cycle. The expected FEI calculated by engine FMEP over IMEP ratio resulted in the right tendency for the tested lubricants, in general with about 1% deviation from the measured results.

Despite no vehicle problem being observed during the tests, regarding pollutant emissions, lubricant consumption or abnormal engine noise, it should be remarked that higher engine speeds and loads were not visited in the carried-out emissions tests and must demand specific validation. Engine durability, oil change interval, and blow-by system performance must be deeply validated, especially considering the potentially higher fuel dilution of low viscosity lubricants and the ethanol use in Brazilian flex fuel applications. Also, the effect of adding GNP on the long-term performance of exhaust system components, e.g.

oxygen sensors and catalytic converters, need to be carefully observed.

REFERENCES

1. TAYLOR, R. I. et al. How much mixed/boundary friction is there in an engine—and where is it? **Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology**, v. 234, n. 10, p. 1563-1579, 2020.

2. VAITKUNAITE, Gerda et al. Low friction tribofilm formation and distribution on an engine cylinder tested with MoDTC-containing low viscosity engine lubricants. **Tribology International**, v. 171, p. 107551, 2022.

3. SKJOEDT, Martin et al. Effects of oil properties on spark-ignition gasoline engine friction. **Tribology International**, v. 41, n. 6, p. 556-563, 2008.

4. DUBEY, Mukesh Kumar et al. Tribological evaluation of passenger car engine oil: Effect of friction modifiers. **Results in Engineering**, v. 16, p. 100727, 2022.

5. CUI, Jun et al. **Measuring Fuel Efficiency in Various Driving Cycles: How to Get Maximum Fuel Economy Improvement from the Lubricant**. SAE Technical Paper, 2015.

6. LEE, Peter; ZHMUD, Boris. Low friction powertrains: Current advances in lubricants and coatings. **Lubricants**, v. 9, n. 8, p. 74, 2021.

7. TOMANIK, Eduardo et al. Effect of Graphene Nanoplatelets as Lubricant Additive on Fuel Consumption During Vehicle Emission Tests. **Eng**, v. 6, n. 1, p. 18, 2025.

8. ROBERTS, Andrew; BROOKS, Richard; SHIPWAY, Philip. Internal combustion engine cold-start efficiency: A review of the problem, causes and potential solutions. **Energy conversion and management**, v. 82, p. 327-350, 2014.

9. ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (ABNT) NBR17011; Light Duty Road Vehicles—Determination of Non-Methane Organic Gases, Hydrocarbon, Carbon Monoxide, Nitrogen Oxide and Carbon Dioxide on Exhaust Gas in Real Driving. Rio de Janeiro, 2022.

10. ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (ABNT). NBR6601: Veículos rodoviários automotores leves – Determinação de hidrocarbonetos, monóxido de carbono, óxidos de nitrogênio, dióxido de carbono e material particulado no gás de escapamento. Rio de Janeiro, 2021, 57p.

11. ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (ABNT). NBR7024: Veículos rodoviários automotores leves – Medição do consumo de combustível – Método de ensaio. Rio de Janeiro, 2010, 13p.

12. ROVAI, Fernando Fusco; TOMANIK, Eduardo. Lubricant viscosity impact in fuel economy: Experimental uncertainties compensation. **Lubricants**, v. 13, n. 2, p. 49, 2025.

13. ROVAI, Fernando Fusco et al. Engine Lubricant Impact in Light-Vehicle Fuel Economy: A Combined Numerical Simulation and Experimental Validation. **Lubricants**, v. 13, n. 4, p. 137, 2025.

14. TOMANIK, Eduardo et al. Combined lubricant–surface system approach for potential passenger car CO_2 reduction on piston-ring-cylinder bore assembly. **Tribology International**, v. 149, p. 105514, 2020.

15. CONSELHO NACIONAL DO MEIO AMBIENTE (CONAMA). Resolução nº 492, de 20 de dezembro de 2018. Estabelece as Fases do PROCONVE L7 e PROCONVE L8 de exigências do Programa de Controle da Poluição do Ar por Veículos Automotores – PROCONVE para veículos automotores leves novos de uso rodoviário.

16. COSTA, Henara Lillian; COUSSEAU, Tiago; SOUZA, Roberto Martins. Current knowledge on friction, lubrication, and wear of ethanol-fuelled engines—A review. **Lubricants**, v. 11, n. 7, p. 292, 2023.

17. BLANCO-RODRÍGUEZ, Javier et al. Modelling the impact of reducing lubricant viscosity on a conventional passenger car fuel economy and wear protection. **Results in Engineering**, v. 24, p. 103159, 2024.

18. ZHANG, Yanyan et al. The effects of ultra-low viscosity engine oil on mechanical efficiency and fuel economy. **Energies**, v. 14, n. 8, p. 2320, 2021.

DEFINITIONS / ABBREVIATIONS

API	American Petroleum Institute
BDC	Bottom Dead Center
BMEP	Brake Mean Effective Pressure

BMS Battery Management System

CO Carbon Monoxide

CVS Constant Volume Sampling

E22 Brazilian Reference Gasoline with 22% v/v of ethanol

EFB Lead Acid-Enhanced Flooded Battery

FEI Fuel Economy Improvement

FM Friction Modifier

FMEP Friction Mean Effective Pressure

FTP75 Federal Test Procedure

GHG Greenhouse Gases

GNP Graphene Nanoplatelets

IMEP Indicated Mean Effective Pressure

KV Kinematic Viscosity

MoDTC Molybdenum Dialkyldithiocarbamate

NBR Brazilian Technical Standards

NEDC New European Driving Cycle

NMOG Non-Methane Organic Gases

NOx Nitrous Oxides

OEM Original Equipment Manufacturer

PL7 PROCONVE Light Vehicles Level 7

PROCONVE Brazilian Vehicle Emissions Control Program

RDE Real Driving Emissions

SUV Sport Utility Vehicle

TCU Transmission Control Unit