A CRITICAL REVIEW OF HC EMISSIONS CALCULATION IN BRAZILIAN NORMATIVE FOR LIGHT VEHICLES AND MOTORCYCLES

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ABSTRACT

When Brazil introduced its vehicular pollution control program (PROCONVE) in 1986, FTP-75 procedure was adopted as a reference to the Brazilian normative 6601 for light-duty vehicles; a few years later the motorcycle's normative followed the same emissions calculation factors. Considering that HC directly jeopardizes human health and also indirectly as precursor to ozone, this paper aims to review this factor and compare it with other procedures in the world, in order to present a more accurate calculation of HC emissions from vehicles. Results from revised tests showed differences in NMHC emissions of up to +66%, resulting in an major impact in the Emissions Inventory; so these more accurate values had become relevant to have more effective air pollution public policies.

INTRODUCTION

Since 1970, vehicle manufacturers in California, United States, must comply with the limits for hydrocarbons (HC) and nitrogen oxides (NOx) emissions [1]. The United States Environmental Protection Agency (US EPA) developed a standard called Federal Test Procedure 75, or FTP-75 for short, to measure in laboratories these emissions from light duty vehicles (LDV), what allows repeatability in the results [2].

In Brazil, since 1986 the regulatory procedure is the normative ABNT 6601, which was based on FTP-75 and uses the same calculations criteria to express the results [3 ABNT 6601]. Ethanol is an important renewable automotive biofuel and its consumption is increasing worldwide, being used in more than 60 countries, including Brazil [4]. In the Sao Paulo State, from 2006 to 2018, the volume of ethanol consumed is almost the same that of gasoline [CETEB Emissões Veiculares] and the ethanol concentration in the gasoline blend is growing; since 2015 it is 27% for regular gasoline [5].

A main parameter in calculating HC is its density in the exhaust gas but this value is the same for gasoline and ethanol in some procedures, although ethanol density in the exhaust gas is higher than HC from gasoline, which introduces a bias in the results. Thus, the objective of this paper is to present the HC emission corrected for the densities of the Brazilian fuels and to estimate the impact on the vehicular emission inventory in the Sao Paulo Metropolitan Area (SPMA).

RELEVANCE OF HYDROCARBONS EMISSION

Hydrocarbon is a term applied to hundreds of different chemical compounds, which contain mainly hydrogen and carbon in their molecular composition, e.g. hexane, benzene, toluene, ethylene, naphthalene and xylene, and usually come from fossil crude oil. The measurement of HC in vehicular emissions laboratory is done by flame ionization detector (FID) that detects almost any flammable organic compound, whatever their composition, so the result is express in Total Hydrocarbon (THC) or simply HC [6].

Many HC compounds are toxic and/or carcinogenic and can contaminate air, soil and water, jeopardizing the environment and human health, causing issues in the fetus development, and also affect hematological, hepatic, immune and renal systems of children and adults [7] [8] [9]. In addition, some HC are precursors to ozone (O_3), the main pollutant in several urban centers, such as the SPMA, together with fine particulate matter [10].

On the hand, ethanol is an organic compound whose molecular formula is C_2H_5OH. The FID cannot distinguish ethanol from HC in the exhaust gas, so the result is expressed as THC, even when the vehicle is burning 100% ethanol; a chromatography or FTIR analyzer would be required to measure individual compounds. Ethanol has less toxicity than HC, although its combustion in the engine and its oxidation in the atmosphere produces acetaldehyde, which is also a precursor to O_3 [11] [12]. Adding to its lower toxicity, ethanol is renewable, so reduces GHG emission from vehicles by at least 75% when compared to gasoline [13].

CALCULATION METHOD AND HC DENSITY ISSUE

FTP-75 CALCULATION METHOD – The FTP-75 cycle is a variant of the EPA Urban Dynamometer Driving Schedule (UDDS) and simulates an 18 km trip in Los Angeles Metropolitan Region, with frequent stops and a short highway trip [2] [14]. The test must be carried out in the laboratory, under controlled conditions, regarding the cycle (speed and distance), temperature, humidity and fuel quality, with the vehicle being driven on rollers and following a standardized driving cycle, while exhaust gas is collected in bags to be analyzed after each test phase, one bag for each of three test phases (cold start, urban trip, hot start) [15].

The pollutant emission is calculated in grams per kilometer (g/km) and the main parameters involved in the equations are the concentration of pollutants in parts per million (ppm), total gas volume sampled in cubic meters (m^3), density of pollutants in grams per cubic meter (g/m^3) and distance travelled in kilometers (km), in the respective test interval. An important point to note here is that according to FTP-75, the density of NOx is 1912 g/m^3, carbon monoxide (CO) is 1164 g/m^3, and carbon dioxide (CO_2) is 1830 g/m^3, they are always the same, no matter what fuel is burned, but for HC this value depends on the fuel composition; for example for pure gasoline or diesel, HC density is 576.8 g/m^3 [15].

HC DENSITY: DIFFERENT CRITERIA USED IN DIFFERENT PROCEDURES – The New European Driving Cycle until 2016 followed the same calculation method and factors as the American method, defining the HC density of 576.8 g/m^3 for gasoline E0 and diesel [16]. The notation used for gasoline-ethanol blends is based in the percentage ethanol content, so pure gasoline is called E0, which means that there is no ethanol mixture; on the other hand, 100% ethanol is called E100. For example, a gasoline-ethanol E22 blend means a fuel with 78% gasoline and 22% ethanol by volume; so, E85 is a blend with 85% ethanol and 15% gasoline.

Since 2017, Europe changed the testing procedure, adopting the global procedures World Motorcycle Test Cycle (WMTC) for motorcycles and the Worldwide Harmonized Light Vehicles Procedure (WLTP) for LDV [17]. These global procedures were developed by the UN technical body in order to be more realistic [18]. WMTC, in addition to Europe, is adopted by Brazil, China, Japan, India, South Korea and others [17], and in this new procedure the HC density remains the same than the previous one, 576.8 g/m3 for gasoline E0 [19].

By other side, WLTP has been implemented by all UNECE members: EU, Turkey, Norway, Iceland, Switzerland and Israel, and it is being implemented in Japan and China [17] [20], but in this procedure, the HC density is specified for different fuels, e.g. 632.0 g/m^3 for gasoline E5 or 934.0 g/m^3 for ethanol E85 [21].

Apart from the laboratory type-approval tests, since 2017, LDV in Europe must comply with real world requirements, with the vehicle being evaluated by the Real Driving Emissions (RDE) procedure [17], which follows the same calculation criteria and densities as WLTP [22].

In the 1980s in Brazil, the ethanol proportion in gasoline was only 10%, so the Brazilian automotive engineering community adopted the same factor for HC density as FTP-75, because they considered the difference negligible; however, in the 1990s the ethanol proportion rose to 20-25% and the differences in the HC results become more significant, as shown in Table 2.

For motorcycles, as previously mentioned, Brazil adopts the normative ABNT 16369, based on WMTC procedure, with only one factor for HC density [23], although 53% of the motorcycles sold in Brazil in 2018 were flexfuel [24].

Table 1 summarizes some of the procedures and HC densities applied worldwide.

Table 1: HC densities and procedures

Country or region	Application	Procedure	HC density (g/m3)
USA	Passenger cars	FTP-75	E0: 576.8 at 20°C
UN ECE (Global)	Passenger cars	WLTP	E5: 632 at 0°C E85: 934 at 0°C
	Motorcycles	WMTC	E0: 577 at 20°C

Europe	Passenger cars	RDE	E10: 646 at 0°C E85: 934 at 0°C
Brazil	Passenger cars	Normative ABNT 6601	E22 and E100: 576.8 at 20°C
	Motorcycles	Normative ABNT 16369	E22 and E100: 576.8 at 20°C

DETERMINING HC DENSITY FOR THE BRAZILIAN FUELS

The Brazilian type-approval regulation determines that the tests must be carried with three fuel options: gasoline E22, ethanol E100 and a blend 50% E22 and 50% E100, also called E61 [25]. According to UNECE GTR-15 [21] the following equation must be applied to determine HC densities:

$$\rho_{HC} - \frac{- \quad -}{\quad}$$

Where:

MWc: molar mass of carbon (12.011 g/mol);

MWh: molar mass of hydrogen (1.008 g/mol);

MWo: molar mass of oxygen (15.999 g/mol)

VM: molar volume of an ideal gas at 293.15 K (20° C) and 101.325 kPa (24.054 l/mol)

For E22 ($CH_{2.02}O_{0.073}$):

$$- \quad \frac{\quad}{\quad} \quad -$$

For E61 ($CH_{2.41}O_{0,243}$):

$$- \quad \frac{\quad}{\quad} \quad -$$

For E100 ($CH_3O_{0,5}$):

$$- \quad \frac{\quad}{\quad} \quad -$$

Table 2 shows the HC densities and their percentage differences from gasoline E0 for the fuel proportion used in the Brazilian type approval tests.

Table 2: HC density for Brazilian fuels

Fuel	Density (g/m^3)	Δ % from E0
E22	632.1	+9.6%
E61	761.6	+32.0%
E100	957.7	+66.0%

As an example, these factors were applied in tests performed into the CETESB vehicular laboratory. The vehicle measured is a compact passenger car, 1.0 liter engine, flexfuel, manual transmission, manufactured in 2014, thus under PROCONVE phase L-5, equivalent to European Euro 4, which has a limit of 0.05 g/km for non-methane HC (NMHC) [25]. It is important to note that the vehicle has a mileage of about 76,000 km and was fueled with commercial fuel, so these results can be compared with each other but should not be used for regulatory proposals.

The vehicle was tested in ABNT 6601 procedure, running on gasoline E22 and ethanol E100 and the NMHC emissions measured were 0.027 g/km for E22 and 0.145 g/km for E100. Recalculating them with the respective densities, the results are 0.030 g/km for E22 and 0.240 g/km for E100.

IMPACT OF THE REVISED FACTORS ON THE EMISSIONS INVENTORY

In vehicular emissions inventories, the emissions are calculated based on the estimated fleet of a region and weighted averaged emissions, average annual mileage, type of fuel, and deterioration due aging, among other factors. So, if the ethanol proportion was taken in account in the inventories, it would certainly change the HC estimation. Taking as example, the Table 3 shows the HC emission in 2018 in the SPMA, and the projection recalculated with the revised factors [26].

Table 3: HC inventory in SPMA in 2018 (in tons/year)

	HC as in normative ABNT 6601	Share	Reviewed HC density	Δ %
Cars	22,132	84.1%	24,626	+11.3%
Motor cycles	2,933	11.1%	3,251	+10.8%

HDV	1,262	4.8%	1,262	-
Total	26,327 t/y	100 %	29,139 t/y	
Total increment:			**+2,812**	**+10.7%**

It is important to consider that HC emission in vehicle emissions inventory comes from several sources, such as exhaust pipeline, evaporative and refueling but in this study the revised densities were applied only for exhaust emission.

CONCLUSIONS

The difference found in the ethanol density in comparison to gasoline is significant, affecting laboratory results and bringing an overall impact in HC inventory of around 11%. However, this emission is already being produced now, affecting ozone levels and impacting the environment but it is just not being taken into account in the emission inventories that could lead to misleading the need to reduce THC and ethanol emissions for reduce O_3 levels in Brazilian metropolitan areas. However, it is necessary to keep in mind that ethanol emissions are generally less toxic than fossil fuels emission for human health. Ethanol is also an important global option for renewable fuel, helping to reduce GHG emissions and mitigating climate changes. Moreover, the ethanol engine technology is well developed, it is not just a future or possible application but it is a real option.

However, regulatory limits are based on the values found in the laboratory tests, therefore the revision of the calculations can lead to rethinking future regulatory limits for homologation, either by defining new limits or by keeping them as today but under a more accurate measurement.

It is certain that the environment will be positively affected if real improvements can be achieved in reducing the emission of pollutants from vehicles, if they are measured correctly, in particular those compounds that are precursors to ozone.

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