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EMISSIONS OF CARBON DIOXIDE, CO_2, FOR AUTOMOTIVE OF TETRA FUEL (GASOLINE-ETHANOL-MGV)

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Abstract. *The first decades of the 20th century were marked by innovation and continuous improvement of energy conversion processes in various forms of work production. The control of pollution from greenhouse gases, for motor vehicles and other sources, has been sought by many researchers, mainly due to the increase of CO_2 emissions, boosting the Governments and non-governmental entities to seek solutions for the reduction of the concentration of this gas in Earth's atmosphere. With the need for reorganization of the mobility in big cities due to the increase in the number of motor vehicles in circulation on urban roads, it is essential to develop studies to support public management in technical and scientific knowledge for the control of environmental pollution caused by the burning of fossil fuels and oxygenated by vehicular internal combustion engines. Public policies that encourage the use of alternatives that include the reduction in vehicular energy consumption and, consequently, CO_2 reduction, should be offered from scientific studies based on alternative energy sources for public-private mobility sector. This work aims to compare CO_2 emissions by motor vehicles that circulate in urban centers according to the different fuels and technologies available on the market. Is determined by CO_2 emissions a vehicle of Tetra Fuel circulating in an urban path predefined, using different fuels, Gasoline 22% of EAAF(Ethyl Alcohol Anhydrous Fuel) – Gasoline 0% of EAAF – Hydrated Ethanol – MGV (Methane Gas Vehicles), available, in addition, to show the impacts of vehicular air conditioning on CO_2 emissions. The results are important for the creation of public policies to encourage the use of alternative fuels that contribute to the reduction in emissions of greenhouse gases like CO_2, besides, strengthen the implementation of public projects that aim to improve air quality in urban centers.*

Keywords: *Greenhouse Effect 1, Vehicular Emissions 2, Fuel Consumption 3, Pollution 4, Carbon Dioxide 5*

1. INTRODUCTION

Currently, oil is the main source of energy that feeds the developing industrial system and, especially, through the automobile, penetrated deep into the global economic structure. With the increased use of road transport, greatly increased the demand for consumption of fossil fuels (gasoline, MGV, diesel, etc.) and bleached (methanol and ethanol). As each fuel has physicochemical characteristics, the combustion of such fuels themselves produces emissions with a high content of photochemical activity with unique features that affect air quality. The mobility sector consumes approximately 30% of all the energy available in the world and is responsible for half of the available oil consumption (Dargay and Gately, 1997 aped Costa and Valle 2013). This gives you a significant importance in world energy matrix. The gaseous pollutants from vehicular source constitute one of the most relevant causes the deterioration of air quality, intensifying due to disordered urban growth, coupled with the increase in the number of vehicles, mostly public-private transport (Taxis, buses, aircraft, etc.). Faced with the prospect that the increase in CO_2 emissions, during this century, can result in a significant increase of the global air temperature with the resulting modifications of the climate, national Governments, researchers and other organizations, have debated about how future emissions can be minimized in the Earth's atmosphere, mainly in urban centers, leaving room, however, so that there could be economic growth. Several institutes have been devoted to studies on global climate change, producing several scenarios concerning the emissions of greenhouse gas inducing. The scenarios are based on estimates of population growth, economic growth, and combination of energy sources and emission control that could be implemented. Among the greenhouse gases is carbon dioxide, CO_2, arising largely from the burning of fossil fuels or bleached, for use in main means of urban transport (IPCC, 1995 aped BAIRD, 2002).

Studies in several countries have allowed establishing maximum permissible emissions levels of carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx), particulates and aldehydes by vehicles, but, these controls do not exist for carbon dioxide (CO_2), being this a non-toxic gas. However, there is a global concern about the levels of emissions of greenhouse gases, in particular CO_2 levels, focused on the energy consumption of fossil fuels or bleached. For being a non-toxic gas CO_2, there are no restrictions or sanctions on the issue, however, there is a Government incentive through reduced tax rates for those who directly or indirectly contribute to the mitigation of this gas, the environment. For auto industries, tax incentives encourage the development of technologies that contribute to the vehicular energy efficiency and developing alternative fuels.

In recent decades, the use of gaseous fuels MGV (Methane Gas Vehicles) and oxygenated, such as methanol and ethanol, pure or in blends with gasoline, has grown due to the benefits introduced in world energy matrix, in addition to being less aggressive air quality. Consequently, there is a need for studies of the possible impacts of greenhouse gas emissions, CO_2, about the burning of these fuels in internal combustion engines for use in motor vehicles. To this end, this study shows the different concentrations of CO_2 emitted by a motor vehicle of Tetra Fuel when it is subjected to an urban traffic and predefined road route, using different fuels (Gasoline E00, Gasoline E25, Ethanol and MGV) with and without air conditioning inserted.

2. THEORETICAL REFERENCE

Santos (2008) studied the energy consumption by the use of fossil fuels and greenhouse gas emissions for light vehicles. The methodology recommended by the "Revised 2006 IPCC Guidelines for National Greenhouse Gas Inventories" was used to evaluate the impact of adding ethanol to gasoline in those emissions. The assessment was made by two methods – the "Top Down" and "Bottom Up". The results show that the addition of ethanol substantially reduces the emissions of greenhouse gases by light vehicles.

The formation of CO is primarily dependent on the equivalence ratio of the mixture, and presents itself in a higher level of concentration for rich mixtures (Heywood, 1988). Rich mixtures make lack O_2 to CO_2 formation. One of the most important variables in determining emissions from internal combustion engines is the equivalence ratio of fuel/air mixture (ϕ).

By 2100, it is envisaged that the air temperature increases 3.2 °C whereas the "high" emissions scenario. This increase is of 2.4 °C in average scenario and 1.4° C in the low setting. If CO_2 emissions continue to increase – rather than remain constant and 1990 levels considered in these scenarios-and sulfate aerosols present in ever-increasing quantities block increasingly incident sunlight, heating scenarios planned for the high and medium scenarios will be reduced to about 2.5 °C and 1.9 °C, respectively. A further increase in temperature would occur after 2100, but the IPCC projections do not go beyond this year. In the absence of additional climate policies, the Intergovernmental Panel on Climate Change (IPCC, 2007a) projects that the average global temperature will rise during this century between 1.1 °C and 6.4 °C above average, 1980 to 1999, depending on the socio-economic scenarios (IPCC, 2000a). This range of uncertainty stems from the uncertainty about the amount of greenhouse gases that will be issued in the future, and the uncertainty about climate sensitivity.

Sodré (2000) demonstrated by a computational model that the concentration of CO increases for richer mixtures, because there is not enough oxygen to burn all the carbon to CO_2. The excess air in the mixtures poor ensures highest oxygen concentration. The simulated results were compared to equilibrium concentration CO with experimental data for various engine-operating conditions. A good correlation was obtained for most operating conditions investigated, with a small gap for rich mixtures. It is known that CO formation is kinetically controlled, so it has been suggested that the calculation of the concentration of CO with this approach can fix discrepancies found for rich mixtures.

3. INSTRUMENTATION AND METHODOLOGY

Planning for data collection, the instruments needed, the allocation of resources, the vehicle and the location for the execution of the tests, along with a methodology applied systematically guarantee results with high degree of reliability.

3.1 Experimental Apparatus

The tests were carried out in a production vehicle, cordially provided by FCA Fiat Chrysler Automobiles with internal combustion engine spark ignition, 1.4-liter four stroke, with Tetra Fuel powered, gasoline 0% of EAAF (Ethyl Alcohol Anhydrous Fuel), gasoline 25% of EAAF, hydrated ethanol and MGV (Methane Gas Vehicles), of 4 cylinders and 8 valves. The technical characteristics of the vehicle are listed according to Tab. 1.

Table 1. Technical characteristics of the vehicle Siena Tetra Fuel.

Vehicle/Model	Siena EL Tetra Fuel
Engine	1.4 8V Tetrafuel
Cycle	Otto
Fuel	Gasoline, Ethanol and MGV
Number of cylinders	4
Number of valves	2 camshafts
Compression ratio	10,35 ± 0.15
Maximum power - Gasoline	58.9 kW @ 5500
Maximum power - Ethanol	59.6 kW @ 5500
Maximum power - MGV	50.0 kW @ 5500
Tank capacity	48 liters
Cylinder capacity	2 x 6.5m³ = 13m³, the CNTP and pressure of 200 bar
4th speed Gear	135 km/h
Minimum speed	850 ± 50 rpm

Source: Technical data sheet of the manufacturer

3.2 Measuring Systems Used

The acquisitions were monitored by measuring systems fitted on the vehicle, throughout the operation. The measurements are performed using a portable computer, an electronic unit that interfaces with the ignition/injection and the measurement equipment of equivalence ratio of fuel/air mixture, Horiba brand. The computer receives and records the information provided by central electronics runs parameters measured by the sensors and the output commands managed by it. The parameters monitored by central electronics were engine speed, position of the throttle valve, injection time, coolant temperature, air temperature, spark plugs, lambda probe signal injection system and position of the stepper motor.

For the tests of consumption, the following instruments were used: PLU (43.84 K Factor); Digital display for PLU; Tachometer Brand Braun GMBH-Mod. C118 Moviport; AVL-Chassis dynamometer Zollner "-200 Model Compact 48 km/h-150 kW – 10000 N; Climatic Chamber; Pressure transducer (WIKA); HBM-MGC plus AB22A; Thermocouple type K-range -30 °C to 1200 °C; Excel tire calibrator 0 to 70 range Pneutronic bar; Pressure gauge accuracy range ± 1.0%; Alpha Scale Instruments Mod. 3104 B; MGC-voltage Boards modules, temperature, of consumption, of strength and speed.

The universal fuel flow meter, manufactured by AVL LIST GmbH, PLU 116H, measure continuously and simultaneously the fuel flow with flow rate of 0.3 to 60 l/h. The measurement is performed directly on the power supply line of the injection system/admission. The measurement signals are amplified in a measuring system, the manufacturer plus GCM HBM. The data is continuously recorded in the computer and processed by Catman ® measuring Software, software from HBM for configuration, visualization and analysis of measurements.

The chassis dynamometer AVL-Zollner "-200 Model Compact 48 km/h-150 kW – 10000 N is used for the simulation of urban road and path in which the measurements are carried out. Speeds and backlogs are simulated taking into account the rolling resistance imposed on the roller dynamometer. With this equipment installed in a climate Chamber it is possible to simulate the vehicle speeds in a lab environment with conditions of temperature, humidity and pressure under control and monitored during all tests.

Lube oil temperatures and cooling fluid have been monitored by thermocouples. A data acquisition system was used to control the ignition and injection time, plus acquisition of temperature, rotational speed of the engine, injection time and pressure on admission. The electro fan input signals, too, were monitored.

3.3 Execution Of The Tests

The standardization of consumer tests for motor vehicles, according to NBR 7024 (ABNT, 2002) prescribes a method for measuring the fuel consumption of road motor vehicles, light through driving cycles developed in chassis dynamometer, which simulate the use of the vehicle in urban transit and road, according to NBR 6601 (ABNT, 2005). This standard adopts the American FTP-75 routine as standard for the testing of emissions and consumption in Brazil. The automaker is defined by a smooth curve specified through the relation: speed versus time. However, this cycle, FTP-75, does not contemplate the reality of roads and of the Brazilian urban centers, it is a cycle that does not consider pending issues in your route. Therefore, in this work, we used a simulation of a cycle on the chassis dynamometer of urban travel in the central area of the city of Belo Horizonte/Minas Gerais/Brazil, Fig. 1, which includes a flat track and real backlogs ascendants and descendants. The roadway is a simulated the BR 381 on a total distance of 81 km (km 513 in the city of Igarapé/MG/Brazil at km 594 in Carmópolis/MG/Brazil).

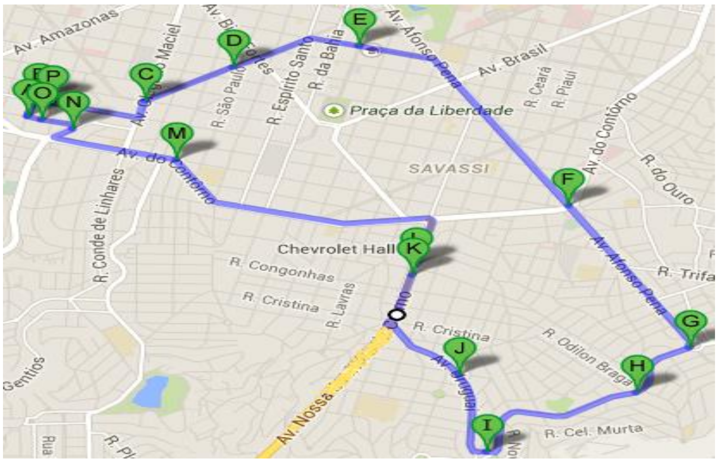


Figure 1. Urban traffic cycle for measuring consumption.
Source: Google Maps, Access in 2015.

The tests were carried out with the vehicle fueled with Gasoline 0% of EAAF, Gasoline 25% of EAAF, Hydrated Ethanol 100% and MGV (Methane Gas Vehicles), under controlled environmental conditions in climatic chamber, Fig. 2. The acquisitions occurred considering the cycle of urban traffic 11.3 km.

Figure 2. Vehicle mounted on chassis dynamometer for proof of consumption.

The acquisitions are carried out with the vehicle in a stabilized phase, motor, coolant heated between 90 and 93 °C with hood closed. The vehicle is put on the chassis dynamometer roller with its gear is taken, by the roller dynamometer, until stabilization and speed before the start of the measurements, it is put through a period of 300 s for conditioning, then start the purchase of consumption measurement. The amount of packaging is necessary to stabilize the engine and similar tests ensuring temperatures for all configurations of the tests.

All charts and tables were constructed from the corrected values of three measurements of each condition, considering their combined uncertainties and its truncation errors imposed by numerical methods.

3. Model Formulation

For gasoline combustion reaction, on vehicular combustion chamber, it is necessary that the fuel react with oxygen from atmospheric air. However, this is not a complete combustion reaction and may summarily, be represented by Eq. (1), whereas the most significant products of incomplete combustion of fuel (SODRÉ, 2000):

$$C_n.H_m.O_r + \left(n + \frac{m}{4} - \frac{r}{2}\right).\frac{1}{\emptyset}.O_2 + \left(n + \frac{m}{4} - \frac{r}{2}\right).\frac{1}{\emptyset}.N_2 \rightarrow$$
$$\rightarrow aCO_2 + bH_2O + cN_2 + dH_2 + eHC + fNO_x + gCO + hCH_3CHO + iHCHO \quad (1)$$

The amount of air varies according to the type of engine and is relevant factor on concentration of the gases regulated in exhaustion, because by varying the amount of air in the fuel/air mixture, incomplete combustion may occur with large concentration of exhaust emissions. On the other hand, the complete burning of fuel will effectively produce natural quantities of carbon dioxide, CO_2, (COSTA and VALLE, 2013).

3.1. Maximum Values of CO_2 Released Into the Atmosphere with the Different Fuels

CO_2, although it is not a toxic gas, is a product of complete combustion of fuels that contribute significantly to the greenhouse effect.

Representing the chemical formula of pure gasoline for C_8H_{18} (isooctane) their stoichiometric combustion reaction (Φ=1) can be written as shown in Eq. (2). This equation shows the maximum amount of CO_2 produced in burning the fuel internal combustion engine Otto cycle.

$$C_8H_{18} + \frac{1}{\emptyset}\left(8 + \frac{18}{4}\right)\left(O_2 + \frac{79}{21}N_2\right) \quad \rightarrow \quad 8CO_2 + 9H_2O + 47{,}02N_2 \tag{2}$$

Has 8 x 44 kg of CO_2 = 352 kg of CO_2 per 114 kg of isooctane. Being the isooctane density equal to 0.75 kg/l (Perry and Chilton, 1973), has 352 kg of CO_2 per 152 liters of isooctane, i.e. 2.315 kilograms of CO_2 per liter of isooctane (C_8H_{18}) consumed.

For ethanol (C_2H_5OH), the stoichiometric combustion reaction (Φ = 1) is:

$$C_2H_5OH + (3)\frac{1}{\emptyset}O_2 + (3)\frac{1}{\emptyset}\left(\frac{79}{21}\right)N_2 \quad \rightarrow \quad 2CO_2 + 3H_2O + 11{,}28N_2 \tag{3}$$

In this case, 2 x 44 kg of CO_2 = 88 kg of CO_2 per 46 kg of ethanol. Being the density of fuel equal to 0.79 kg/l (Russomano, 1987 aped Costa and Valle, 2013), has 88 kg of CO_2 per 58.2 liters of ethanol, i.e. 1.512 kg CO_2 per liter of ethanol (C_2H_5OH) consumed.

In the State, anhydrous ethanol is miscible in gasoline (isooctane), which allows the use in cars of a mixture that reduces gas consumption. This reduction has varied over the years between 20% and 27% by volume basis. An automobile that runs 10000 kilometer per year, with gasoline containing 25% of anhydrous ethanol and an average consumption of 10 km per liter, will, theoretically, tops the following annual rate of CO_2:

$$(0.75 \times 2.315 + 0.25 \times 1.512)\left(\frac{kgCO_2}{L}\right) \times 10000\frac{km}{ano} \times \frac{1}{10}\frac{litro}{km} \times \frac{1}{1000}\frac{L}{litro} = 2.114\frac{tCO_2}{ano} \tag{4}$$

This calculation does not consider the portion consumed by the vehicle when it is still idling.

Natural gas can be defined as a mixture of light hydrocarbons and in lower concentration with inert and oxygen, found underground. Under conditions of temperature and pressure environment (1atm and 25° C), the gas remains in the gaseous state. In the Southeast the compositions feature as threshold value of quantities of methane (CH_4) to 86%, ethane (C_2H_6) the 10%, propane (C_3H_8) at 3%, butane (C_4H_{10}) the 1.5%, oxygen (O_2) and the inert (N_2 and CO_2) a value of 4% in volume (Ordinance nº 104, PNA 2002). However, this value may vary according to several factors, especially the geological and those relating to the process. Soon, in motor vehicles to MGV complete combustion reaction can be represented by Eq. (5).

$$0.905CH_4 + 0.086C_2H_6 + 0.009C_3H_8 + 1.052O_2 + 1.052(3.76)N_2 \rightarrow 1.104CCO_2 + 2.104H_2O + 1.052(3.76)N_2 \tag{5}$$

In which, 1.104 x 44 kg of CO_2 = 48.576 kg of CO_2 per 17.456 kg of GNV burned, i.e., the specific mass of the GNV equals 0.777 kg/m³, has the burning of 22.465 m³ of GNV a production of 48.576 kg of CO_2. Soon, each m³ of GNV will produce 2.162 kg of CO_2.

4. RESULTS AND CONSIDERATIONS

The results of emissions of carbon dioxide, CO_2, are presented in systemic, depending on the consumption of each fuel in urban and roadway course with and without air conditioning on. Are confronted with the different fuels used for analysis. In addition to the vehicle results working in condition of minimum rotation (idling) and in conditions of constant speeds of 60, 90 and 120 km/h.

4.1 CO_2 Emissions

The results of CO_2 emissions by burning of different fuels in internal combustion engine applied to vehicles are presented in Figs. 3 to 7, exploring the different operating conditions of the vehicle. These results assume complete combustion of fuel in the combustion chamber.

In Figure 3 represented the CO_2 emissions for the vehicle operating with different fuels without air conditioning switched on in urban traffic and roadway.

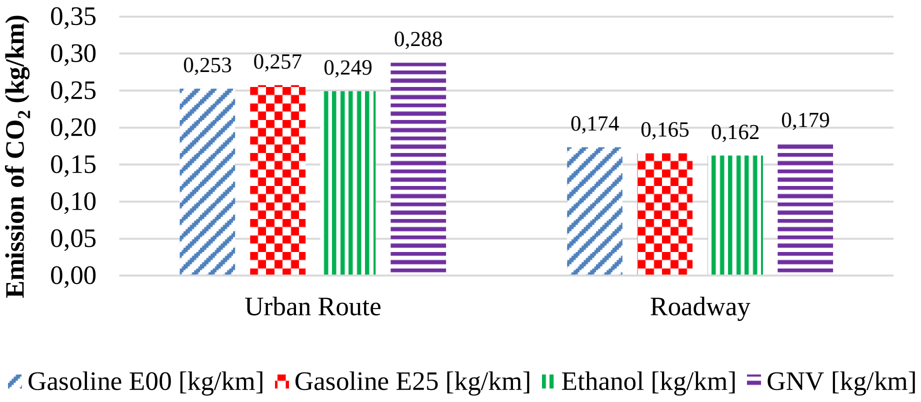


Figure 3. CO_2 emission in kg/km, with the vehicle without air conditioning in urban road and roadway.

The results show that the gaseous fuel will produce greater quantities of CO_2, both in urban and in the roadway, followed by gasoline E25. Ethanol is the fuel with the lowest emission of CO_2, around 13.5% in urban pathway, and 9.5% in the roadway. With the air conditioning turned off. Fig. 4 shows the results of CO_2 emissions when the vehicle is with air conditioning switched on.

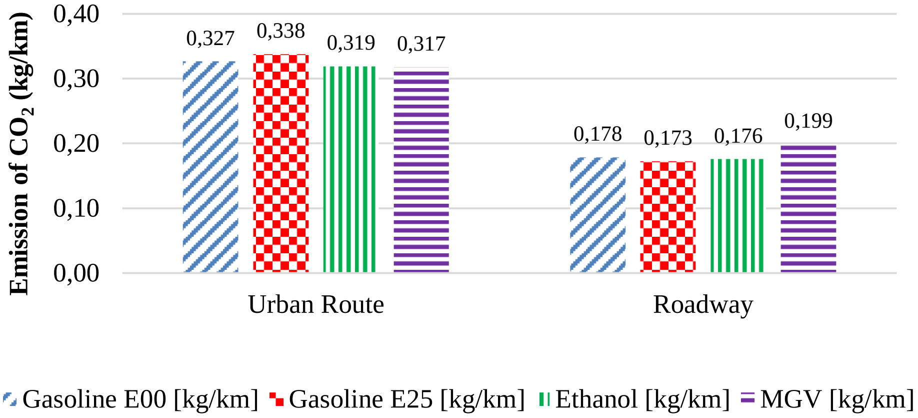


Figure 4. CO_2 emission in kg/km, with the vehicle with air conditioning inserted into urban traffic and roadway

In the urban traffic gasoline E25 was the fuel that showed the highest CO_2 emission, followed by gasoline E00. The fuel ethanol and MGV gaseous fuel in urban traffic did not show differences among themselves. Already in the roadway this condition is reversed, i.e. the MGV gaseous fuel will emit greater amounts of CO_2, followed by ethanol. This condition can be understood by the greater sensitivity of Ethanol fuels and MGV, the operation of the air conditioning compressor. In other words, the more times the air conditioning compressor turns on and off, during a course of drivability, the consumption of ethanol and MGV also increase. Considering the trials vehicle with constant speeds 60 km/h, 90 km/h and 120 km/h, were also carried out and are presented in Fig. 5 and Fig. 6, without air conditioning and with air conditioning, respectively.

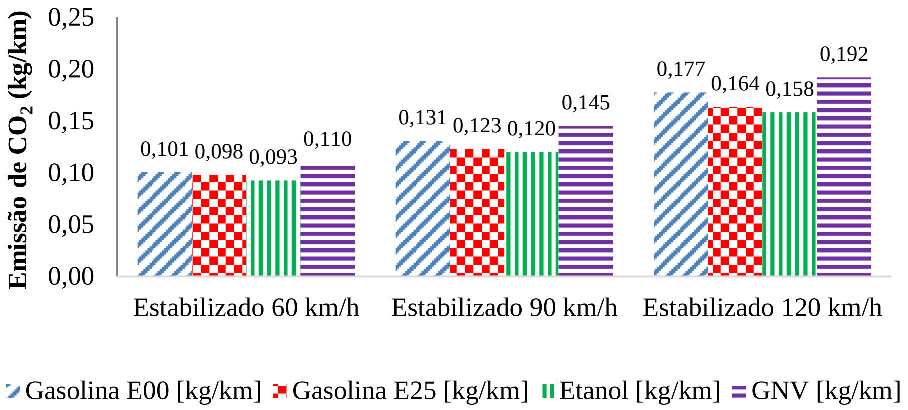


Figure 5. CO_2 emission in kg/km at speeds of 60, 90 and 120 km/h, without air conditioning

With the speeds of 60 km/h, 90 km/h and 120 km/h and air conditioning turned off, Fig. 5, the MGV gaseous fuel produced higher concentrations of CO_2, followed by gasoline E00. Moreover, the fuel that less CO_2, Ethanol was issued. Fig. 6 shows the same trend, but with the air conditioner on.

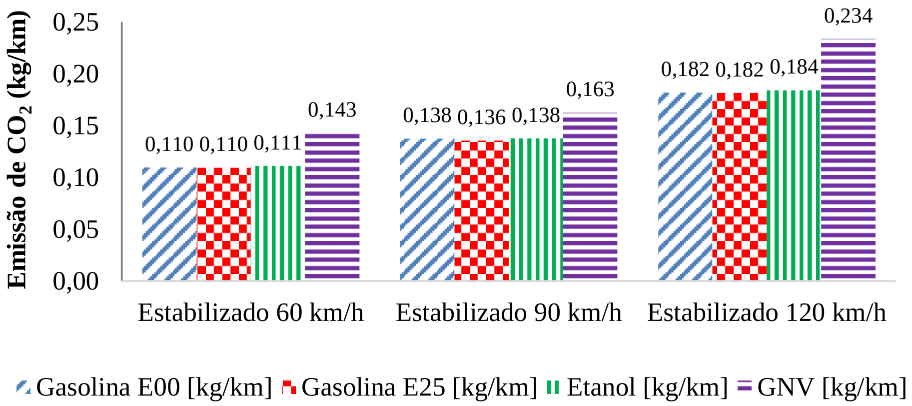
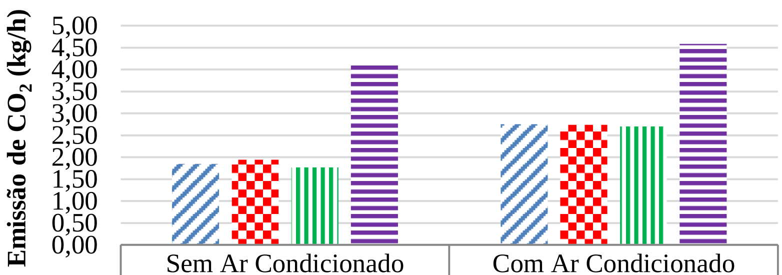


Figure 6. CO_2 emission in kg/km at speeds of 60, 90 and 120 km/h, with air conditioning switched on

The results in operating speeds with air conditioning on, confirm the highest CO_2 emissions by fuel and MGV, the other fuels, Gasoline E00, Gasoline E25 and Ethanol presented values of equivalent CO_2 emissions. Tests on the vehicle operating on minimum rotation (idling), were also carried out, Fig. 7.



	Sem Ar Condicionado	Com Ar Condicionado
Gasolina E00 (kg/h)	1,85 kg/h	2,75 kg/h
Gasolina E25 (kg/h)	1,95 kg/h	2,74 kg/h
Etanol (kg/h)	1,77 kg/h	2,71 kg/h
GNV (kg/h)	4,15 kg/h	4,58 kg/h

Figure 7. CO_2 emission in kg/h, with and without air conditioning in minimum rotation (idling)

With the vehicle operating at idling condition the gaseous fuel, MGV, emits greater quantities of CO_2, both with the air conditioner on and with the air conditioning turned off. The remaining fuels present a little detour, among them, on CO_2 emission while the vehicle is operating with air conditioning turned off, i.e. ethanol in this specific condition, emits less CO_2, and with the air conditioning turned on there is no difference in emissions between the three liquid fuels. On condition that idling operation the liquid fuels emit, around 30% of the CO_2 more when the air conditioner is connected and the MGV gaseous fuel, emits 10% more CO_2 when the air conditioner is connected, i.e., is when the vehicle is running at idle, the air conditioning compressor input requires greater consumption of liquid fuels, comparing with the operation of the vehicle with the air conditioner compressor off. In General, the results showed that the MGV consumes more, therefore, emits greater quantities of CO_2.

5. ACKNOWLEDGEMENTS

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7. RESPONSIBILITY NOTICE