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Impact of adding ethanol to gasoline on greenhouse gas emissions

Impacto da adição de etanol à gasolina nas emissões de gases de efeito estufa

Impacto de agregar etanol a la gasolina en las emisiones de gases de efecto invernadero

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Abstract
The growing concern about one of the biggest environmental problems today, air pollution and its effects on the population, resulted in several studies and research to minimize the impacts on global health. This crescent happened after industrial and urban expansion in the mid-nineteenth century, where it ran rampant through the industrial revolution. The challenges to finding a sustainable balance between the diversity of fuels and sources, the costs, and the environmental impact lead to several research fronts. According to the World Health Organization (WHO), in 2019, more than 4 million people died prematurely from pollution. This study discusses the possibilities of ethanol/gasoline blends, engine performance variations, and impacts on the resulting results and gas emissions. The study used a powertrain with Otto cycle engine model K7M from Renault, manufactured in 2008, with approximately 1600 cc, 4-cylinder in-line configuration with two valves each, generating a power of 95 HP, 14.1 mkgf (alcohol) and fuel system through multipoint electronic injection. The teste applied five fuel mixtures – 0%, 25%, 50%, 75%, and 100% of hydrated ethanol in the blend. Results indicated that at low speeds, the CO_2 emissions increased as the blend increased. However, the emissions increased considerably when the speed increased. The Nox emissions were irregular in the proportions of the blends. It could be concluded that NOX does not behave linearly, and the best condition is found with the mixture of 75% ethanol, where we reach the lowest points of NOX and HC.
Keywords: Air pollution; Global health; Noxious gases.

Resumo
A crescente preocupação com um dos maiores problemas ambientais da atualidade, a poluição do ar e seus efeitos sobre a população, resultou em diversas pesquisas para minimizar os impactos na saúde global. Essa crescente aconteceu após a expansão industrial e urbana em meados do século XIX, onde ascendeu na revolução industrial. Os desafios para encontrar um equilíbrio sustentável entre a diversidade de combustíveis e fontes, os custos e o impacto ambiental levam a diversas frentes de pesquisa. Segundo a OMS, em 2019, mais de 4 milhões de pessoas morreram prematuramente devido à poluição. Este estudo discute as possibilidades de misturas etanol/gasolina, variações de desempenho do motor e impactos nos resultados resultantes e nas emissões de gases. O estudo utilizou motor ciclo Otto modelo K7M da Renault, fabricado em 2008, com aproximadamente 1600 cc, configuração de 4 cilindros em linha com duas válvulas cada, gerando uma potência de 95 HP, 14,1 mkgf (álcool) e sistema de combustível através de injeção eletrônica multiponto. O teste aplicou cinco misturas de combustível – 0%, 25%, 50%, 75% e 100% de etanol hidratado na mistura. Os resultados indicaram que em baixas velocidades, as emissões de CO2 aumentaram à medida que a mistura aumentou. No entanto, as emissões aumentaram consideravelmente quando a velocidade aumentou. As emissões de Nox foram irregulares nas proporções das misturas. Pode-se concluir que o NOX não se comporta de forma linear, e a melhor condição é encontrada com a mistura de 75% de etanol, onde alcançamos os pontos mais baixos de NOX e HC.
Palavras-chave: Poluição do ar; Saúde mundial; Gases nocivos.

Resumen
La creciente preocupación por uno de los mayores problemas ambientales de nuestro tiempo, la contaminación del aire y sus efectos en la población, dio lugar a varias investigaciones para minimizar los impactos en la salud global. Esta media luna ocurrió después de la expansión industrial y urbana a mediados del siglo XIX, donde ascendió en la

revolución industrial. Los desafíos de encontrar un equilibrio sostenible entre la diversidad de combustibles y fuentes, costos e impacto ambiental conducen a varios frentes de investigación. Según la OMS, en 2019, más de 4 millones de personas murieron prematuramente a causa de la contaminación. Este estudio analiza las posibilidades de las mezclas de etanol/gasolina, las variaciones en el rendimiento del motor y los impactos en los resultados resultantes y las emisiones de gases. El estudio utilizó un motor de ciclo Otto modelo K7M de Renault, fabricado en 2008, con aproximadamente 1600 cc, configuración de 4 cilindros en línea con dos válvulas cada uno, generando una potencia de 95 HP, 14.1 mkgf (alcohol) y un sistema de combustible a través de inyección electrónica multipunto. La prueba aplicó cinco mezclas de combustible: 0 %, 25 %, 50 %, 75 % y 100 % de etanol hidratado en la mezcla. Los resultados indicaron que a bajas velocidades, las emisiones de CO2 aumentaban a medida que aumentaba la mezcla. Sin embargo, las emisiones aumentaron considerablemente a medida que aumentaba la velocidad. Las emisiones de NOx fueron irregulares en las proporciones de las mezclas. Se puede concluir que el NOX no se comporta linealmente, y la mejor condición se encuentra con la mezcla de 75% de etanol, donde alcanzamos los puntos más bajos de NOX y HC.
Palabras clave: Contaminación del aire; Salud global; Gases nocivos.

1. Introduction

Climate change has been closely observed among all the adverse environmental conditions today. In October 2018, the Intergovernmental Panel on Climate Change (IPCC) reported that the temperature of the planet earth has risen by 1.5ºC compared to the period before the industrial revolution. We know that this change is linked to the greenhouse effect, caused by the accumulation of gases in the atmosphere of planet earth, with carbon dioxide (CO2) being the element that most contributes to this effect. The consequences of global warming are diverse, including the rise in sea level resulting from the melting of the polar ice caps, meteorological impacts (droughts and storms), devastation of fauna and flora, and food production, among others (An, 2018).

Research carried out at the Experimental Atmospheric Pollution Laboratory of the Faculty of Medicine of the University of São Paulo (USP) (Saldiva et al., 2007) indicates that approximately 3,000 deaths per year in the Metropolitan Region of São Paulo (RMSP) are related to air pollution. Such a scenario demands an annual cost of approximately R$ 1.5 billion, in addition to treating around 200 associated diseases. This number of deaths in São Paulo indicates that in Brazil, the problem generated by the high concentration of polluting elements, mainly nitrous oxides (NOx) and hydrocarbons released in the burning of fossil fuels, is alarming.

The use of ethanol blend can lead to better air quality in the cities because it reduces emissions of noxious gases, despite increasing hydrocarbons (HC) in conventional engines (Rice et al., 1991). Ethanol has a higher-octane number that allows the operation with higher compression rates without entering auto-ignition and greater efficiency (Roso et al., 2019). Technically, these engines will enable the ignition times to be changed (anticipate or delay the ignition point, when necessary), the operating temperature (electronic thermostatic valves), and the variation of the fuel injection time, as detected by the λ probes in the exhaust system and the pressure sensors of the intake manifold.

Nowadays, there is a critical concern about the emissions of pollutants from burning fossil fuels, which is still the primary energy source for internal combustion engines. Biomass may present a sustainable alternative solution to this issue since biofuels are produced from renewable energy sources due to chemical conversions (Cuoci et al., 2021; Kunwer et al., 2022; Ocanha et al., 2022).

Conversely, Barakat et al. (2016) noted a low slope linear correlation between fuel use and ethanol concentration. Other authors (Guerrieri et al., 1995; Topgul et al., 2006; Cataluna et al., 2008) reported a substantial increase in fuel consumption utilizing the ethanol-gasoline blend. Cahyono & Bakar (2011) observed a decrease in engine torque and power when ethanol was used as a fuel in difference to gasoline. However, those conclusions are connected to the use of ethanol blends in standard gasoline ignition engines.

This study aims to investigate and explain how the concentration of fuel mixtures between gasoline and ethanol can

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affect the efficiency of the powertrain system and the benefit of CO_2 emissions. Simulation models predict the CO, CO_2, NO_x, HC, and lambda factors of five fuel configurations at three different speeds.

2. Methodology

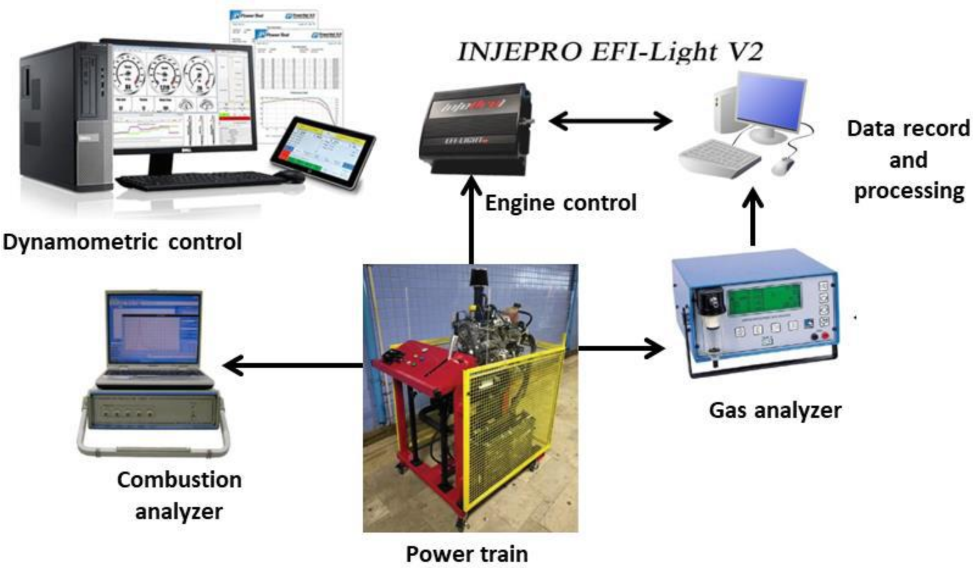
For meeting the objective, we used the investigative qualitative and quantitative approaches, where a sets of data was generated and analyzed using analytical methods applicable to the process of gasoline-ethanol blending process (Pereira et al., 2018).

The project employed an Otto cycle engine model K7M from Renault, manufactured in 2008, with approximately 1600 cc, 4-cylinder in-line configuration with two valves each, generating a power of 95 HP, a torque of 14.1 mkgf (ethanol) Renault S.A. and fuel system through multipoint electronic injection.

The INJEPRO EFI-LightV2 management module was used to control and analyze the variations of this engine. The maps were accessed using the EFI-MANAGER software connected to an external interface via a USB cable. In this setup, it was possible to obtain nitrous oxide control, traction, electronic booster, and correction by a narrow band lambda probe, adjusting the conditions of use due to the complete map system. There was access to all conditions of load or pressure interpolated every 200 RPM.

The following materials and devices were used to separate the fuels: a graduated test tube, beaker, separation funnel, pendular shaking table model TE-24I, gasoline, and gallons for storage. The PC-MULTIGÁS NAPRO was utilized to measure gases emitted by fuel combustion. The PC-MULTIGAS gas analyzer uses the non-dispersive infrared measurement method, meeting the NBR, OIML R99 CLASS1, ISO3930, and ASM/BAR 97 standards. The whole setup of the record of the variables and processing of data is presented in Figure 1.

Figure 1 - Setup of the experimental tests using the power train and the recording and processing devices.



Fonte: Autores.

For the tests to be carried out with the five fuel mixtures – 0%, 25%, 50%, 75%, and 100% of hydrated ethanol in the mix – it is necessary to create a routine to be followed, as this will allow the comparison between the results obtained, showing the fundamental differences between the fuel blends. Clearly, there will be deviations between the results that escape only the differences between the fuels since the optimization of the electronic injection calibration was made with a substantial tolerance, given the lack of accurate measurement equipment needed in the process. In addition to this deviation, it is also necessary to consider the experimental variations already expected in a theoretical experiment.

To begin the data recording, the Powertrain was installed in a specific test cabin with appropriate exhaust and an air-conditioned environment with controlled humidity. Thermocouples, transducers, and sensors were used to record water temperature, oil, fuel, exhaust, and air mass data. In the same way, the fuel pressure and the inlet air, the relative humidity of the air in the intake manifold, and the fuel-air ratio before and after the catalytic converter were extracted using a lambda probe.

The procedure was started with 5 L of pure gasoline in the tank (zero addition of ethanol) separated in the laboratory and all instrumentation installed for verification, as well as the reading of gases through the Multigas Napro PC, seated at the end of the exhaust. There was the preparation of the engine in a steady state to obtain standard results since the engine must be in conditions at the beginning of each measurement. To achieve this condition, the engine must have the oil decontaminated and has already reached its operating temperature, around 90°C. These conditions can be achieved by following the procedure described below.

The decontamination procedure is as follows: (1) Start the engine and, after the first opening of the thermostatic valve, (2) let it run for at least 30 minutes at idle. The recommended instrumentation points are as follows: (1) Intake manifold (temperature and pressure), (2) exhaust manifold (temperature, pressure, and λ), crankcase (temperature), (3) engine cooling system (temperature), and (4) fuel line (temperature and pressure). The analyzer was kept for an initial warm-up period, which consisted of two cycles of fan activation to ensure the correct measurement of the gases. Within this period, the program reported that it was warming up.

The sealing test (tightness) of the multigas pc was also evidenced by closing the gas capture probe and waiting for the instructions on the main screen to start the tests. Before starting the measurement, the equipment checks to detect the presence of HC residues in the environment. This procedure aims to confirm that, before measurement, the indicated value is less than 20 ppm vol., in terms of n-hexane, for a sample of ambient air captured by the probe. If the HC residue value exceeds 20 ppm vol., in terms of n-hexane, the measurement is not allowed.

With the entire system installed and in compliance, the engine was kept at idle speed (approximately 900 rpm) for 60 seconds, which was the estimated time to stabilize the gas reading and thus obtain a smaller variation in the collection. At the end of the 60-second cycle, a new cycle with a rotation of 2000 rpm and 3000 rpm later was introduced and maintained similarly to the previous test, and the collection was performed.

3. Results and Discussion

The results of the noxious gases are presented in Figures 2 and 3. The CO_2 emissions linearly increase at low speed as the percentage of ethanol increases in the blend. However, as the rotation increased, the tested blends raised considerably, decreasing when rotation increased to 3000 rpm.

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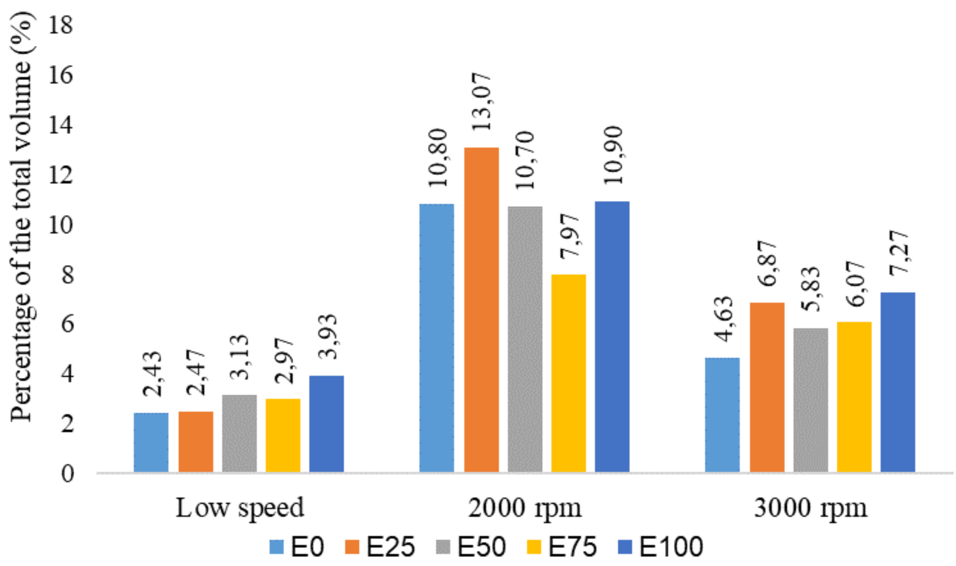
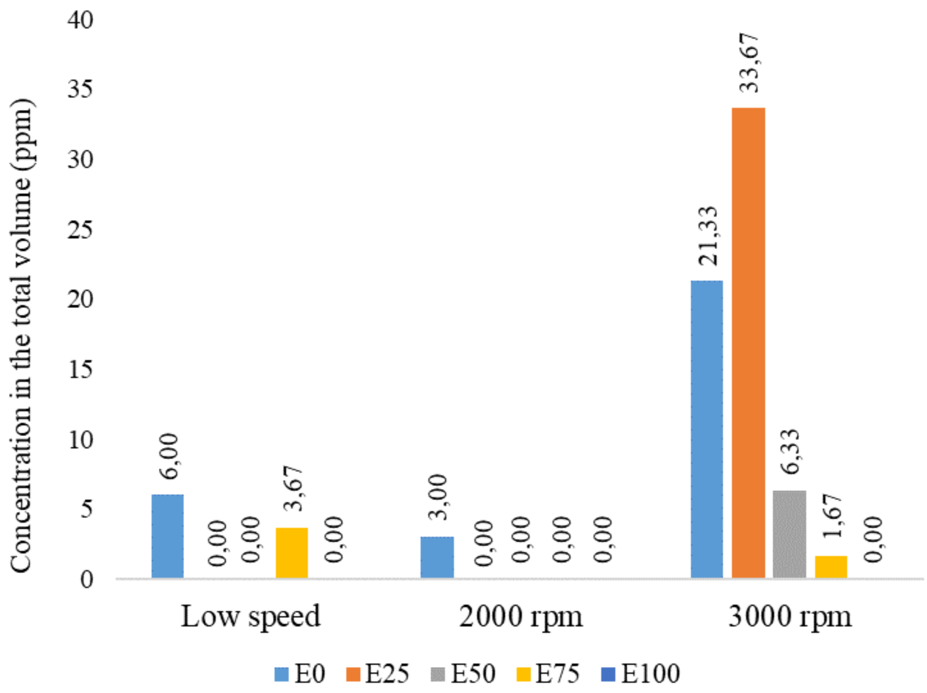
Figure 2 - Results of the CO_2 emissions at 0, 25, 50, 75, and 100% addition of ethanol to the gasoline.



Fonte: Autores.

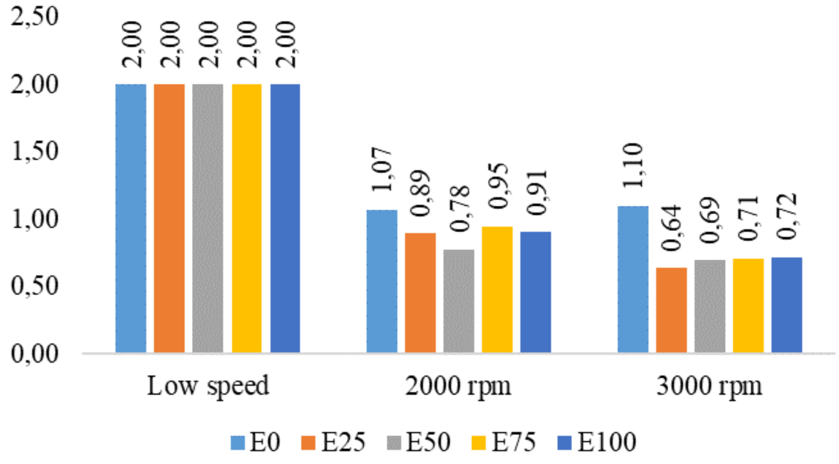
Figure 3 - Results of the NOx emissions at 0, 25, 50, 75, and 100% addition of ethanol to the gasoline.



Fonte: Autores.

Due to the emission of NOx, an irregularity in the proportions was found. The anomaly was non-linear regarding the concentrations of the ethanol in the blend and the speeds applied. Some studies indicate that low concentrations of NOx are seen when there is a higher proportion of ethanol (Turner et al., 2011). Irregularities in the ratio of ethanol are also observed when studied in fuels such as Diesel (Lapuerta et al., 2008).

Figure 4 - Results of the lambda at 0, 25, 50, 75, and 100% addition of ethanol to the gasoline.



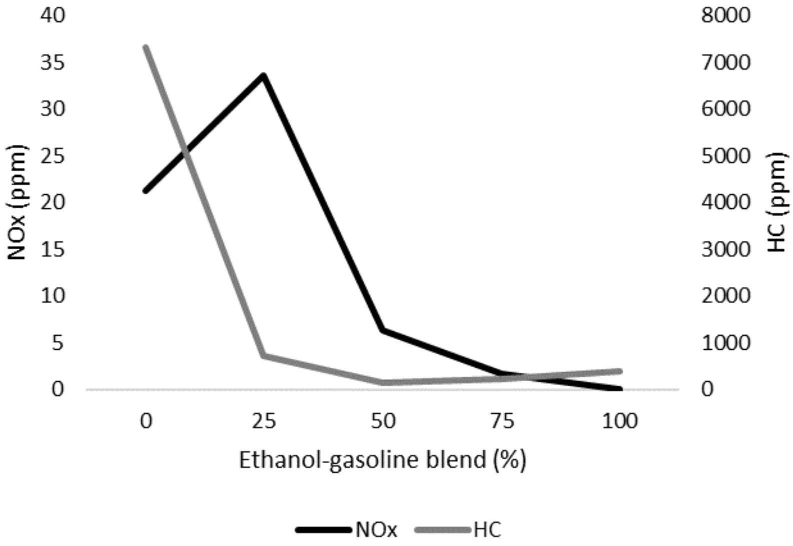
Fonte: Autores.

With the products of combustion, each vehicle's lambda factor (λ) can be determined, which is defined as the ratio between the amount of air needed to produce complete combustion in a stoichiometric relationship and the actual amount of air drawn in by the vehicle motor.

The ideal mass ratio of air and fuel for complete combustion is 14.7:1 (E0 - pure gasoline). This is given as lambda λ = 1, which is known as the stoichiometric value. This value can be calculated by taking the exact number of oxygen atoms required to completely oxidize the particular number of hydrogen and carbon atoms in the hydrocarbon-based fuel, then multiplying it by the atomic mass of the respective elements (Denton et al., 2017).

Figure 5 shows the variation of the NO_x in the tests of ethanol/gasoline blends in combination with the HC ratio, showing the intersection that occurs at 75% of Ethanol-gasoline blend.

Figure 5 - Results of the NOx and HC ratio in various ethanol-gasoline blends.



Fonte: Autores.

The results of previous research (Gravalos et al., 2011) corroborate the present study's findings. The result was due to the heat of vaporization properties of ethanol. Its higher concentration in the mixture decreases the amount of NOx in the exhaust, reaching its minimum when the proportion of ethanol reaches 100%. The attribution of this property of ethanol being characteristic in the decrease of NOx concentrations was also conclusive in other studies carried out (Yao et al., 2009)

4. Conclusion

It was found that the higher the ethanol concentration in the fuel blend, the lower the emissions of NO_X and CO_2. It was also verified that the lambda at low speeds does not present changes, and the stoichiometric function shows that the best condition would be only the burning of pure gasoline at medium and high speeds.

It was concluded that the greater the addition of ethanol in the mixture, the lower the emission of pollutant gases. The ideal blend of 75% ethanol and 25% gasoline achieves the best fuel-burning efficiency.

Further investigation is suggested to have enough results to subsidize public educational policies in city traffic. How drivers drive their cars and the speed adopted may considerably impact toxic gas emissions.

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