Efficiency of hydrogen depending on viscosity, combustion capacity and capacity of release of energy

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<u>Research Question:</u> To what extent does Hydrogen fuel surpass the efficiency of gasoline considering viscosity, combustion capacity, calorific capacity and energy utilization performance in automobilistic use?

Introduction

Society is searching for environmental solutions and one of the main problems nowadays is the contamination with transportation, and the gasoline engines that generate a substantial amount of carbon footprint, approximately 27% of the CO2 emissions in urban areas surge from engine exhausters (Brinson, Guzman, and Kiger, n.d.). Since I was a little kid, one of may favourite hobbies was to watch races with my dad. However, while I was growing up I understood the limitations and problematics present in those vehicles, they were highly pollutant and harmful for the environment. And as an automobilistic enthusiast, I felt that I could not simply watch that progress and development just happening, but instead be part of the solution. Many alternatives have been already tested, but the one that has highlighted itself from the others was the Hydrogen fuel. This due to the fact that it works almost equally to the gasoline, in the terms of recharging the tank capacity, that only takes a few instants, in contrast to electric vehicles, that usually takes hours. Summed to the same chemical reaction that takes place, meaning that the standards of calorific capacity, combustion capacity and viscosity, that are essentials for the operations of a combustion engine, summed to the comprehension of the specific energy, could be used to determine the quality of hydrogen as a fuel, having as a consequence, the transition towards a clean source, reducing substantially the carbon emissions into the environment.

Nevertheless, what differentiates this clean fuel from a pollutant one, is the outcome of the reaction that takes place when the combustion process happens. During the hydrogen combustions small impurities can be found, in which some are, if the reaction contacts with other substances, for example nitrogen, being capable of causing Nitrogen Oxides, and with carbon, carbon dioxide, summed to the probability of having an incomplete reaction non impurities in the combustion reaction, producing Oxygen Peroxide. This reaction, if it is not influenced by external substances, has the only product being water in the form of vapor that is released into the atmosphere. In the other hand for gasoline, the main product of the reaction is carbon dioxide, that is one of the main causes of the greenhouse effect that is harmful for all the living kind ("The 10 Most Potent & Harmful Greenhouse Gases | Workiva Carbon" 2023). Furthermore, some scientists affirm that Hydrogen could be more effective due to the higher versatility that the resource had to react. But, because of the lack of knowledge regarding the viability of the usage of this fuel for commercial purposes, investments are not taken into account and this implementation into the market does not occur. Therefore, having as an objective understanding **To what extent does Hydrogen fuel surpass the efficiency of gasoline considering viscosity, combustion capacity and calorific capacity in automobilistic use?** By collecting secondary data, making comparisons between the two fuels and understanding which information is the most adequate for the investigation and how large is the gap in performance regarding power and energy utilization performance.

Background Research

Vehicles are just capable of moving due to the existence of the engine, that works as a heart. The role that this part takes in the whole process is transforming the input, that is the fuel, or the electricity for electric vehicles, into kinetic energy ("Engine", n.d.). When it comes to engines that use the combustion method, that is every kind of automobilistic engine excluding the electric ones, what happens is that the fuel in inserted into the compressor and the piston summed to the spark of a candle, it makes the fuel combust quickly making the piston go down and rotate a chain of mechanisms that make the car work. (depending on the type of fuel, some use candles some do not, this varies according to the volatility of the fuel) ("WHY DON'T DIESEL ENGINES HAVE SPARK PLUGS | MTAQ" 2020). And the factors mentioned before, viscosity, combustion and calorific capacity does interfere in the process. Moreover, another aspect that was previously mention was the existence of a statement in which some scientists, for example Ian Gates, affirm that hydrogen is very volatile to enter combustion. Nevertheless, if this rate is too high, it might create so much heat that the engine starts to melt, not being capable of resisting (Nacarri and Handa 2013).

Nowadays, the engines are created to follow up a standard of viscosity, calorific and combustion capacities, that, for the average Brazilian automobiles, is of 0,860 Pa.s, for viscosity, 1.535 of heating capacity, and 228.2Jmol in average for combustion capacity ("STUDY OF KINEMATIC VISCOSITY, VOLATILITY AND IGNITION QUALITY PROPERTIES OF BUTANOL/DIESEL BLENDS", n.d.).

Viscosity is the quantity expressing the magnitude of internal friction, as a measured by the force per unit area resisting a flow in which parallel layers unit distance apart have unit speed relative to one another. When it comes to calorific capacity, is a physical property of mater, defined as the amount of heat to be supplied to an object to produce unit change in its temperature. Combustion capacity in the other hand is the total value of energy that is released as heat when a substance undergoes complete combustion with oxygen under standard conditions. Finally, specific energy is the numeric value representing the energy of a substance proportionally between its particles.

Now, what actually matters when a new fuel source is being searched for is a fuel with low viscosity, in order to be capable of injecting it into the system easily, higher calorific capacity, due to the fact that the energy that is realized will be rearranged into the system, so as much energy it releases better for the operation of an engine, and finally, for combustion capacity, the logic is the same ("STUDY OF KINEMATIC VISCOSITY, VOLATILITY AND IGNITION QUALITY PROPERTIES OF BUTANOL/DIESEL BLENDS", n.d.). As higher the combustion capacity, as easier it gets for an engine to perform, creating the internal ignitions and combustions as planned and finally as higher the specific energy of a substance, the more potent it is for the performance of the engine (Cleveland 2024).

Gasoline is an organic compound that is a complex mixture of hydrocarbons, majorly from the group of the alkanes, cycloalkanes and some aromatic hydrocarbons ("Gasoline, Automotive | Toxic Substances | Toxic Substance Portal | ATSDR", n.d.). These hydrocarbons are primarily built by carbons and hydrogens and go from C4 until C12, that means that it contains from 4 to 12 atoms of carbon per molecule. This structure could be arranged in several different ways, and depending on the variable organizations of particles, it could even lose the features that make it viable for being a fuel. In addition, there are still a group of organized molecules that create different types of gasoline, and they are: Hexane (C_6H_{14}), Heptane (C_7H_{16}), Octane (C_8H_{18}), Nonane (C_9H_{20}), Benzene (C_6H_6), Toluene (C_7H_8) and Xylene (C_8H_{10}). But for the objective of this investigation, the fuel that will be considered during the research will be the Isooctane (C_8H_{18}), also called as 2,2,4-trimephylpentane. This decision was made due to purely being the variant most commonly used in the gasoline engines (Hardesty and Tucker, n.d.). Finally, the reaction that takes place when the combustion of isooctane occurs is this:

$$2C8_8H_{18}(aq)+25O_2(g)\rightarrow16CO_2(g)+18H_2O(g)$$

In which, it is possible to notice the creation of 16 molecules of CO_2 that is being released into the atmosphere per 2 of C_8H_{18} (isooctane) that is being reacted with oxygen.

Hydrogen fuel is a quite simple element, is just the mixture of 2 Hydrogen particles, that is even commonly found in the atmosphere due to the electro balance being reached by the two atoms when are in conjunction. The reaction that takes place when hydrogen fuel enters combustion is the following one:

$$2H_2(aq)+O_2(g)\rightarrow2H_2O(g)$$

As it is possible to observe, in this combustion reaction, the only outcome is 2 particles of water per 2 of hydrogen gas reacting with a particle of oxygen gas, making this reaction much more environmentally sustainable compared to the reaction in which the isooctane takes place.

Data Collection

When it comes to the three factors previously mentioned, viscosity, combustion and calorific capacity, the data for the substances that were analysed are the following:

Viscosity, Calorific and Combustion capacity of the compounds

	Hydrogen	Isooctane
Calorific Capacity	28.836 K	2.15 K
Viscosity	0.84	0.503
Combustion capacity	from 119.3 to 141.86 MJ/kg	from 44.4 to 49.4 MJ/kg

Label 1: Label done by the author using ("Calorific value and heating value of hydrogen » SFC Energy AG", n.d.)

It will be important to understand how these factors affect the performance of an engine, in order to learn if the substitution is viable or not. Therefore, a case study will be taken in place with the objective of understanding these differences, and the chosen engine was the BMW Hydrogen (E68) - 2006, that is capable of running in both hydrogen and gasoline. The questions that will be attempted to answer will be:

- Which fuel presents a higher autonomy?
- Which fuel will produce the higher power?
- Does the Hydrogen fuel present any hazard for the engine?
- Does the hydrogen fuel present any hazard for the driver?

Hypothesis 1

The first hypothesis that can be drawn out of the case study is that the hydrogen fuel will actually be highly more efficient than the isooctane (gasoline) fuel, due to the higher calorific and combustion capacity that is presented, granting more power for the engine. When it comes to liability of the fuel, it is possible to predict that the hydrogen, Consequently, to this, the safety of the usage of hydrogen fuel into the engine of a vehicle should be more reliable than the usage of isooctane.

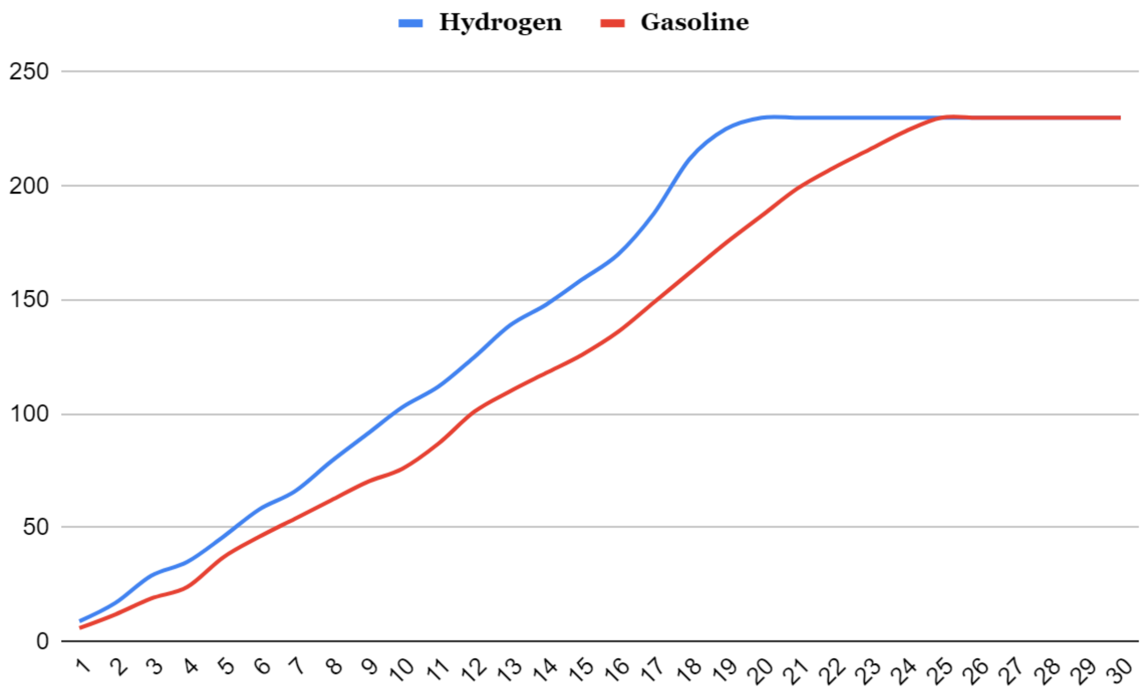
Hypothesis 0

In the other hand, the calorific and combustion capacity may not be a crucial aspect in order to make a relevant change on the power of the engine, summed to a possible hazard that it could provoke in the engine itself by the additional heat that is being generated, causing a possible hazard as well for the driver. Finally, the autonomy is even higher than the one presented by the isooctane due to the higher viscosity of the fuel that is being used in the process of the engine.

Methodology

In order to make this comparison and analyse which fuel is more efficient for engine usage, it will be necessary to gather information on several aspects of the car, BMW

Hydrogen 7, during different stages of the driving, like acceleration, maximum speed, autonomy, between others.



***The X-axis represents the time in seconds.**
***The Y-axis represents the speed in Km/h.**

Safety

As affirmed by the US National Resources Defence Council, the Hydrogen fuel was demonstrated to be safer compared to gasoline. This is because if all the factors are taken into consideration, for example the air pollution, stability and purity, the hydrogen presents a lower level of hazard for the driver compared to isooctane, summed to the registered amount of accidents that occurred per capita, in which the hydrogen does as well outperforms the gasoline. Nevertheless, the last factor could be a qualitative factor that is not exactly precise or does not actually meet the comparison itself due to several other variables, such as technological development, the experience of the driver and the country in which the statistics were taken from.

Moreover, the same institute developed research in which it made a comparison between the two fuels in the manner of safety for the engine of the car, and, as predicted by the hypothesis one, the results for the hydrogen fuel were better compared to the isooctane, due to the fact that the impurities that were present in the gasoline affect directly the parts of the engine, causing a higher damage to it, and reducing its maximum possible lifecycle. The estimative of lifecycle for a car that is running uniquely on hydrogen is of about 15 years. In the other hand, if the same car is taken into consideration but now under the usage of gasoline uniquely, have in average a lifecycle of 12 years, 20% less compared to the hydrogen usage.

Autonomy

In 2007, during the testing of the BMW Hydrogen 7 prototype, the engineers found something that was not expected. The consumption per kilometre of Hydrogen was lower, being of 3.6 litres of hydrogen per 100 km, than the consumption of gasoline per kilometre, that was of 26 litres per kilometre, meaning that, the autonomy of the hydrogen fuel is higher than the gasoline one, therefore a driver could go farther with the usage of hydrogen fuel compared to gasoline.

Specific Energy

Understanding and finding the specific energy for a substance can be very important while working in this investigation in order to comprehend the amount of energy that is being contained within those particles ("How much energy is released in hydrogen combustion reaction?" 2016). The formula of the Specific energy is the following one:

$$SE = \frac{E}{m}$$

First, calculating the Specific energy of hydrogen, it will be necessary to change the values of the formula into the correct ones:

$$SE = \frac{142}{50} = 2,84v^2$$

Now, the sale will be done for the gasoline, sign the 50 Kg as reference as well:

$$SE = \frac{E}{m}$$

$$SE = \frac{44}{50} = 0,88v^2$$

In comparison, hydrogen's fuel specific energy is high above the gasoline's, being of $2,84v^2$ against $0,88v^2$. This would demonstrate hydrogens higher efficiency to the engine but, it is important as well to understand how much of that energy is being actually consumed and not wasted in other forms of e energy dispersion.

Energy Efficiency

The gasoline combustion process has an average of 50% of performance upon the amount of generated energy that is actually being used, meaning that from those $0,88v^2$, it is only being used $0,44v^2$ into the movement of the car, and the rest is being dissipated into the environment ("How much energy is released in hydrogen combustion reaction?" 2016). In the other hand, the energetic efficiency from hydrogen combustion reactions is of, on average, 80% of efficiency, meaning that those $2,84v^2$ would turn out to be $2,2v^2$ ("How much energy is released in hydrogen combustion reaction?" 2016). Therefore, the energy efficiency is as well bigger in the case of the hydrogen fuel compared to Gasoline.

Analysis

As seen before, the Hydrogen fuel does actually present a higher calorific and combustion capacity, but in the other hand the viscosity is higher at least when compared to the isooctane (gasoline fuel). Both specific energy and energetic efficiency were presented to be strongly higher than the ones from gasoline. The autonomy, directly correlated with the specific energy, presented by this alternative source was higher as well than the one presented by the gasoline, granting more time span. When it comes to the safety that this exchange would give to the driver and to the engine had positive effects as well, being less harmful to the engine and safer to the driver as well, being a great alternative in order to walk through a carbon free society.

Conclusion

In order to conclude, Throughout the analysis it was possible to comprehend and now state the vast superiority that hydrogen fuel has when compared to gasoline, being more efficient in calorific and combustion capacity, having a higher viscosity but outperforming as well in specific energy and in energetic efficiency. Throughout the research some mistakes were made, for example some extra tools could have been used for a better analysis of the research question, having a huge potential lost due to this lack of organization in this manner.

EVALUATION

Weaknesses

Throughout the research, several limitations could be found, for example in the time period of a part of the sources that were used, possibly having some problematics there with outdated information. The lack of tools was as well a limitation, what could have been very positive for the investigation, giving more insights to the work and making it capable to be a more in depth research.

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