



24th COBEM - 2017



24th ABCM International Congress of Mechanical Engineering  
December 3-8, 2017, Curitiba, PR, Brazil

COBEM-2017-2870

# HYDROGEN ADDITION EFFECTS IN AIR-FUEL MIXTURE ON ALTERNATIVE INTERNAL COMBUSTION ENGINE

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**Abstract.** *Internal combustion engines are thermal machines that convert thermal energy into mechanical and are the most used by the population. However, with the continuous increase in prices and a possible future shortage, which are very relevant factors, there is a need for studies on new technologies to suppress such problems through alternative fuel. Thus, it was studied how  $H_2+O_2$  could be applied to the air-fuel ratio, taking into account all beneficial aspects or any kind of adversity. After the studies, a comparison is made of the fuel efficiency before and after the addition of the gases in the cylinder.*

**Keywords:** *Internal combustion engine, air-fuel, cell of hydrogen, fuel and calorific value.*

## 1. INTRODUCTION

With the economy in Brazil stagnant and inflation higher since 2002, one of the products that suffers the greatest price increase is fuel, which results in a direct increase of all products and services, reducing the purchasing power of the entire population. There are studies being conducted on other forms of fuel such as hydrogen cars. This fuel is a cheaper alternative being more acquisitive, in addition to less use of fossils.

One of the objectives of this project is to obtain a better performance of gasoline combustion engines through a technology developed using addition of hydrogen in the air-fuel mixture. Thus, this study aims to clarify how the cars work through gasoline powered by hydrogen, the product of electrolysis, achieving a higher yield with economy. It is also intended to explain the consequences and adaptations needed to prepare a motor to receive this new fuel.

## 2. METHODOLOGY

Thermal machines are equipments that transform the heat generated into mechanical work. Internal combustion engines are thermal machines created to convert chemical energy into mechanical energy, which is directly responsible for the work of a force through the expansion of gases. This work generates the reciprocating movement of the piston, which is turned into a crank by the crank. Below is the image (figure 1) of a 4 stroke alternating engine.

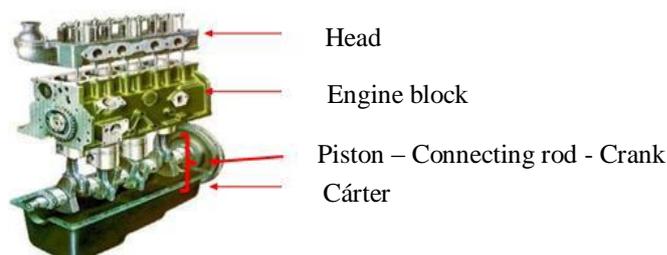


Figure 1: 4-stroke alternative engine. (Barbosa, 2003.)

### 2.1. The four times of the Otto cycle

The Otto cycle engines are divided into four stages: intake, compression, combustion and exhaust (exhaust), and it is a coupling mechanism: the piston is coupled to the crank connected to the crank Crankshaft), thus it transmits movement to the toothed belt which is also connected to the crankshaft itself (crankshaft) of the engine, and it is connected to the valve control shaft which maintains the mechanical synchronism of opening and closing of the intake valves / Exhaust due to piston displacement.

To explain the first time, let's assume that the piston is in Top Dead Center (TDC). Soon after the engine is turned on, the "crank will bring the TDC piston to Lower Dead Center (LDC)" (because at that time one of the cylinders will be burning) in sync with the valve control that will open the valve To receive the air-fuel mixture.

In the second time (compression), the crank changes its direction by pushing the piston upward, causing it to move from the LDC position towards the TDC, reaching the compression ratio parameters. At the point of ignition (close to the TDC due to chemical ignition delay of the fuel or simply ignition delay), the combustion chamber is already at optimum pressure and temperature as the valves are closed.

In the third period, as the air-fuel mixture is already completely pressurized, with the TDC piston and the valves closed, the spark plug releases a spark and thus a combustion occurs that releases the flame front, which propagates with much Velocity by pushing the piston from TDC to LDC.

In the fourth time is the time to expel the gases generated by the combustion. Then the exhaust valve is opened and the piston is pushed from the LDC to TDC, pushing the gases out of the cylinder, thus closing a complete cycle already prepared for the beginning of a new cycle.

The following diagram shows the operation of the motor times:

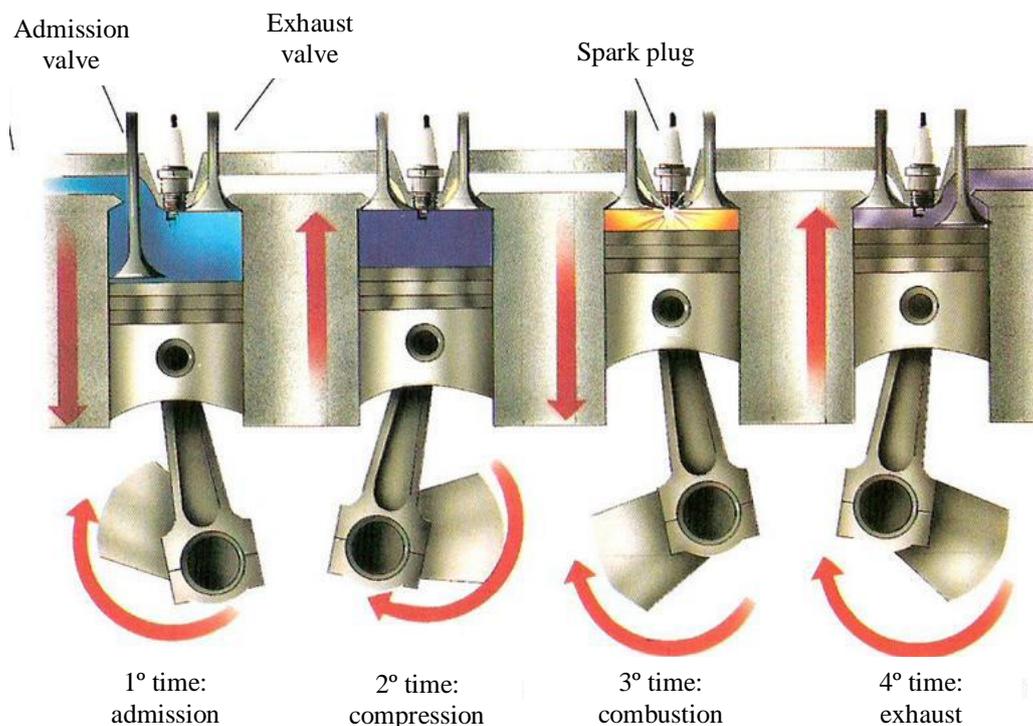


Figure 2: Engine operation

### 2.2. Compression ratio or Volumetric Ratio ( $V_r$ )

Compression ratio is the ratio of the total cylinder volume ( $V_1$ ) to the volume of the combustion chamber or dead volume ( $V_2$ ). An example would be the motors that have 10: 1 compression ratio, this means that  $V_1$  has 10 times the volume of  $V_2$ , that is,  $V_1$  is compressed until it decreases to  $V_2$ .

The most commonly used compression rates are 10: 1 for gasoline and 13.5: 1 for alcohol.

In general, the higher the gasoline quality, especially in octane, the higher the engine performance, as higher compression rates can be applied, which will generate me, after ignition, higher pressure energy, than by Its turn will be converted, not in its entirety due to heat losses, into mechanical energy by the piston-rod-crank assembly.

$$V_r = \frac{V_1 \equiv V_{ud}(\text{Unitary displacement}) + V_2}{V_2} \tag{Eq. (1)}$$

## 2.3. Fuels

Fuels can be defined as any substance that when burned or altered is capable of producing energy. At the end of the nineteenth century gasoline already existed, but what dominated the market was kerosene. Currently we have several types of gasoline developed to serve the entire automotive market.

For the commercialization of gasoline it is necessary that it meets a series of parameters, such as quality, environmental and performance requirements. They must also have a certain tolerance so that manufacturers can put the product on the market at a flexible price. Some properties are quite rigid and have no additive function, for example, octane, pressure and vapor which leaves more complex the production process.

In Brazil, two types of gasoline are marketed: Gasoline A, which does not have anhydrous ethyl alcohol; however, it is sold only from refiner to distributor and we also have gasoline C, which can vary from anhydrous ethyl alcohol to 18-25%. Of the variation of the sugarcane harvest, and, yes, it is sold at the gas stations.

### 2.3.1. Octane

Each engine has a different design, however they all have to be aligned with the gasoline parameters so that the ignition occurs at the correct time. If these parameters are not aligned, in the compression process when the fuel air mixture is at high temperatures and pressures, it can happen to the autoignition / detonation that is when the fuel ignites before the moment (sparkling time), motor. That is why octane is so important because it will represent the relation of the air-fuel mixture to the autoignition, which is responsible for the detonation.

The most common problem caused by autoignition is the colliding metal noise, more popularly called "pin strike", which in fact the correct name would be detonation. The "pin strike" produces in the engine a noise similar to the moment when the vehicle is at a low speed for the gear engaged. The detonation can also bring several other problems such as erosion wear, candle electrodes and head. As a result there is a loss of power in the engine shaft, because the gasoline burned out is no longer used for the release of mechanical energy and happens mechanical shock waves, causing a kind of motor brake.

### 2.3.2. Air-fuel ratio ( $F_r$ )

When we talk about admission, the air-fuel mixture is a key factor for combustion. In the case of internal combustion engines (ICE), gasoline is fuel and atmospheric air is the oxidizer. It is very important that the mixing parameters are met because the closer to the desired parameters the better the combustion and consequently the higher the calorific value, the more fuel economy and the less polluting gases to the environment. The air-fuel mixture can be defined within four limits, poor limit, economical blend, maximum power blend and rich limit.

The poor limit is an undesirable situation because the flame is too slow which can cause it to last until the start of the intake which causes the engine malfunction as it is below the tolerance of the poor limit for the operation of the Otto cycle. The poor limit for Otto occurs with  $F_r$  between 0.7 and 0.85.

Economical mixing is a slightly poor mix so that excess air can burn all the fuel in the combustion process. Through this blend we can achieve the minimum of fuel consumption and also contribute to the reduction of CO emissions.

The mixture of maximum power is an almost rich mixture, which despite the excess fuel, still can achieve the burning of the fuel that the engine can admit, thus achieving the highest possible power. The problem with this mixture is in the increase of CO in the exhaust.

The rich limit is a mixture that adds a lot of fuel inside the chamber, which increases the difficulties of the combustion process and the flame front that is formed, creates an instability in the rotation of the motor and beyond this limit the motor does not work, which is called drowned engine.

### 2.3.3. The combustion process

There are two types of combustion: complete combustion and incomplete combustion. Complete combustion occurs when the amount of oxygen present in the air-fuel mixture is sufficient for the complete oxidation of the fuels present in the combustion chamber. Incomplete combustion occurs when the fuel is not completely oxidized, thus, wasting hydrocarbon waste into the environment. The ideal stoichiometric ratio of the air-fuel mixture, considering pure gas:



In this study, we will try to improve the performance of the engine by including  $\text{H}_2 + \text{O}_2$  through the intake system, thus improving the combustion power, as we would be increasing the amount of oxygen (oxidizer), soon we would be reducing the amount Carbon, since there is a greater possibility of complete combustion. As for the  $\text{H}_2$ , it is an element that increases the calorific value of the combustion, being able to obtain a better yield in kg / s. However, the increase in

temperature within the combustion process results in a chemical reaction between oxygen and nitrogen, generating a higher NO<sub>x</sub> emission.

Below (table 1) follows information of some substances:

Substance	Formula	Mass (UTM)	Power calorific (kJ / kg)
Hydrogen	H <sub>2</sub>	2	120300,432
Carbon monoxide	CO	28	10130,400
Gasoline	C <sub>8</sub> H <sub>18</sub>	114	39480,000
Carbon	C	12	32839,800

Tabela 1: Calorific power of fuels.

## 2.4. Electrolysis

Obtaining H<sub>2</sub> through electrolysis is extremely important because the risks of H<sub>2</sub> storage are very large. Generating the H<sub>2</sub> and consuming it immediately, in addition to reducing the risks, is saved with the logistics and the process of storage.

There are two types of electrolysis: igneous electrolysis and aqueous electrolysis (Senra and Abreu. 2014). Igneous electrolysis occurs when the passage of electric current occurs in an ionic (liquefied) substance. This process always occurs at high temperatures, around 1073 K. Already the aqueous electrolysis is when an electric current passes through an electrolyte dissolved in water, in low temperatures, around 318 to 373 K.

Electrolysis is a non-spontaneous process that has an exactly inverse process to that of the cell because the cell transforms chemical energy into electrical energy and electrolysis transforms electrical energy into chemical energy. It is a chemical process caused by an electric current where the result is the dissociation of H<sub>2</sub>O molecules. The following illustration (figure 3):

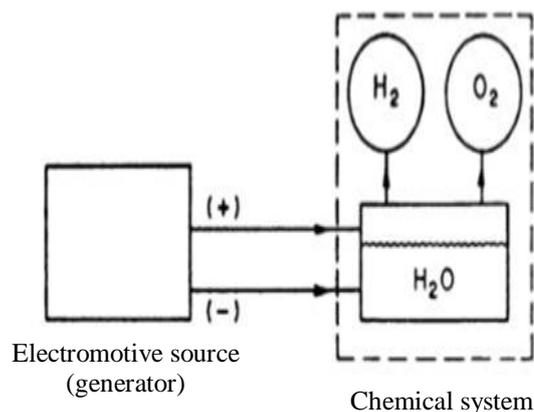


Figure 3: Connection for electrolysis. (Senra and Abreu. 2014)

The higher the electric current applied to the electrolysis, the greater the mass of the product (H<sub>2</sub> + O<sub>2</sub>). The reactions in the electrodes (equations 4 and 5) (Neto, 2016) are described as:



The generator then functions as an "electron pump", something similar to a water pump, that is, through it the electrons received by the positive pole are transferred to the negative pole.

### 2.4.1.HHO Cell

As explained in the previous item the best way to achieve H<sub>2</sub> is through aqueous electrolysis, and nowadays we have the technology of the hydrogen cell.

Characteristics of H2PRO H2PRO manufacturer (Source, 2017):

Production up to 0.00005 m<sup>3</sup> / s. Production of 0.001 m<sup>3</sup> / 86W of power by eliminating the screw as conductor. Low carbon steel from the screw is lousy conductor.

Stainless steel 316L, economy proven from 10 to 30% on average.

- 2 Acrylics, 170mm x 170mm x 10mm thick
- 11 INOX 316L, hexagonal plates, 140mm x 140mm x 1mm thick
- 12 O'rings, 120mm x 3.53mm
- 3 "female" connectors for positive and negative plates
- 2 Quick-Connect Connectors for 10mm PU Hoses (Blue)
- 6 screws of 5 "or 130mm
- 12 Washers
- 6 Parlock Nuts (Travante)

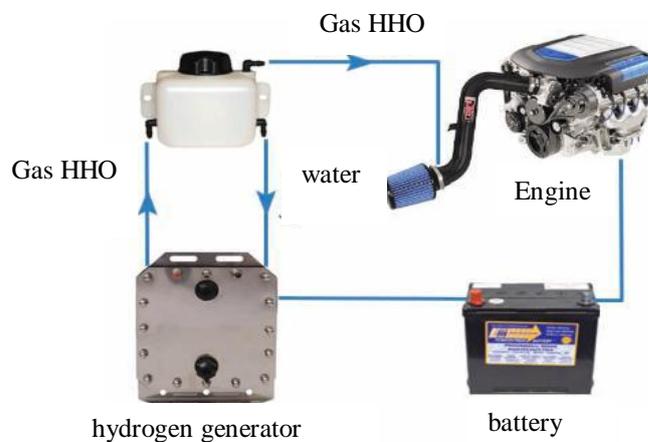


Figure 4: Hydrogen cell kit and installation schematic. (Source, 2017.)

HHO generator for FLEX, Diesel, Gasoline, Alcohol or natural gas vehicles (NGV). Ideal for Engines 1.0 to 1.9.

### 2.5. Basis of calculations

In this section we will relate the calculations referring to a normal ICE (Internal Combustion Engine) with an ICE to gasoline and H<sub>2</sub>.

Stoichiometric relationships (Brunetti, 2012):

Standard:



Molecular masses:

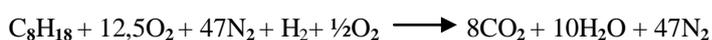
$$\text{Fuel: } (8 \times 12) + (18 \times 1) = 114$$

$$\text{Atmospheric air: } (32 \times 12,5) + (28 \times 47) = 1716$$

Air-fuel relationship:

$$\lambda = 1716 / 114 = 15.05$$

Modified:



Molecular masses:

$$\text{Fuel: } (8 \times 12) + (18 \times 1) + (2 \times 1) = 116$$

$$\text{Atmospheric air: } (32 \times 12.5) + (28 \times 47) + (16 \times 1) = 1732$$

Air-fuel relationship:

$$\lambda = 1732 / 116 = 14.93$$

The fuel mass increase is 1.75% and air mass 0.93%. Despite the increase in molecular weights, the air-fuel ratio hardly varies and still decreases the amount of air required for combustion.

## 2.6. Application of calculations (Sonntag et. al., 2003):

1<sup>st</sup> stage: Conversion of HP (horse power) into kW and Joule.

Car Power 1.0

$$\text{HP} = 0.735 \text{ kW} = 0.735 \text{ kJ / s}$$

$$\text{W} = 73\text{HP} \times 0.735 \text{ kJ/s} = 53.7 \text{ kJ / s}$$

2<sup>nd</sup> stage: Energy spent.

$Q_h$  = Energy consumed

$N_t$  = Thermal yield = 30%

$$Q_h = W / N_t$$

Eq.(6)

$$Q_h = 53.7 / 0.3$$

$$Q_h = 179.00 \text{ kJ / s}$$

3<sup>rd</sup> Stage: mass flow (standard)

$\dot{m}$  = Mass flow

$q_h$  = calorific value.

$$\dot{m} = Q_h / q_h$$

Eq.(7)

$$\dot{m} = 179 / 39,480.00 \text{ kJ/kg}$$

$$\dot{m} = 0.00453 \text{ kg / s}$$

4<sup>th</sup> Stage: Gasoline and H<sub>2</sub> mass flow.

$$\text{C}_8\text{H}_{18} + \text{H}_2 = 38,042.00 \text{ kcal / kg} = 159,776.4 \text{ kJ / kg.}$$

$$\dot{m} = 179 / 159,776.4 \text{ kJ / kg}$$

$$\dot{m} = 0.00112 \text{ kg / s}$$

There is a reduction in fuel consumption due to H<sub>2</sub> addition, since it has high energy per unit mass.

## 3. CONCLUSION

It is concluded that the increase in calories is linked to fuel economy.

With the results, it is understood that the HHO cell is a viable design because it reduces fuel consumption, but requires better engine preparation so that there is no damage due to increased calories.

It is understood that, to improve this work, an experimental development is necessary, and through the application of electronic components such as pressure sensors, temperature, among others, in the sense of measuring and monitoring certain parameters. From these measurements, other necessary calculations would be possible, arriving at new results such as: new graph pressure volume (P x V), the force generated by the pressure energy of the expansion of combustion

gases on the surface of the piston, The torque on the motor shaft would be calculated, and finally, through the rotation sensor, a new power in kJ would be calculated on the motor shaft.

#### **4. ACKNOWLEDGMENT**

The authors want to thank Estácio de Sá University (UNESA) for all collaboration.

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