

HYDROGEN AS ADDITIVE IN CARS WITH INTERNAL COMBUSTION ENGINES.

Jaime Lorenzo Fonseca Ruiz*¹, José Ramón Armendáriz Gutiérrez², Dr. Eduardo Herrera³.

¹ UACH, Ing. Física. Circuito #1, Nuevo campus Universitario C.P. 31125

² UACH, Ing. Física. Circuito #1, Nuevo campus Universitario C.P. 31125

³ CIMAV, Miguel de Cervantes 120, Complejo Industrial Chihuahua CP: 31109

* contact email: shadow32x@hotmail.com

ABSTRACT

Hydrogen can be used directly in internal combustion engines, due to small amounts of energy require, and the wide range of combustion power. The generation of hydrogen needed as an additive in the hydrocarbon is achieved through the chemical process of electrolysis, carried out using dry cells.

For a better analysis and understanding of the system, through the multi-physical program "COMSOL" and design software "SOLIDWORKS" is developing the entire system in order to display different parameters, in order to configure the system to generate hydrogen, and the same electrical system of the car to get the desired results.

The system is being tested in several vehicles with models from 1993 to 2004, reporting favorable results. We also found some problems with the system which is still under investigation.

We decided to change the type of prototype hydrogen generator and previously used an electrolytic cell completely submerged in water, now we are using a dry cell which in principle performs the same task as above.

Once the system has to generate hydrogen, is decide to inject it into the car through the air ducts. Thus begin all the necessary studies to obtain the optimal values and to configure the system to achieve higher efficiency combustion in power.

The values of oxygen-gasoline ratio that controls the brain of the vehicle will be modified to achieve better results in the efficiency of combustion power, and observe the increase in efficiency through lower demand for gasoline in the normal operation of the vehicle

Key words: Combustion, Engine, Efficiency, Hydrogen.

1. Background

Over time transportation methods have been evolving the means our planet, trains, planes, boats, but the most widely used vehicle is the automobile, which uses an internal combustion engine using hydrocarbons to move us from one place to another. This vehicle has been evolving through the years and today you can see the hybrid cars which no longer require gasoline or diesel using only electric current, which can be obtained from fuel cells.

Cars are an indispensable transportation method, and the source of energy that require increases their prices day by day increasing transportation's cost , also an internal combustion engine emits gaseous pollutants because of its lack of efficiency . The system of the automotive internal combustion can be improved using hydrogen as an additive by making a complete and more efficient combustion process resulting in a decrease in the consumption of gasoline or diesel. [1]

2. Hydrogen in internal combustion engines.

2.1 *Injection system of internal combustion engines.*

The fuel is needed to produce the power required to move a vehicle. Currently there are several fuels that can be used in engines; the diesel and gasoline are the most common but we can also use: liquefied petroleum gas (LP), compressed natural gas (CNG), liquefied natural gas (LNG), propane, methanol, ethanol among others.

If we want to maximize the energy of the fuel it is required mix it with oxygen, to generate the combustion. There are three factors that influence the combustion's phenomena:

a. Temperature

The temperature of the combustion chamber is essential to generate a good combustion. Usually at a high temperature gives a better combustion, however this affects emissions of nitrogen oxides (Nox) which are increased to the higher temperatures. A low temperature generates a poor combustion and generally result in high emissions of unburned hydrocarbons (HC) and carbon monoxide (CO).

b. Turbulence

Refers to the way in which the air and fuel mix. In this sense the manufacturers have tried by different means of increasing turbulence, sometimes through the design of the admission multiple, the piston head, the shape of the camera, etc.

c. The time of residence time

Refers to the time that mix air fuel remains inside the combustion chamber. At this time, mixing air fuel should burn completely. [2]

A fuel system that does not meet the necessary requirements can produce the following effects:

- Fuel Over-consumption
- Premature wear of parts by contamination of the lubricant with fuel and cause thinning of the lubricant film
- Lack of power
- Damage to the catalytic converter
- Leakage of fuel
- Fire conatuses

All this is important to know how it works the fuel system, the actions that can affect negatively the performance of the vehicle.

Objective

The fuel system has several objectives:

- Provide the right value mix according to the vehicle's operation conditions
- Mixing air and combustible for fuel's optimization
- Measure the fuel or the blend value in the combustion chamber

To meet these goals there are fuel injection systems, among them are: carburetor or natural admission systems and injection systems (fuel Injection systems).

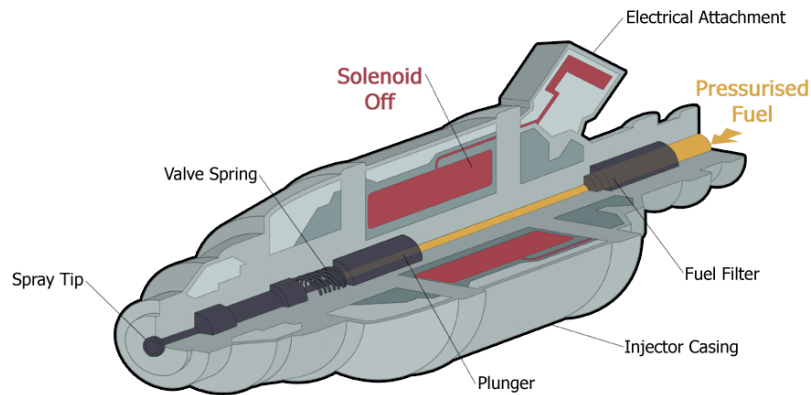


FIGURA 1: Gasoline Injector

Today we use the fuel injection engine, which still does not take full advantage of gasoline energy

Using hydrogen as an additive this burning process will be more efficient, due to the properties given by mixing it with gasoline and oxygen, because hydrogen is the most oxidant gas, its ability to easy combination with other gases, and their high energy power makes this ideal gas for the purpose which is to be achieved.

2.2 Hydrogen Combustibility Properties

Owing to the high diffusivity, low viscosity, and unique chemical nature, combustibility of hydrogen is somewhat different than the other fuels. Various combustibility properties are described in the following:

Table 1. Comparison of Hydrogen with other Fuels. [3]

Fuel	Stoichiometric Air/Fuel Ratio (kg)	Combustible Range (%)	Flame Temperature (°C)	Min. Ignition Energy (MJ)	Autoignition Temperature (°C)
Methane	17.2	5.-15	1914	0.3	540-630
Propane	15.6	2.1-9.5	1925	0.3	450
Octane	0.31	0.95-6.0	1980	0.26	415
Methanol	6.5	6.7-36.0	1870	0.14	460
Hydrogen	34.3	4.0-75.0	2207	0.017	585
Gasoline	14.6	1.3-7.1	2307	0.29	260-460
Diesel	14.5	0.6-5.5	2327		180-320

2.3 Hydrogen Internal Combustion Engine

Hydrogen can be used as a fuel directly in an internal combustion engine, almost similar to a spark-ignited (SI) gasoline engine. Owing to low spark-energy requirement and wide flammability range, hydrogen is an excellent candidate for use in SI engines [3, 4].

Owing to its high auto ignition temperature, finite ignition delay, and the high flame velocity, hydrogen internal combustion engine (HICE) vehicles have less knocking tendency compared to gasoline engines. Hence, HICE have a higher research octane number (>120) than gasoline engines (91–99). HICE also offers CO₂ and hydrocarbon-free combustion and lean operation, resulting in lower NO_x emissions. Hydrogen cannot be used directly in a diesel or “compression ignition” engine since hydrogen’s auto ignition temperature is too high. Thus, diesel engines must be outfitted with spark plugs or use a small amount of diesel fuel to ignite the gas known as pilot ignition. [4]

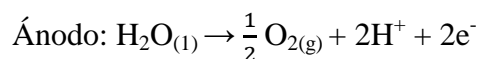
3. Hydrogen Production by Water Electrolysis

3.1 Electrolysis.

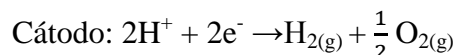
Electrolysis of water to generate hydrogen and oxygen has a history of more than 200 years it is the simplest of all the water-splitting techniques and comparatively efficient.

The theoretical OCV (open Circuit Voltage) of the hydrogen–oxygen cell at 25°C is 1.229 V. Electrolysis is conducted with a cell voltage of 1.8 to 2.1 V at current densities of 2 to 4 kA/m². Improved designs where the working voltage is 1.6 to 1.7 V have been developed recently. The electrical energy consumption is 3.5 to 5 kWh per cubic meter of hydrogen. A process involving water electrolysis is the production of heavy water. During cathodic polarization the relative rates of deuterium discharge and evolution are lower than those of the normal hydrogen isotope. Hence, during electrolysis the solution is enriched in heavy water. When the process is performed repeatedly, water with a D₂O content of up to 99.7% can be produced. Electrochemical methods are also used widely in the manufacture of a variety of other inorganic and organic substances.

The water is decomposed by an oxidation reaction with the release of oxygen and hydrogen to feed the cell with electrons flowing through the external circuit, leaving positively charged ions (protons H⁺), which diffuse through of electrolyte [11, 12].



At the cathode takes place the reduction reaction which the protons in the presence of electrons, forms molecular hydrogen gas that is released.



La reacción global es:



[7]

Oxygen, a highly useful gas, is the only by-product. Water electrolyzers today satisfy approximately 3.9% of the world's hydrogen demand. Electrolyzers are used to produce hydrogen at levels ranging from a few cm³/min to several thousand m³/hour, with units ranging in physical size from portable to essentially immovable. Electrolyzers generally use electricity from the power grid, which in turn is predominately powered by the combustion of coal, resulting in expensive and eco-hostile operation. For sustained development the electrolyzers will need to be run using electrical energy derived from renewable sources such as windmills or solar cells. [6]

On this project, we obtain the energy from electrical system of cars.

3.2. *Electrolyzers (Dry Cell)*

The system used to generate an electrochemical process (electrolysis) is efficient using a dry cell. Consists of several stainless steel plates separated by an insulator, has 3 electrodes (two cathodes and an anode) and 8 neutral plates. Within the system of plates and insulation will be pass water distilled with an electrolyte, NaOH or KOH, it will pass voltage depending on the amount of plates arranged [14].

This design is an improvement from a previous prototype, which reported favorable results, the difference of the old prototype to the dry cell is that the dry cell will not be submerged in a

container with water, therefore the system is more practical, also for the plate's arrangement the electrolyte is used in an efficient way. The design is more productive, compact and simpler.

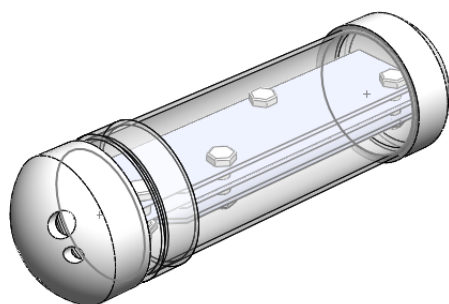


Fig 2. *First Prototype Electrolyzer (design submerged)*

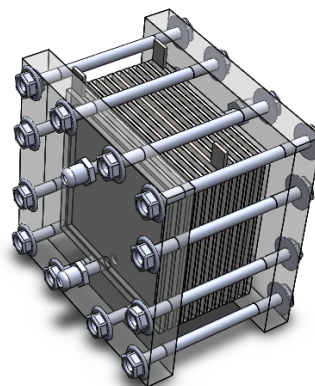


Fig 3. *Second Prototype Electrolyzer "Dry Cell"*

At standard ambient temperature and pressure, the change in Gibb's free energy ΔG for the water splitting reaction is positive and hence the reaction is non-spontaneous; for the reaction to occur the electrical energy equivalent to the change in the Gibb's free energy ΔG of the reaction must be supplied. In an electrolytic cell the electrical energy is supplied by applying a potential difference between two electrodes placed in an electrolyte. Electrical energy to chemical energy conversion takes place at the electrode-solution interface through charge transfer reactions. A potential difference V applied between the electrodes can be used to do maximum work of nFV , where F is the Faraday constant and n is the number of moles of electrons involved in the reaction. If V_{rev} is the minimum voltage needed to drive the water splitting reaction,

$$\Delta G = nFV_{\text{rev}}$$

Where:

V_{rev} = corresponds to the reversible work.

Then we can calculate the efficiency of Hydrogen generation where it is defined as ratio of the energy content of hydrogen (the energy that can be recovered by reoxidation of the hydrogen and oxygen to water) to the electrical energy supplied to the electrolyzer. In terms of voltage, the efficiency can be expressed as:

$$\varepsilon = V_{\text{tn}}/V_{\text{op}}$$

Where:

V_{tn} = the thermoneutral voltage,

$$V_{\text{tn}} = \Delta H/nF = 1.482 \text{ V}$$

V_{op} = operating voltage.

$$V_{\text{op}} = V_{\text{rev}} + \eta_a + |\eta_c| + \eta_\Omega$$

Where η_a and η_c are the anodic and cathodic overpotentials associated with the reaction kinetics (electrode polarization effects) and η_Ω is the Ohmic overpotential that arises due to the resistive losses in the cell.

Ideally, a cell operating at V_{tn} can produce hydrogen at 100% thermal efficiency [6, 8].

4. DESIGN AND IMPLEMENTATION

The new design is in development, the first step is designing the Dry Cell, taking in mind the best materials for the build, select plates and bases materials and the insulation between plates. After this, is necessary to conduct several experiments to check the distance between plates and the concentration of electrolyte which must contain the water. In each experiment will take data such as the temperature of the cell, current demand of the electrolyzer, electrical conductivity of the electrolyte, and hydrogen generation [15].

Table 1. Design of experiments for the construction of the Dry Cell.

Design of the dry cell				
Efficiency of hydrogen generation.				
Material	Voltage	Distance between plates	Electrolyte (NaOH) 4% to 15 % Concentrations	Electrolyte (KOH) 4% to 15 % Concentrations
Steel 316 L	1.2 to 2V	0.3 cm to 0.8 cm		
Steel 304 L	1.2 to 2V	0.3 cm to 0.8 cm		
Coatings	1.2 to 2V	0.3 cm to 0.8 cm		
Graphite	1.2 to 2V	0.3 cm to 0.8 cm		

In this experiment we watch the current demanded by the cell, the temperature reaches depending on the configuration of the cell, the amount of hydrogen that it generates in ml/s in order to determine the material, the voltage, and distance between electrodes, concentration and type of electrolyte more efficient to generate hydrogen.

Having a generation of hydrogen suitable for this purpose, it is possible to dispose of it without hydrogen purification (the hydrogen is in small amounts nebulized and it can be used in an internal combustion engines without problems.), injected through the vehicle air ducts, its essential to monitor the vehicle with an automotive scanner to verify the efficiency of combustion, by measuring the speed, pressure in combustion chamber, engine temperature, behavior of the admission and extraction of gas among other things.

Table 2. Efficiency of internal combustion engine using hydrogen.

EFFICIENCY OF HYDROGEN IN ENGINES OF INTERNAL COMBUSTION.				
	Configuration Map injection oxygen sensor	Configuration of injection gasoline (ml/s)	Concentration hydrogen – gasoline	Concentration hydrogen - DIESEL
			5% - 20%	5% - 20%
The car computer program	1	1		
		2		
		3		
	2	1		
		2		
		3		
	3	1		
		2		
		3		
	4	1		
		2		

The system will be efficient and would only work if it reaches a greater power of combustion.

Table 2 shows the steps to follow to be able to inject the amount of exact hydrogen to obtain improved efficiency.

The computer of the vehicle can ignore the new fuel and start working irregularly, so the parameters work with which the vehicle must be rescheduled, by varying the values that launch of oxygen and fuel injection sensors to make the engine work properly, also can be modified the parameters with which the brain of the computer works making it inject less fuel to get the same power of operation of the engine, in this way you may verify that the system works properly and is saving gasoline or diesel if necessary.

The system will be mounted on a Ford F-250 model 1999; with a v8 the current to feed the dry cell will be taking of the electrical circuit of the same truck and will be monitored with an oscilloscope and multimeters to avoid energy deficiency in the vehicle. Once you start to work the equipment, this will be monitored by an automotive Scanner Maxidas DS708, with which we can monitor behavior from any sensor vehicle's: temperature of the engine, air, injection of gasoline, revolutions per minute, even the consumption of gasoline in the vehicle [13].



Figura 4. Scanner automotriz
Maxidas DS708

The computer of the vehicle shall be rescheduled through a programmer Devil sport or for control of fuel Turboxs Dtec, these developers will make it possible to modify the values of control of injection of gasoline and oxygen to the engine, will also enable reschedule other systems such as torque and modify the speed limiting devices allowing to find the most optimal configuration hydrogen by using.



Figure 5. Programmer Devil sport, programmer Turboxs Dtec.

5. SIMULATION OF THE SYSTEM IN COMSOL

5.1 COMSOL multiphysics simulation of Dry Cell.

During the developing of the hydrogen generator prototype and it's implemented in vehicles with internal combustion engines, the system is also designed and analyzed with design programs and multiphysics programs like SolidWorks and COMSOL and thus be able to define more precisely

the type of materials used in the dry cell and the necessary concentration in the mixture of hydrogen-Gasoline - oxygen in the combustion chamber.

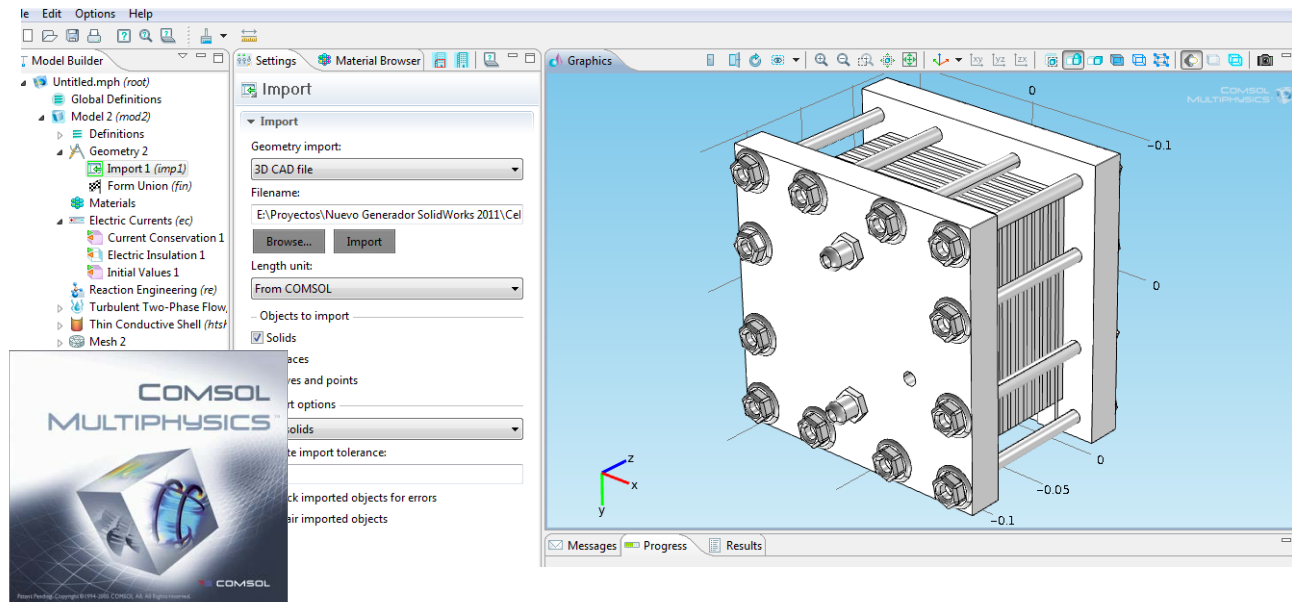


Figure 6. Simulation at COMSOL. (Begins to put the system to the simulation)

To carry out the simulation of the electrolysis in the program of simulation COMSOL is needed:

- Electrical currents.
- Engineering of reaction
- Two-phase flow modules
- Thermodynamic Module
- Electrochemical module.

Three different simulations were carried out in order to understand luxury of detail what happens in the process.

The first simulation be drawn up in two dimensions, in which a water-filled container will be represent with an electrolyte at different concentrations, will be inserted where an anode and a cathode, which pass them current. This simulation was conducted exchanging properties of the electrodes with which it has steel 316, steel 204, graphite and a coating of substrate of Platinum to observe which is optimal for the obtaining of the hydrogen, as well as its acquisition in the cathode.

The second simulation will be also drawn up in two dimensions, but instead of using a pair of electrodes, we will use a spatial arrangement between plates "-nnnn+nnnn-" where "n" is equivalent to a neutral electrode, "-" equivalent a cathode and "+" equivalent a anode (Fig 7), to which a voltage of 1.2v reached them 2.8v current will be obtained from the same vehicle. It is raised using different materials steel 316L, graphite and a coating of substrate of Platinum, exchanging their property in the electrodes, with the purpose of observing the amount of hydrogen generated with this arrangement, the rate of reaction as well as the amount of hydrogen generated at the cathode.

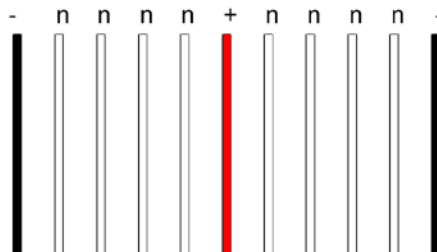


Fig 7. Electrodes space configuration.

The latest development of simulation in three dimensions, by importing the design of the cell designed in solidworks to the electrodes will be them the properties of the material that gave us better results in the past simulations. This latest simulation aims to observe the electric potential that is necessary to run the electrolyzer, chemical behavior and deduce if the selected materials are suitable for the development of a prototype.

5.2 Solution in COMSOL Multiphysics™ of Hydrogen Combustion in internal combustion engines.

Finally a fake combustion by injecting gasoline, hydrogen and oxygen in the combustion chamber of a motor vehicle, in order to observe the behavior of the power of flame in that environment, verify if the hydrogen helps or not in the process of normal combustion of the vehicle.

The droplet is surrounded by a spherically symmetric flame in which the fuel and oxidizer react in stoichiometric proportions. The species of interest in the gas phase are fuel vapor, oxidizer and combustion products, while the liquid fuel is the only condensed phase.[9]

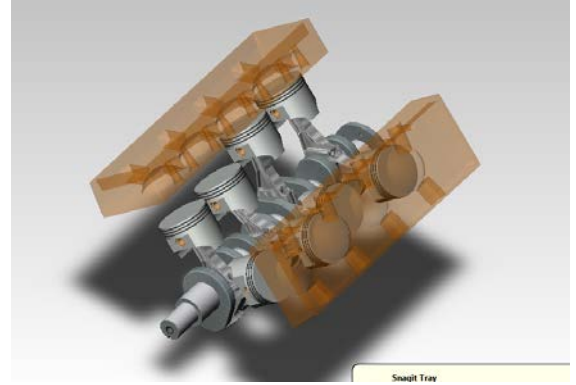
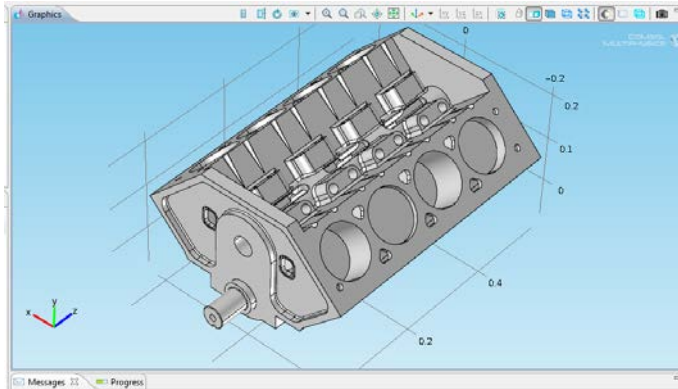


Figura 8. Internal combustion system of a car model used for simulation in COMSOL

The problem was setup using a simple 2D and 3D geometry and the coupled Fluid-Chemical Reactions sub-model in Comsol Multiphysics. The following governing equations are included to solve the system [10]:

- Convection and Diffusion (Mass Conservation).
- Convection and Conduction (Energy Conservation).
- Incompressible Navier-Stokes (Momentum Conservation).

Also we use the thermodynamics, chemical and fluids modules are helping in this process and help to understand and verify the operation of the system using the hydrogen, thus we will check in a simulated manner if the hydrogen will help in the combustion and increase of efficiency of functioning of the internal combustion engine.

5.3 Thermal Efficiency

The theoretical thermodynamic efficiency of an Otto cycle engine is based on the compression ratio of the engine and the specific-heat ratio of the fuel as shown in the equation

$$\eta_{th} = 1 - \frac{1}{\left(\frac{V_1}{V_2}\right)^\gamma} - 1$$

Where:

V_1/V_2 = the compression ratio

γ = ratio of specific heats

η_{th} = theoretical thermodynamic efficiency

The higher the compression ratio and/or the specific-heat ratio, the higher the indicated thermodynamic efficiency of the engine. The compression ratio limit of an engine is based on the fuel's resistance to knock. A lean hydrogen mixture is less susceptible to knock than conventional gasoline and therefore can tolerate higher compression ratios.

The specific-heat ratio is related to the fuel's molecular structure. The less complex the molecular structure, the higher the specific-heat ratio. Hydrogen ($\gamma = 1.4$) has a much simpler molecular structure than gasoline and therefore its specific-heat ratio is higher than that of conventional gasoline ($\gamma = 1.1$).

6. Conclusions

Hydrogen can be used as an additive in internal combustion engines to increase the power of engine combustion. The system to be installed on older model cars with favorable results as a increment power of combustion showing fuel saving results. Now the system is being tested in more recent models that present a few problems such as the imbalance in the mix that creates the burning, this is because the computer does not make the oxygen-fuel mixture for the proper functioning optimally, so is therefore necessary to change these values for obtain more efficient combustion process and wait for a lower consumption that we obtained earlier. To do this, we start testing with scanner that allows a monitoring temperature, pressure and fuel consumption by plotting the car's behavior in real time. This study will be done in conjunction with a programming device, which is used to modify values that the vehicle used to make oxygen-gasoline mixture.

After configuring the vehicle's computer and injecting the hydrogen using a 10% concentration in gasoline is expected to fuel savings of 40%.

7. REFERENCES

- [1]. **White, C.M., R.R. Steeper and A.E. Lutz, The hydrogen fueled internal combustion engine:** A technical review. Int. J. Hydrogen Energy, 2006.
- [2]. **El sistema de combustible de los motores de combustion interna.** Direccion de transporte CONAE (Comision Nacional para el Ahorro de Energia), 2006.
- [3]. **Das, L.M., Hydrogen engines: A view of the past and a look into the future.** Int. J. Hydrogen Energy, 1990.
- [4]. **Hydrogen Fuel, Production, Transport and Storage.** (Ram B. Gupta, Tylor & Francis Group, LLC, CRC Press, 2009).

- [5]. **¿Por qué Hidrogeno?** (Suilma M. Fernandez Valverde, Instituto Nacional de Investigadores Nucleares, ININ).
- [6]. **Light, Water, Hydrogen- Craig A. The Solar Generation of Hydrogen by Water Photoelectrolysis.** (Grimes, Oomman K. Vargherse, Sudhir Rajan, Springer Science+Business Media, LLC, 2008).
- [7]. **Electrolisis.** (Rosa de Guadalupe Gonzalesz Varela, Laboratorio de Catalisis. ESQIE- IPN-CINVESTAV).
- [8]. **Water electrolysis in a low and medium temperature regime. In: Wendt H (ed) Electrochemical hydrogen technologies -Electrochemical production and combustion of hydrogen. Elsevier, (Divisek J, New York, 1990).**
- [9]. **An Introduction to Combustion. Concepts and applications (2nd ed.)** (Stephen R. Turns, McGRAW-HILL INTERNATIONAL EDITIONS. 2000)
- [10]. **Simulation of H₂-O₂ constant Volumen Combustion using COMSOL MultiphysicsTM.** (Peter Perez, The Pennsylvania State University Energy and geo environmental engineering mathematical methods for energy systems. 2007).
- [11]. **HandBook of Electrochemistry.** (Cynthia G. Zoski, 2007).
- [12]. **Electrochemical Methods, Fundaments and Applications.** (Allen J. Bard, Larry R. Faulkener. 2001).
- [13]. **Understanding automotive Electronics,** sixth edition. (William B. Ribbens, NEWNES, 2003).
- [14]. **Metodos de sintesis de electrolizadores** (Miguel Angel Garcia Contreras, Instituto Nacional de Investigadores Nucleares ININ).
- [15]. **Fundamentos de ciencia e ingeniería de materiales. Tercera Edicion.** (William F. Smith, University of Central Florida, 1998).

