

Palestine Polytechnic University



College of Engineering and Technology
Mechanical Engineering Department

Graduation Project

Studying and Testing of Combustion of Hydrogen-Enriched Gasoline in
A Spark Ignition Engine

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Abstract

The effect of the amount of hydrogen addition on the fuel consumption and emission of a spark ignition has been studied. Dynamometer test results for specific engine speed, engine load, equivalent ratio and hydrogen enrichment under steady state operation are presented and the engine minimum b.s.f.c specified. Experiments carried out with a four-cylinder four stroke SI engine confirmed the possibility of expanding the combustion stability limit, which correlates well with the general trend of enhancing the rate of combustion. An increase of brake thermal efficiency has been obtained with a reduction of HC emission; the NO_x emissions were higher, except for very lean mixtures.

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Chapter One

General Introduction

- Project Background.
- Project Scope.
- Project Goals and Objectives.
- Project Components.
- Time Table.
- Primary Budget.

1.1 Introduction:

As a result of increasing the number of vehicles in the world, the amount of environment pollution increased, the trouble of today's vehicle is that they still put out a lot of pollution due to their basic fuel which is the fossil fuel.

Many technologies that arrived to the world today tried to solve the Automotives Gas emission but these solutions were on the account of engine efficiency.

In this project we will build a device that extract hydrogen and Oxygen from water then add it in parallel with Gasoline to the combustion chamber in SI engines, by this we will try to reduce the emission of toxic gases and increase the efficiency of the Engine.

1.2 Project Background:

That the majority of vehicles nowadays are powered by internal combustion engines. More specifically, most vehicles use gasoline according to the so-called Otto Cycle and therefore sometimes called Otto engines.

Since the beginning of the twentieth century, specifically in the sixties the Governments of the manufacturers of vehicles became aware of the problem of environmental pollution from toxic gases emitted from vehicles. Evidence showed that environmental pollution has started to take a critical form that is a threat to everything on earth.[10]

Finding the best ways to manage and reduce the pollution caused by cars is the biggest interest of all designers and car manufacturers. Extensive research studies and experiments are carried over to achieve that task. Some did that by changing the design of the engine itself and made a few changes on the basic structure of the engine to reduce the emission of toxic gases. Others

developed systems for treating exhaust gases such Catalytic Converter which oxidizes and reduces these gases or like the E.G. R. " exhaust gases recycling " in which some of the exhaust gases are returned to the combustion chamber with new fresh mix. These methods have proved effectiveness in reducing exhaust gas, but at the expense of engine efficiency and in addition to that it needs certain conditions to be met.

Research is continued on the subject and it is divided into two categories:

The use of alternative fuel

The creation of hybrid systems

The look for the use of alternative fuel and the use of hybrid engines was due to several reasons, most importantly:

To reduce the emission of toxic gases

The continuing decline in global stock of natural oil, which is the main source of fuel for cars. It is expected the oil will be completely used in the next fifty years.

The idea of using alternative energy was first raised in the beginning of the twentieth century, but was put to use in a practical way at the end of that century. Among the most prominent types of alternative fuels:

Cooking gas

Liquefied natural gas

Hydrogen

Researchers and experiments in this direction were faced with so many problems. In particular when bio fuels were used ethical questions raised because those are food sources that a lot of the underdeveloped countries do not even have.

Other problems emerged from using hydrogen as a source of fuel. Extraction of pure hydrogen and its storage needs advanced technology costs a lot of money. Also some people considered the cars containing hydrogen tanks to be moving bombs in the streets since hydrogen is extremely flammable and combustible (i.e. its reaction with oxygen is sort of an explosion).

The word hybrid means composed of elements originally drawn from different origins. And when it comes to cars it means involving a number of specific elements in the formation of a single operation (i.e. Work generated by more than one source of energy). [3]

There are several types of hybrid systems:

Hybrid electric motor and internal combustion engine

Hydraulic hybrid engine with an internal combustion engine

Internal combustion hybrid engine using more than one fuel such as gasoline and cooking gas

The electric motor may use several sources to charge its batteries. Batteries might get charged through the work of the internal combustion engine, or through the movement of the wheels during braking or driving down hill, and some are charged by solar cells.

The process of producing Hydrogen from water is not new technology. Producing hydrogen from water was discovered in 1879. Only recently hydrogen has been applied to fueling cars, trucks, and tractors.[3]

Water (H_2O) disintegrates to (Hydrogen and Oxygen) through a process of electrolysis. The Hydrogen and Oxygen atoms are separated; the hydrogen is usable fuel for internal combustion engine.

Developing this technology specifically to supplement the existing fossil fuel required by most vehicles on the road today is new trend in the world. Our systems are designed to be hydrogen on demand system.

This means that the engine uses the hydrogen fuel as it is produced. There is no storage of hydrogen and it's not stored in a pressurized environment.

The system use a small portion of excess electrical energy that engine produces to supply the hydrogen generator with the electrical current necessary to the electrolysis process and to the resonance circuit. The System Control Manager monitors and regulates the electrical current to the generator protecting it and the vehicle.[2]

1.3 Project Scope:

The scope of the project is to build extraction device to get hydrogen and oxygen gases to reduce emission and to increase the engine performance. This includes the following main topics:

- Design and building of water based Hydrogen gas extraction Device.
- Measure the amount of Hydrogen gas we can extract from specific amount of water by the device we will build.
- We will choose a gasoline car so we test the emission, performance, fuel consumption of the engine.
- Installation the hydrogen gas Device in the engine housing and connect it to the intake manifold
- Testing the emission, performance, fuel consumption of the engine after installing and operating the hydrogen gas device and compare it with previous test.

1.4 Project Components

- MAZDA 323 1.6L
- Hydrogen Extraction Device Based on electrolyte and resonance circuit.
- Brook volume flow meter
- Electric power supply
- Gas analyzer device
- Revolution counter

1.5.1 Time Table:

The time table for the first semester is illustrated in (Table 1.1).

Table 1.1: The time table for 1st semester

Objective	Week Number															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Selecting Project title	■	■	■													
Setting the Project Goals and Objects				■	■											
Determining the Scope of the project					■	■	■	■								
Collecting the related information			■	■	■	■	■	■	■	■	■	■				
Theoretical data and analysis of Combustion for hydrogen-Gasoline Mixture							■	■	■	■	■	■				
Writing and Finalizing the project					■	■	■	■	■	■	■	■	■	■	■	
Presentation																■

1.5.2 Time table

The time table for the second semester is illustrated in (Table 1.2).

Table 1.2: The time table for 2nd semester

Objective	Week Number																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
Finding an existing Gasoline engine	■	■															
Do all tests needed on the engine without enriched			■	■	■												
Bought the equipment which needed					■	■	■	■									
Build HHO device						■	■	■	■	■	■	■					
Repeat tests with enriched by hydrogen							■	■	■	■	■	■					
Writing and Finalizing the project					■	■	■	■	■	■	■	■	■	■	■	■	
Presentation																	■

1.6 Primary Budget

Preliminary estimates are made for the project components as listed in table (1.2)

Table 1.2 Budget

TASK	COST (NIS)
Rescarches and Internet	130
Transportations	100
Printing papers	120
Equipments	1450
Accessories of the project	500
TOTAL	2300

Chapter Two

Hydrogen from Water

Introduction.

Hydrogen properties

Hydrogen Extraction Device Layout.

Hydrogen Extraction Device Components.

2.1 Introduction

Hydrogen can be generated from water by 'splitting' it from oxygen. The most well-known process is electrolysis, but other mechanisms exist as well, such as catalyst in the presence of heat (e.g. solar), or superimposing radio frequencies. This project will use the resonance circuit in addition to electrolysis process in order to have a larger amount of hydrogen to be sufficient for an internal combustion engine.

The simple statement that water is made from hydrogen and oxygen doesn't give us a very clear picture of what really goes into the creation of a molecule of water. A quick look at the chemical equation for the formation of water tells us more. [12]



It takes two molecules of the diatomic hydrogen gas, combined with one molecule of the diatomic oxygen gas to produce two molecules of water. In other words the ratio of hydrogen to oxygen is 2:1, the ratio of hydrogen to water is 1:1, and the ratio of oxygen to water is 1:2.

There's something more though that doesn't show up in the equation. Energy. The formation of water from its elements produces, in addition to water, a tremendous amount of energy, 572 kJ to be exact. [7]



This is an example of an exothermic reaction, a reaction that produces energy. It is also an example of what is called a combustion reaction, where a substance (in this case hydrogen gas) is combined with oxygen.

Hydrogen is a good, clean fuel, producing only water as a by-product. Unfortunately it produces so much energy that it can get out of control, resulting in an explosion. But let's forget about that

explosive part for a minute and think about the possibilities. Hydrogen as a New Clean Fuel could be the end of the energy crisis, but where would we get the hydrogen?

It's the same chemical reaction, but run in reverse:



2.2 Hydrogen properties

2.2.1 Introduction to Hydrogen

Hydrogen is the simplest; It is made up of one proton and one electron revolving around the proton. In its normal gaseous state, hydrogen is colorless, odorless, tasteless, and non-toxic and burns invisibly.

In 1766-81, Henry Cavendish was the first to recognize hydrogen gas as a discrete substance, and that it produces water when burned, a property which gave it later its later name, which in Greek means "water-former". At standard temperature and pressure, hydrogen is a colorless, odorless, nonmetallic, tasteless, highly combustible diatomic gas with the molecular formula H_2 .

It is 14.5 times lighter than air and does not naturally exist as hydrogen gas but rather as part of a compound where it is bonded to other elements. For example, it is found in water (H_2O) and in hydrocarbons such as natural gas (CH_4). To produce pure hydrogen we have to 'unlock' the chemical bonds in the molecules that form these substances.[12]

2.2.2 Density and Related Measures

Hydrogen has lowest atomic weight of any substance and therefore has very low density both as a gas and a liquid.

Specific Volume

Specific volume is the inverse of density and expresses the amount of volume per unit mass. Thus, the specific volume of hydrogen gas is 191.3 ft³/lb (11.9 m³/kg) at 68 °F (20 °C) and 1 atm, and the specific volume of liquid hydrogen is 0.226 ft³/lb (0.014 m³/kg) at -423 °F (-253 °C) and 1 atm. [11]

Expansion Ratio

The difference in volume between liquid and gaseous hydrogen can easily be appreciated by considering its expansion ratio. Expansion ratio is the ratio of the volume at which a gas or liquid is stored compared to the volume of the gas or liquid at atmospheric pressure and temperature.

When hydrogen is stored as a liquid, it vaporizes upon expansion to atmospheric conditions with a corresponding increase in volume. Hydrogen's expansion ratio of 1:848 means that hydrogen in its gaseous state at atmospheric conditions occupies 848 times more volume than it does in its liquid state. [12]

When hydrogen is stored as a high-pressure gas at 3600 psi (250 bar) and atmospheric temperature, its expansion ratio to atmospheric pressure is 1:240. While a higher storage pressure increases the expansion ratio somewhat, gaseous hydrogen under any conditions cannot approach the expansion ratio of liquid hydrogen. [12]

Hydrogen Content

Even as a liquid, hydrogen is not very dense. Ironically, every cubic meter of water (made up of hydrogen and oxygen) contains 111 kg of hydrogen whereas a cubic meter of liquid hydrogen contains only 71 kg of hydrogen. Thus, water packs more mass of hydrogen per unit volume, because of its tight molecular structure, than hydrogen itself. This is true of most other liquid

hydrogen containing compounds as well; a cubic meter of methanol contains 100 kg of hydrogen and a cubic meter of heptane contains 113 kg. Hydrocarbons are compact hydrogen carriers with the added advantage of having higher energy density than pure hydrogen.

2.2.3 Leakage

The molecules of hydrogen gas are smaller than all other gases, and it can diffuse through many materials considered airtight or impermeable to other gases. This property makes hydrogen more difficult to contain than other gases.

Leaks of liquid hydrogen evaporate very quickly since the boiling point of liquid hydrogen is so extremely low.

Hydrogen leaks are dangerous in that they pose a risk of fire where they mix with air. However, the small molecule size that increases the likelihood of a leak also results in very high buoyancy and diffusivity, so leaked hydrogen rises and becomes diluted quickly, especially out-doors. This results in a very localized region of flammability that disperses quickly. As the hydrogen dilutes with distance from the leakage site, the buoyancy declines and the tendency for the hydrogen to continue to rise decreases. Very cold hydrogen, resulting from a liquid hydrogen leak, becomes buoyant soon after it evaporates. [7]

In contrast, leaking gasoline or diesel spreads laterally and evaporates slowly resulting in a widespread, lingering fire hazard. Propane gas is denser than air so it accumulates in low spots and disperses slowly, resulting in a protracted fire or explosion hazard. Heavy vapors can also form vapor clouds or plumes that travel as they are pushed by breezes. Methane gas is lighter than air, but not nearly as buoyant as hydrogen, so it disperses rapidly, but not as rapidly as hydrogen.[12]

2.2.4 Energy

Energy Content

Every fuel can liberate a fixed amount of energy when it reacts completely with oxygen to form water. This energy content is measured experimentally and is quantified by a fuel's higher heating value (HHV) and lower heating value (LHV). The difference between the HHV and the LHV is the "heat of vaporization" and represents the amount of energy required to vaporize a liquid fuel into a gaseous fuel, as well as the energy used to convert water to steam. [6]

The higher and lower heating values of comparative fuels are indicated in appendix C.

Hydrogen has the highest energy-to-weight ratio of any fuel since hydrogen is the lightest element and has no heavy carbon atoms. It is for this reason that hydrogen has been used extensively in the space program where weight is crucial.

The amount of energy liberated during the reaction of hydrogen, on a mass basis, is about 2.5 times the heat of combustion of common hydrocarbon fuels (gasoline, diesel, methane, propane, etc.) Therefore, for a given load duty, the mass of hydrogen required is only about a third of the mass of hydrocarbon fuel needed. [12]

Energy Density

The energy density is really a measure of how compactly hydrogen atoms are packed in a fuel. It follows that hydro-carbons of increasing complexity have increasing energy density. At the same time, hydrocarbons of increasing complexity have more and more carbon atoms in each molecule so that these fuels are heavier and heavier in absolute terms.

On this basis, hydrogen's energy density is poor (since it has such low density) although its energy to *weight* ratio is the best of all fuels (because it is so light). The energy density of

comparative fuels, based on the LHV, is indicated in appendix C. The energy density of a lead acid battery is approximately 8700 Btu/ft^3 ($324,000 \text{ kJ/m}^3$). [12]

2.2.5 Flammability

Three things are needed for a fire or explosion to occur: a fuel, oxygen (mixed with the fuel in appropriate quantities) and a source of ignition. Hydrogen, as a flammable fuel, mixes with oxygen whenever air is allowed to enter a hydro-gen vessel, or when hydrogen leaks from any vessel into the air. Ignition sources take the form of sparks, flames, or high heat.

Flashpoint

All fuels burn only in a gaseous or vapor state. Fuels like hydrogen and methane are already gases at atmospheric conditions, whereas other fuels like gasoline or diesel that are liquids must convert to a vapor before they will burn. The characteristic that describes how easily these fuels can be converted to a vapor is the flashpoint. The flashpoint is defined as the temperature at which the fuel produces enough vapors to form an ignitable mixture with air at its surface. [7]

Flame Characteristics

Hydrogen flames are very pale blue and are almost invisible in daylight due to the absence of

2.3 Extraction Device Layout

One way to convert Water to Hydrogen and Oxygen is through the process of Electrolysis - using electricity as the source of energy to drive the reaction. Let's take a look at what that might look like:

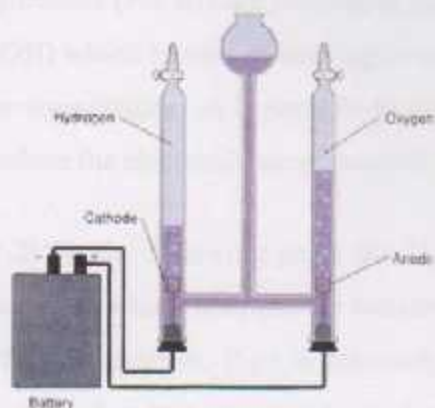
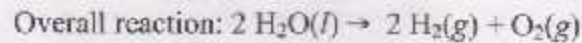
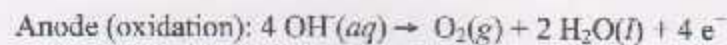
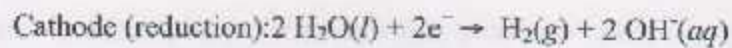


Figure (2-1) water electrolysis process, [11]

An electrical power source is connected to two electrodes, or two plates (typically made from platinum or stainless steel because it have good corrosion resistance) which are placed in the water. In a properly designed cell hydrogen will appear at the cathode (the negatively charged electrode, where electrons are pumped into the water), and oxygen will appear at the anode (the positively charged electrode). Assuming ideal faradays efficiency the generated amount (moles) of hydrogen is twice that of oxygen, and both are proportional to the total electrical charge that was sent through the solution. However, in many cells competing side reactions dominate, resulting in different products and less than ideal faradays efficiency.[3][12]

Electrolysis of pure water requires excess energy in the form of over potential to overcome various activation barriers. Without the excess energy the electrolysis of pure water occurs very slowly if at all. This is in part due to the limited self-ionization of water. Pure water has an electrical conductivity about one millionth that of seawater. Many electrolytic cells may also lack the requisite electro catalysts. The efficacy of electrolysis is increased through the addition of an electrolyte (such as a salt, an acid or a base) and the use of electro catalysts.[7]



Strong acids such as sulfuric acid (H₂SO₄), and strong bases such as potassium hydroxide (KOH), and sodium hydroxide (NaOH) are frequently used as electrolytes. This project will use sodium hydroxide (NaOH) which known as backing or cooking soda. the electrolysis reaction is more efficient at higher temperatures so it possible to use the engine heat as supplied energy to the reaction, this will reduce the electrical energy needed .

Referring to Figure (2-2) on the following page, the Hydrogen extraction device housing is a round cylinder constructed with high temperature resistance pipe, a material widely used by the building industry in plumbing systems. Pipe is extremely durable and temperature tolerant. It's also a very "friendly" material in that it's easy to work with and can be used to fabricate other things such as furniture, planters. The Generator housing contains basic plates and ten square electrodes; used to generate both hydrogen and oxygen. Each can be made from a variety of materials such as stainless steel, also very durable materials. However, the generated hydrogen is a very powerful and fast burning gas created by the plate electrodes. A precisely controlled, high frequency electronic signal from the electronic Module activates and controls the electrodes.[7]

The Module contains electronics circuits for controlling and/or providing power to all the water-hybrid system's electrically operated devices. Separate circuits exist to perform each of the following functions:

- Provide power to the Generator electrodes in the form of a high frequency signal, creating hydrogen and oxygen.
- Control power to the water tank pump via signals received from the Generator water level sensor.

. Provide busing and terminal points for distributing power to system gauges, indicators, and sensors.[6]

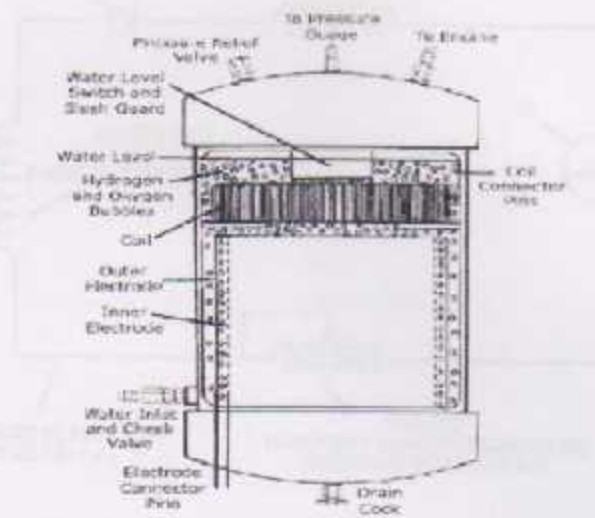


Figure (2-2) hydrogen extraction device [2]

2.4 Hydrogen Extraction Device Components

The main component of the hydrogen extraction device is the resonance circuit which treats water as the intermediate material in the capacitor

The pulsing transformer (A/G) steps up the voltage amplitude or voltage potential during pulsing operations. The primary coil is electrically isolated (no electrical connection between primary and secondary coil) to form Voltage Intensifier Circuit (AA) Figure (3-2). Voltage amplitude or voltage potential is increased when secondary coil (A) is wrapped with more turns of wire. Isolated electrical ground (J) prevents electron flow from input circuit ground.[2]

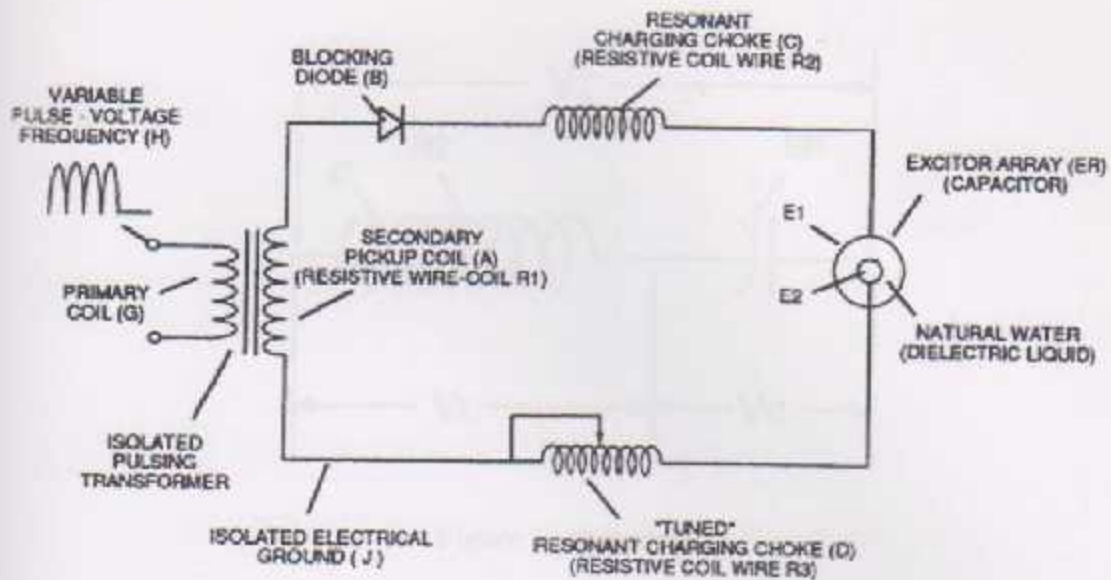


Figure (2-3) voltage intensifier circuit

Blocking Diode

Blocking Diode (B) prevents electrical "shorting" to secondary coil (A) during pulse-off time since the diode "only" conducts electrical energy in the direction of the schematic arrow.

LC Circuit

Resonant Charging Choke (C) in series with Excitor-array (E1/E2) forms an inductor-capacitor circuit

(LC) since the Excutor-Array (ER) acts or performs as an capacitor during pulsing operations, as illustrated in Figure (2-4) as to Figure (2-3).

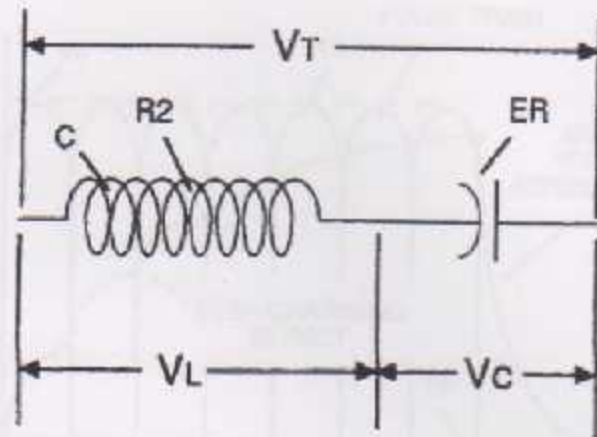


Figure (2-4) LC circuit

The Dielectric Properties (insulator to the flow of amps) of natural water (dielectric constant being 78.54 @ 25c) between the electrical plates (E1/E2) forms the capacitor (ER). Water now becomes part of the Voltage Intensifier Circuit in the form of "resistance" between electrical grounds and pulse frequency Positive-potential ... helping to prevent electron flow within the pulsing circuit (AA) of Figure (2-3).

The Inductor (C) takes on or becomes a Modulator Inductor which steps up an oscillation of a given charging frequency with the effective capacitance of a pulse-forming network in order to charge the voltage zones (E1/E2) to an higher potential beyond applied voltage input.

The Inductance (C) and Capacitance (ER) properties of the LC circuit are therefore "tuned" to resonance at a certain frequency. The Resonant Frequency can be raised or lowered by changing the inductance and/or the capacitance values. The established resonant frequency is, of course, independent of voltage amplitude, as illustrated in Figure (2-5) as to Figure (2-6).

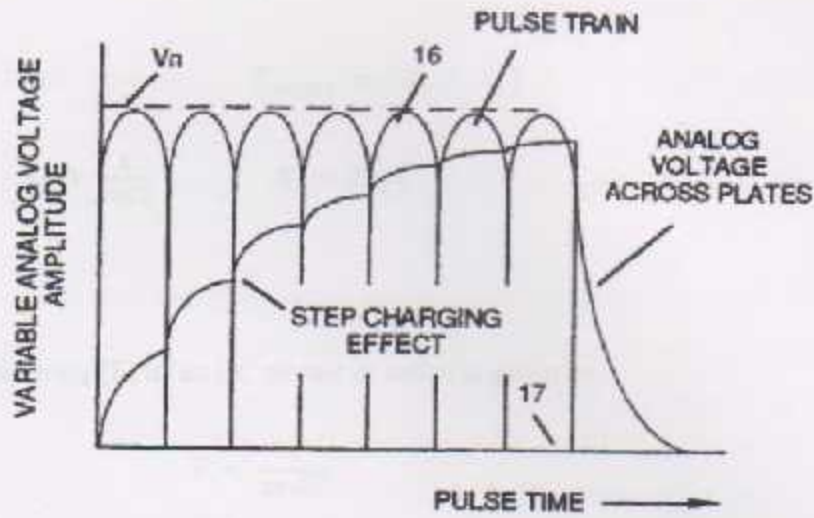


Figure (2-5) applied voltage to the plates

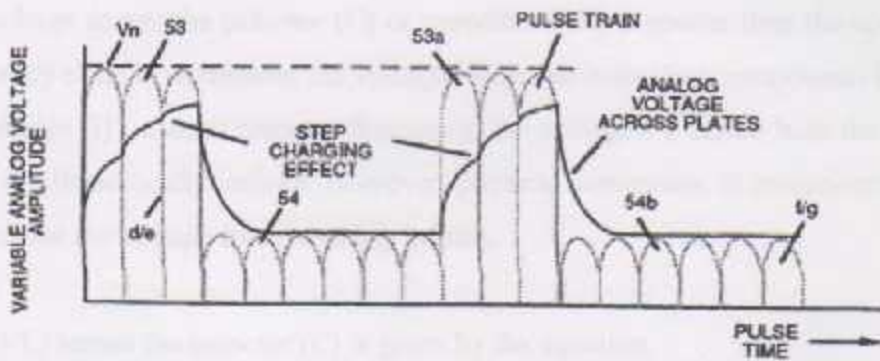


Figure (2-6) applied resonant

The value of the inductor (C), the value of the capacitor (ER), and the pulse-frequency of the voltage being applied across the LC circuit determines the impedance of the LC circuit.

The impedance of an inductor and a capacitor in series, Z_{series} is given by

$$Z_{series} = (X_c - X_l)$$

Where $X_c = \frac{1}{2\pi f c}$ $X_l = 2\pi f l$ (2-4)

The Resonant Frequency (F) of an LC circuit in series is given by

$$F = \frac{1}{2\pi\sqrt{LC}} \quad (2-5)$$

Ohm's Law for LC circuit in series is given by

$$V_t = IZ \quad (2-6)$$

LC Voltage

The voltage across the inductor (C) or capacitor (FR) is greater than the applied voltage (H). At frequency close to resonance, the voltage across the individual components is higher than the applied voltage (H), and, at resonant frequency, the voltage V_T across both the inductor and the capacitor are theoretically infinite. However, physical constraints of components and circuit interaction prevent the voltage from reaching infinity.

The voltage (V_L) across the inductor (C) is given by the equation.

$$V_L = \frac{V_t X_l}{(X_l - X_c)} \quad (2-7)$$

The voltage (V_C) across the capacitor is given by

$$V_C = \frac{V_t X_c}{(X_l - X_c)} \quad (2-8)$$

During resonant interaction, the incoming unipolar pulse-train (H) of Figure (2-3) as to Figure

2-7) produce a step-charging voltage-effect across Exciter-Array (ER), as illustrated in Figure (2-

6) And Figure (2-5). Voltage intensity increases from zero 'ground-state' to a high positive voltage Potential in a progressive function. Once the voltage-pulse is terminated or switched-off, voltage Potential returns to "ground-state" or near ground-state to start the voltage deflection process over again.[6]

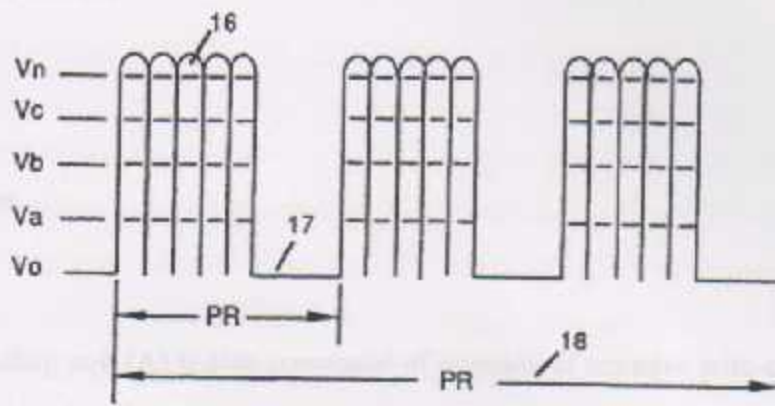


Figure (2-7) variable amplitude gated unipolar pulse frequency dynamically controls hydrogen gas yield on demand while inhibiting current flow

Voltage intensity or level across Executor-Array (ER) can exceed 20,000 volts due to circuit (AA) interaction and is directly related to pulse-train (H) variable amplitude input.

RLC Circuit

Inductor (C) is made of or composed of resistive wire (R2) to further restrict D.C. current flow beyond inductance reaction (XL), and, is given by

$$Z = \sqrt{R_l^2 + (X_l - X_c)^2} \quad (2-8)$$

Dual-inline RLC Network

Variable inductor-coil (D), similar to inductor (C) connected to opposite polarity voltage zone (E2) further inhibits electron movement or deflection within the Voltage Intensifier Circuit. Movable wiper arm fine "tunes" "Resonant Action" during pulsing operations. Inductor (D) in relationship to inductor (C) electrically balances the opposite voltage electrical potential across voltage zones (E1/E2).[7]

VIC Resistance

Since pickup coil (A) is also composed of or made of resistive wire-coil (R_1), then, total circuit resistance is given by

$$Z = R_1 + Z_2 + Z_3 + R_E \quad (2-10)$$

Where R_E is the dielectric constant of natural water.

Ohm's Law as to applied electrical power, which is

$$E = IR$$

Where

$$P = EI$$

Whereby

Electrical power (P) is a linear relationship between two variables, voltage (E) and amps (I).

Voltage Dynamic

Potential Energy

Voltage is "electrical pressure" or "electrical force" within an electrical circuit and is known as voltage potential". The higher the voltage potential, the greater "electrical attraction force" or "Electrical repelling force" is applied to the electrical circuit. Voltage potential is an "unaltered" or "unchanged" energy-state when "electron movement" or "electron deflection" is prevented or restricted within the electrical circuit.[3]

Voltage Performs Work

Unlike voltage charges within an electrical circuit sets up an "electrical attraction force; whereas, like electrical charges within the same electrical circuit encourages a "repelling action". In both cases, electrical charge deflection or movement is directly related to applied voltage. These electrical "forces" are known as "voltage fields" and can exhibit either a positive or negative electrical charge.

Likewise, Ions or particles within the electrical circuit having unlike electrical charges are attracted to each other, ions or particle masses having the same or like electrical charges will move away from one another, as illustrated in Figure (2-8).[2]

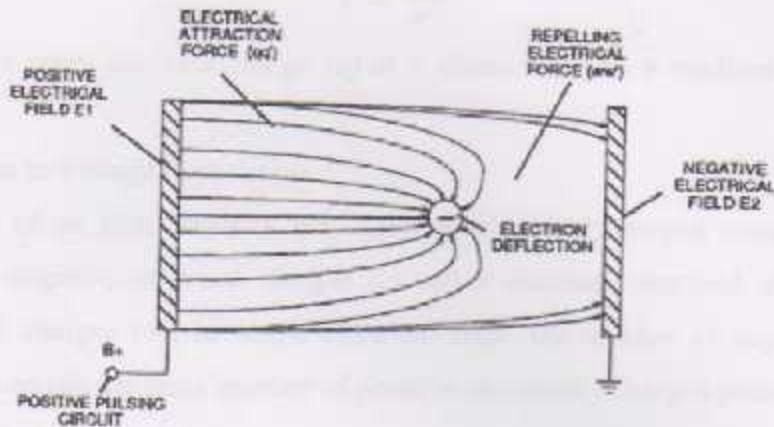


Figure (2-8) voltage potential performing work

Furthermore, electrical charged ions or particles can move toward stationary voltage fields of opposite polarity, and, is given by Newton's second Law

$$a = \frac{F}{m}$$

Where

The acceleration (a) of an particle mass (m) acted on by a Net Force (F).

Whereby

Net Force (F) is the "electrical attraction force" between opposite electrically charged entities, and, is given by Coulomb's Law

$$F = \frac{qq'}{R^2}$$

Whereas

Difference of potential between two charges is measured by the work necessary to bring the charges together, and, is given by

$$V = \frac{q}{e^r}$$

The potential at a point due to a charge (q) at a distance (R) in a medium whose dielectric constant is

Atomic Interaction to Voltage Stimulation.

Atomic structure of an atom exhibits two types of electrical charged mass-entities. Orbital electrons having negative electrical charges (-) and a nucleus composed of protons having positive electrical charges (+). In stable electrical state, the number of negative electrically charged electrons equals the same number of positive electrically charged protons ... forming an atom having "no" net electrical charge.

Whenever one or more electrons are "dislodged" from the atom, the atom takes on a net positive electrical charge and is called a positive ion. If an electron combines with a stable or normal atom, the atom has a net negative charge and is called a negative ion.

Voltage potential within an electrical circuit (see Voltage Intensifier Circuit as to Figure 2-2) can cause one or more electrons to be dislodged from the atom due to opposite polarity attraction between unlike charged entities, as shown in Figure (2-9) (see Figure (2-7) again as to Figure (2-3)) as to Newton's and Coulomb's Laws of electrical force (RR). [2]

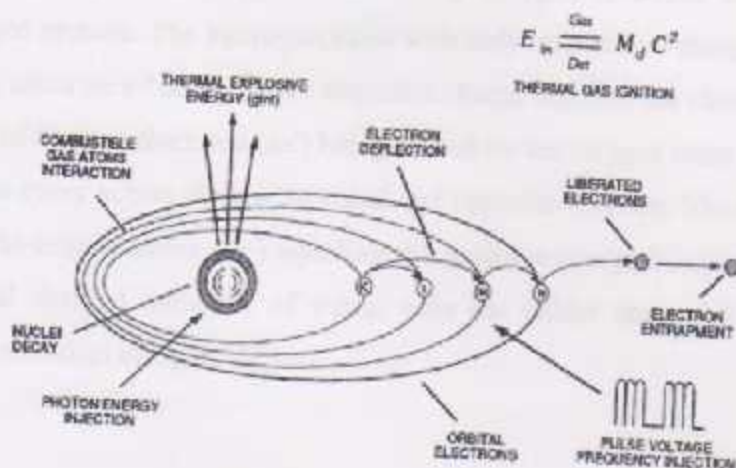


Figure (2-9) hydrogen fracture process

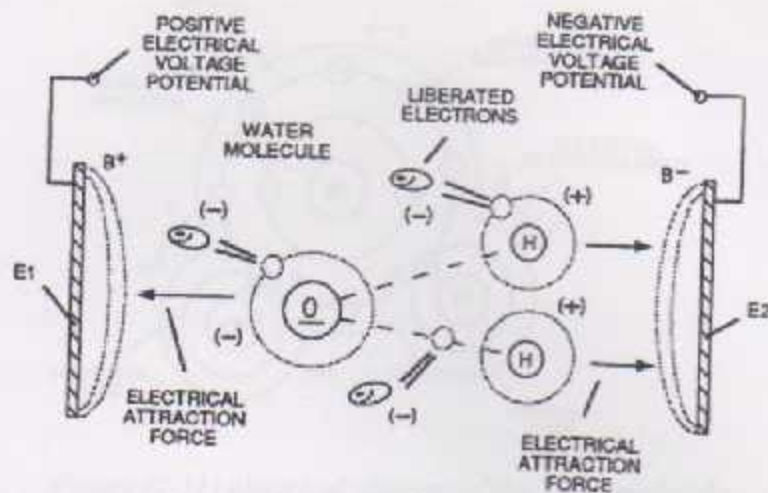


Figure (2-10) electrical polarization process

The resultant electrical attraction force (qq') combines or joins unlike atoms together by way of covalent bonding to form molecules of gases, solids, or liquids. When the unlike oxygen atom combines with two hydrogen atoms to form the water molecule by accepting the hydrogen electrons, the oxygen atoms become "net" negative electrically charged $(-)$ since the restructured oxygen atom now occupies 10 negative electrically charged electrons as to only 8 positive electrically charged protons. The hydrogen atom with only its positive charged proton remaining and unused, now, takes on a "net" positive electrical charge equal to the electrical intensity of the negative charges of the two electrons (aa') being shared by the oxygen atom ... satisfying the law of physics that for every action there is an equal and opposite reaction. The sum total of the two positive charged hydrogen atoms $(++)$ equaling the negative charged oxygen atom $(--)$ forms a "no" net electrical charged molecule of water, only the unlike atoms of the water molecule exhibits opposite electrical charges. [2]

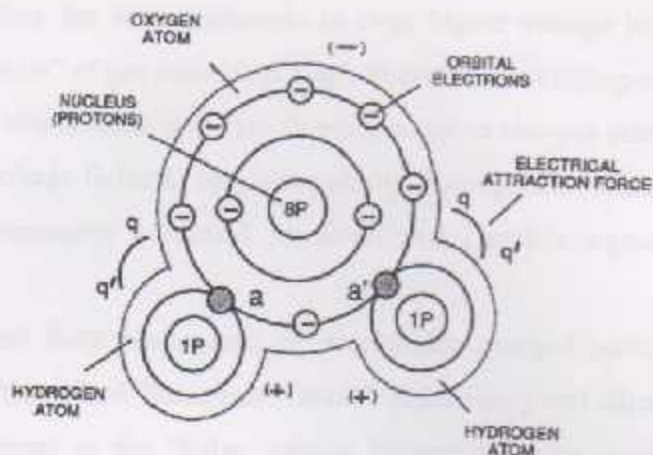


Figure (2-11) electrical charges of the water molecule

Voltage Dissociation of the Water Molecule

Placement of a pulse-voltage potential across the Exciter-Array (ER) while inhibiting or preventing electron flow from within the Voltage Intensifier Circuit (AA) causes the water molecule to separate into its component parts by, momentarily, pulling away orbital electrons from the water molecule, as illustrated in Figure (2-11).

The stationary "positive" electrical voltage-field (E1) not only attracts the negative charged oxygen atom but also pulls away negative charged electrons from the water molecule. At the same time, the stationary "negative" electrical voltage field (E2) attracts the positive charged hydrogen atoms. Once the negative electrically charged electrons are dislodged from the water molecule, covalent bonding (sharing electrons) ceases to exist, switching-off or disrupting the electrical attraction force (qq') between the water molecule atoms.

The liberated and moving atoms (having missing electrons) regain or capture the free floating electrons once applied voltage is switched-off during pulsing operations. The liberated and electrically stabilized atom having a net electrical charge of "zero" exit the water bath for hydrogen gas utilization.

Dissociation of the water molecule by way of voltage stimulation is herein called "The Electrical Polarization Process".[2]

Subjecting or exposing the water molecule to even higher voltage levels causes the liberated atoms to go into a "state" of gas ionization. Each liberated atom taking-on its own "net" electrical charge. The ionized atoms along with free floating negative charged electrons are, now, deflected (pulsing electrical voltage fields of opposite polarity) through the Electrical Polarization Process imparting or superimposing a second physical-force (particle-impact) unto the electrically charged water bath.

Oscillation (back and forth movement) of electrically charged particles by way of voltage deflection is hereinafter called "Resonant Action". Attenuating and adjusting the "pulse-voltage-amplitude" with respect to the "pulse voltage frequency", now, produces hydrogen gas on demand while restricting amp flow.

The natural frequency of water is a bit more complicated, because it takes into account the mass of water molecules, the attraction between molecules, the distance between molecules, and some other stuff. Suffice it to say that most microwave ovens put out a frequency of 2.5 gigahertz. This means that these microwaves pulse 2,500,000,000 times per second. This isn't the lowest (also known as "primary") resonant frequency for water, but microwave manufacturers use 2.5 GHz because they want the microwave to work at any and all water temperatures. There's lots more techno-babble about resonance, matching, and the engineering of microwaves.

Chapter Three

Data and analyses of Internal Combustion Engine

- Introduction.
- The engine operation
- Operation Parameters
- Engine Thermodynamic Equation

3.1 Introduction

This chapter talks about analyze ICE from the thermodynamic point of view for hydrogen and gasoline. The ICE is an energy converter that converts the fuels internal (chemical) energy into mechanical energy. The first ICE appeared in the second half of the 19th century. The thermodynamic process that approximates the gasoline engine is named after Nikolas Otto, who built the first successful engine in 1876- hence the Otto Cycle.[1]

The thermally-technical calculations of working cycles of piston ICE have a great important in the optimal works of research and development programs (for calculations of the theoretical courses of pressure and temperature of cylinder charge and for the measuring indicated diagram).

3.2 Operation Parameters

3.2.1 Rating Values of Engines

The most common parameters for engine performance are:

Maximum rated power: The highest power that an engine is allowed to develop for a short period of operation.

Normal rated power: The highest power that an engine is allowed to develop in continuous operation

Rated speed: The rotational speed of the crankshaft, at which the rated power is developed.

For vehicle application, engine performance is more precisely defined by:

1. The maximum power (or maximum torque) available at each speed within a useful engine operating range.
2. The range of speed and the power over which engine operation is satisfactory.

The equations needed for calculation are:

This equation were goatherd from variable sources according to secondary air-fuel ratio condition.

The heat added given by:

$$Q = M_{\text{fuel}} * \text{LHV} * \eta_{\text{ch}} \quad (\text{J}) \quad (3.1)$$

Where:

η_{ch} is the chemical efficiency equal 94%.

The mass of fuel given by:

$$M_{\text{fuel}} = \frac{M_{\text{act-tot}}}{\lambda * A/F + 1} \quad (\text{g/cycle}) \quad (3.2)$$

The total mass of the mixture that input to the combustion chamber given by:

$$M_{\text{act-tot}} = \frac{v_d * P_a}{r_{\text{mix}} * T_0} \quad (\text{g/cycle}) \quad (4.3)$$

Where:

v_d is displacement volume, it's given by:

$$v_d = \frac{r * S * D^2}{4} \quad (\text{m}^3) \quad (3.4)$$

r_{mix} is the ratio between gas constant and molecular weight of mixture (fuel and air).

The mass of air is given by:

$$M_{\text{air}} = M_{\text{act-tot}} - M_{\text{fuel}} \quad (3.5)$$

The mass of residual gases is given by:

$$M_{rg} = 0.06(M_{air} + M_{fuel}) \quad (3.6)$$

The charge of the cylinder (which is formed from the sum of masses fresh air, fuel, residual gases) was for simplifying considered as air, it's given by: [7]

$$M_{act} = M_{air} + M_{fuel} + M_{rg} \quad (3.7)$$

The ratio between gas constant and molecular weight of mixture (fuel and air and residual gases) given by:

$$r_{mix-tot} = \frac{(M_{air} + M_{rg}) \cdot r_{air} + M_{fuel} \cdot r_{fuel}}{M_{air} + M_{fuel} + M_{rg}} \quad (3.8)$$

The calculating models with high level of the theoretical description are often inaccessible. Their advantages are possibly used as far as for the adoption of the series of the routine solution. So, the research and development work of the piston engine, couldn't overcome without thermodynamic calculations. The research laboratory of the internal combustion engines for a long time uses its own calculating simulation model of the pressure and thermal states of the working cycle, and watches the changes of the cylinder working charge as well as by quasi static description. The calculating model consists of using the series of the engineering simplifying, which facilitates the design of model and the determination of major parameters of the working cycle with sufficient accuracy. calculating model describes the real (polytropic) course of the volumetric changes such as the combination of the adiabatic and isochoric changes, the heat transfer between the in-cylinder charge and cylinder wall can be calculate by:[7]

$$W_{2\alpha} = \alpha \cdot S_{\alpha} (T_{\alpha} - T_s) \Delta \tau \quad (J) \quad (3.9)$$

Where:

α =heat transfer coefficient (w/m²k).

S_{α} =chamber surface area (m²)

T_{α} =the temperature of cylinder charge (k).

T_s = the cylinder wall temperature (k).

$\Delta \tau$ = time of cycle (minute).

Heat transfer coefficient:

$$\alpha = 792(k1.P\alpha)^{0.792} \cdot 0.786 D^{-0.214} \cdot T\alpha^{-0.525} \quad (3.10)$$

Where,

$k1$ = constant

$P\alpha$ = pressure of working cycle

D = bore (piston diameter)

$T\alpha$ = the temperature of cylinder charge (k).

$$k1 = (2.28 + 0.30k2) \cdot cs \quad (3.11)$$

Where,

$k2$ = constant [3.5-5]

cs = piston speed (m/s)

$$CS = \frac{S \cdot N}{30} \quad (3.12)$$

Time of the cycle can be written it as:

$$\Delta \tau (1) = \frac{1}{6N} \quad (3.13)$$

The chamber surface area which detected to the heat can be calculated by:

$$S\alpha = \frac{S}{2} \left[1 - \cos \alpha + \frac{S}{4L} \sin^2 \alpha \right] \pi D^2 + \frac{2\pi D^2}{4} \quad (3.14)$$

During the compression stroke of the engine the piston moves to the top dead center, the gas volume decreases, and the pressure increase because work is done on the gas by the piston. During this stroke start the combustion of the fuel/air mixture.

The combustion occurs very quickly and the volume remains constant. Heat is release during combustion, which increases both the temperature and the pressure.

The heat release from the combustion of fuel can be explained as:

$$W_{1\alpha} = \frac{6Q}{H}(J+1) \left[\frac{\alpha-s}{H} \right] \cdot 2.71828^{-6 \left(\frac{\alpha-s}{H} \right)^{(J+1)}} \quad (J) \quad (3.15)$$

The gained heat can be conclusion from the last equations, and calculated by:

$$W_{\alpha+1} = \frac{W_{1\alpha} + W_{1\alpha+1}}{2} - W_{2\alpha} \quad (3.16)$$

The cylinder volume (specific volume) at any crank position α can be determined by:

$$V_{\alpha} = 392.7 \frac{D^3 S}{M_{act-total}} \left[1 - \cos\alpha + \frac{s}{4L} \sin^2\alpha + \sin^4\alpha \right] \quad (m^3/kg) \quad (3.17)$$

Cylinder pressure changes with crank angle as result of cylinder volume change and combustion and heat transfer to the chamber walls flow into and out the crevice regions and leakage. The below equation indicated how calculating the pressure of the working cycle inside the cylinder for 1° crank angle:

$$P_{\alpha+1} = P_{\alpha} \left[\frac{V_{\alpha}}{V_{\alpha+1}} \right]^{\alpha} + \frac{0.2871}{V_{\alpha+1} \cdot C_{v, \text{Mact}}} W_{\alpha+1} \cdot \Delta \alpha \quad (\text{M Pa}) \quad (3.18)$$

Where

$\Delta \alpha$: crank angle duration (equal 1)

α : specific heat ratio

C_v : a specific heat at constant volume (J/kg.k)

The temperature of cylinder charge changes with cylinder pressure and cylinder volume. It can be calculated by:

$$T_{\alpha+1} = \frac{P_{\alpha} \cdot V_{\alpha}}{r_{\text{mix}}} 10^6 \quad (\text{K}) \quad (3.19)$$

Where

r_{mix} : the ratio between gas constant and molecular weight of (fuel, air and residual gases)

The specific heat ratio on temperature could be also determined for Diatomic gases using empirical equation as:

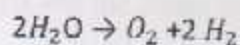
$$K_{\alpha} = (1.41 - 5.72) \cdot 10^{-5} T_{\alpha} \quad (3.20)$$

From the previous equation, a specific heat at constant volume can be expressed

$$C_{v, \alpha} = \frac{r_{\text{mix}}}{K_{\alpha} - 1} \quad (3.21)$$

To determine the specific heats of real gas mixture, it is necessary to know the Composition of the mixture as well as the specific heats of the individual component.

3.2.2 Hydrogen equation:



When we dissociate water (H_2O) to hydrogen (H_2) and oxygen (O_2) and the percentage of hydrogen and oxygen take from water is:

The percentage of oxygen from water is = $\frac{\text{molar mass of oxygen}}{\text{molar mass of water}}$

Molar mass of oxygen (O_2) = $2 * 16 = 32$

Molar mass of water (H_2O) = $2 * [(2 * 1) + 16] = 36$

So:

The percentage of oxygen from water = $\frac{32}{36} * 100\% = 89.9$

Molar mass of hydrogen (H_2) = $2(2 * 1) = 4$

The percentage of Hydrogen from water = $\frac{4}{36} * 100\% = 11.1\%$

A one mole of electrons means one farad, its mean the amount of electricity that carries by one mole electron.

Farad = charge electron (column) * Avogadro's number

$$= 1.6 * 10^{-19} + 6.02 * 10^{23}$$

= 96352 column & to make calculation easy

= 96500 coulomb

Intensity of the current that applicable in fuel cell:

The amount of electricity = current * time

The net current required for the electric process depending on the alternator is 44 ampere after taking other demand on consideration, so the amount of hydrogen depends on current.

After taken the molar mass of hydrogen and the molar mass of oxygen extracted from water, the mass flow rate of oxygen entered manifold is summing of the oxygen from water and from air, so the oxygen from water decrease the amount of oxygen from air.

3.2.3 Volumetric efficiency (η_v)

$$\eta_v = \frac{\text{mass of charge actually inducted}}{\text{mass of charge represented by swept volume at ambient temperature \& pressure}} \quad (3.22)$$

$$\eta_v = \frac{m_{act}}{m_{th}}$$

$$\eta_v = \frac{2m_{act}}{\rho N V_d}$$

Where;

ρ = inlet air density

N = engine speed

V_d = displacement volume

3.2.4 Heating value

Lower heat value for the hydrogen-gasoline mixture

$$h_c = (N h_f^{\circ})_{CO_2} + (N h_f^{\circ})_{H_2O} - (N h_f^{\circ})_{fuel} \quad (3.23)$$

$$= 8(-393520) + (-241820) - [1(-208450) - (28600)]$$

$$= -3148160 - 2176380 + 494450$$

$$= 48300901 \text{ Kj/Kmol}$$

$$\text{LHV} = 41638.71 \text{ Kj/Kg}$$

Lower heat value for gasoline

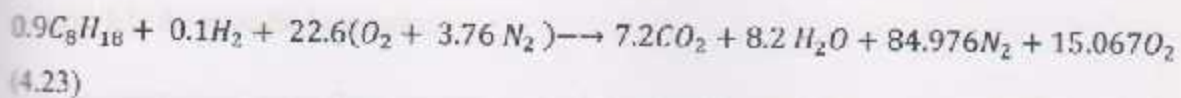
$$44.88 \text{ Mj/Kg}$$

Lower heat value for hydrogen

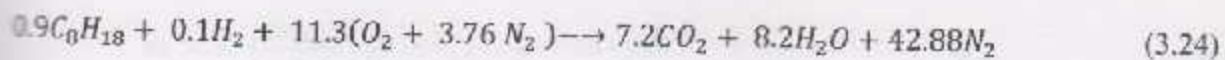
$$113.73 \text{ Mj/Kg}$$

Air fuel ratio for hydrogen is 34.3:1

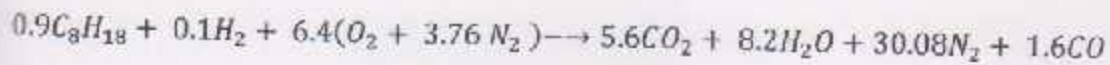
$$\text{Lambda} = 1.5$$



$$\text{Lambda} = 1$$



$$\text{Lambda} = 0.8$$



3.3 Engine Thermodynamic Equations

The thermodynamic state of the cylinder content was calculated from the first law of thermodynamics written for the cylinder volume:

$$Q = W + \frac{dE}{dt} + m_e h_e + m_i h_i \quad (3.25)$$

Where W is the rate of work done by the open system (which is equal to $P dV/dt$) $Q = Q_c + Q_w$, Q_c is the rate of heat releases during combustion, Q_w is the rate of heat transferred from the cylinder wall to the cylinder content, dE/dt is the rate of energy change inside the open system (which is equal to $d(m c_v T)/dt$) and h_e and h_i are the enthalpies of the leaving and entering molecules respectively, the rate of the pressure change inside the cylinder is obtained by introducing the ideal gas law in the form of

$$P \frac{dV}{dt} + V \frac{dP}{dt} = R \frac{d(mT)}{dt} \quad (3.26)$$

Into equation (3.25) and assuming the entering mass undergoes a perfect mixing process. Then, after rearranging equation (3.25) becomes:

$$\frac{dP}{dt} = \frac{(Q - m_e c_p T + m_i c_p T_i)(k-1) - kP dV/dt}{V} \quad (3.27)$$

Where k is the specific heat ratio.

The instantaneous mass flow rate, m , through any port in any direction (including back flows) was determined by:

$$m = A \left(\frac{2kP_u \rho_u \theta}{k-1} \right)^{1/2} y^{1/k} (1 - y^{(k-1)/k})^{1/2} \quad (3.28)$$

Where

$$y = \frac{P_l}{P_u} \quad \text{for } \frac{P_l}{P_u} > \left(\frac{2}{k+1}\right)^{k/(k-1)} \quad (3.29)$$

And

$$y = \left(\frac{2}{k+1}\right)^{k/(k-1)} \quad (3.30)$$

Where A is the instantaneous effective port area, which was taken as 0.8 for its actual value, and H and L denoted upstream and downstream conditions respectively.

The heat-transfer model

The instantaneous heat interaction between the cylinder content and its confined walls was calculated by using the empirical expression of Annand for four stroke engine as following:

$$\frac{Q_w}{A} = 0.26 \frac{K}{D} \left(\frac{u_p D}{\nu}\right)^{0.7} (T - T_w) + 0.69 \sigma (T^4 - T_w^4) \quad (3.31)$$

Where K is the thermal conductivity of the gas, ν is its kinematic viscosity, u_p the piston velocity, D its diameter, σ the Stefan-Boltzmann constant and T_w the temperature of the inner side of the cylinder wall. For this calculation, the temperature of the outside of the cylinder wall was assumed to be constant at the temperature of the cooling water. The time - dependent temperature of the inner side was therefore-calculated by using the analogic ohms law, while the temperature profile across the cylinder wall was assumed to be linear.

The combustion process

The mass fraction of the burned mixture at any time was calculated by using the wiebe function as follows:

$$X = 1 - \exp \left\{ - \left[\frac{(\theta - \theta_{ig})}{\Delta\theta_b} \right]^b \right\} \quad (3.32)$$

Where θ and θ_{ig} are the crank and the start of the combustion angles, $\Delta\theta_b$ is the crank angle interval from start to completion (100 per cent) of combustion, c is an

Efficiency parameter and b is a form factor. The values of b and r were determined by matching the computed $P - \theta$ diagram with experimental measurements.

The crank angle interval from the spark onset to the start of combustion ($\theta_{spark} - \theta_{ig}$), as well as the interval from the start to completion of combustion, $\Delta\theta_b$, were

Estimated by using the proposed correlation of Hires et al. (3.32). As follows:

$$\frac{\theta_{spark} - \theta_{ig}}{(\theta_{spark} - \theta_{ig})_{ref}} = \left(\frac{N}{N_{ref}} \right)^{1/3} \left(\frac{u_{b,ref}}{u_b} \right)^{2/3} \quad (3.33)$$

Where N is the engine speed and u_b is the laminar burning velocity, and

$$\frac{\Delta\theta_b}{\Delta\theta_{b,ref}} = \left(\frac{N}{N_{ref}} \right)^{1/3} \left(\frac{u_{b,ref}}{u_b} \right)^{2/3} \quad (3.34)$$

For small quantities of hydrogen enrichments, where it is reasonable to assume that there is enough air to facilitate the complete oxidation of the hydrogen, Yu et al (3.33) suggested that the laminar burning velocity, u_b , may be calculated by using the following correlation:

$$U_b = U_{b,f} + YS \quad (3.35)$$

Where $U_{b,f}$ is the laminar burning velocity of the fuel/ air mixture without hydrogen addition, S is a constant (≈ 0.83 m/s for hydrocarbon fuels) and Y is an indication of the relative amount of hydrogen addition, which is defined by

$$Y = \frac{[H] + [n]/[H]([H]/[air])_{st}}{[F] + ([air] - [H]([H]/[air])_{st})} \quad (3.36)$$

Here [F], [H] and [Air] denote the molar concentration of the fuel, hydrogen (H₂) and air respectively, and "st" stands for stoichiometric.

The laminar burning velocity of the fuel/air mixture without hydrogen addition, $U_{b,f}$, was calculated by using the correlation of Metghalchi and Keck (3.34), as follows :

$$U_{b,f} = \left(\frac{T}{T_{std}}\right)^{\alpha} \left(\frac{P}{P_{std}}\right)^{\beta} (1 - 2.1f)^{\phi'} \quad (3.37)$$

Where f is the mass fraction of the residual, 'std' stands for standard

$$\alpha = 2.18 - 0.8(\phi - 1) \quad (3.38)$$

$$\beta = -0.16 + 0.22(\phi - 1) \quad (3.39)$$

ϕ is the equivalence ratio which is defined as follows

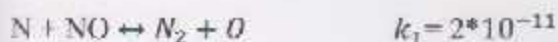
$$\phi = \frac{[F]/[air] - [H]([H]/[air])_{st}}{([F]/[air])_{st}} \quad (3.40)$$

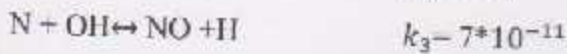
and

$$\phi = 0.2758 - 0.7834 (\phi - 1.11)^2 \quad (3.41)$$

Nitrate oxide formation

It is now widely accepted that the formation of NO in an engine combustion chamber is a non-equilibrium process. In the present study the kinetic model for NO is based on the theory developed by Lavoie et al in this model, only the processes occurring in the burned gas behind the reaction zone are considered, reactions in flame are sufficiently fast so that the burned gases are close to thermodynamic equilibrium, we may therefore assume equilibrium concentrations for all the species involved except for the NO, Lavoie et al have shown that on the time scale of interest, only the following three kinetic reactions are important (the extended Zeldovich mechanism):





Where v is in units of cubic centimeter per second, an explicit equation for nitric oxide formation is then obtained to yield

$$\frac{1}{v} \frac{d([NO]V)}{dt} = 2(1 - \alpha^2) \frac{R_1}{1 + \alpha R_1 / (R_2 + R_3)} \quad (3.42)$$

Where R_i is the one-way equilibrium rate of the reaction (for example $R_1 = k_1 [N]_e [NO]_e$, with the subscript 'e' denoting equilibrium concentration), $\alpha = [NO]/[NO]_e$ and the equilibrium model (36, 37) was used to determine the species concentrations required in the NO formation rate equation. In this model 37 elementary reactions were considered. 3.5 Carbon monoxide formation Starkman and Newhall (37) have noted that the CO concentration followed the same trend as the peak equilibrium value for CO. However, during expansion CO concentration lags between the current equilibrium value and the peak equilibrium value obtained in the cycle. Benson and Baruah (38) suggested that the following simple model may best fit experimental observation:

$$[CO] = [CO]_e + f ([CO]_{peak} - [CO]_e) \quad (3.43)$$

where the factor f is a calibration constant which lies between 0 and 1.

Chapter Four

Practical and experimental data of hydrogen enrichment

- Introduction.
- Practical hydrogen extraction device.
- The engine instrumentation and data collection
- Practical data
- Conclusion

4.1 Introduction

An investigation has been done on the influence of small amounts of hydrogen added to hydrocarbons-air mixtures on combustion characteristics.

Experiments carried out with a four cylinder four stroke SI engine confirmed the possibility of expanding the combustion stability limit, which correlates well with the general trend of enhancing the rate of combustion. An increase of brake thermal efficiency has been obtained with reduction of HC emissions; the NO_x emissions were higher, except for very lean mixtures.

The present work was conducted to further investigate the following issues:

1. Assess influence of small amounts of hydrogen addition on combustion characteristic in typical passenger car engine, with minimum adaptations
2. Assess improvement of engine brake specific fuel consumption and brake emissions by addition of small amount of hydrogen associated with a shift to the overall fuel-air ratio toward leaner mixture.

In order to address the above objectives a four cylinder version of the 1.6 liter passenger car engine was tested. And it was focused on light load operation.

The first step of the project was to build the hydrogen extraction device which takes the most time because the lack of materials in the national market, such as getting the MOSFET driver for the control circuit which took about 6 months.

4.2 Practical hydrogen extraction device



Figure (4-1) the practical hydrogen extraction device as we built ready to be connected with power source.

On demand hydrogen extraction device was built mainly from Stainless steel plates which used to be the electrolysis process electrodes, this project used 8 plates with dimensions as shown in the figure (4.2); 4 cathodes, 4 anodes.

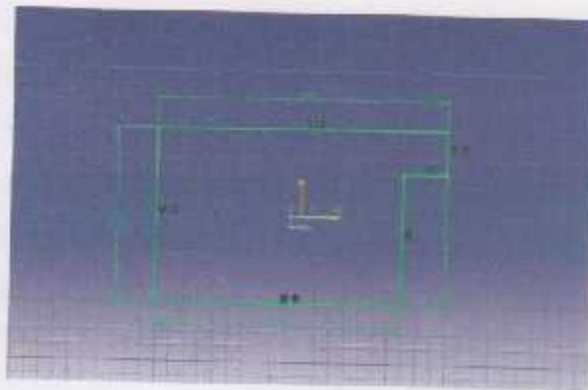


Figure (4-2) Cathodes plates with dimensions designed by CATIA

Expansion plastic container with diminution as follows, this container has two ports, one for supplying water, second for output hydrogen. Also the electric poles go out through the container wall with sealing for no leakage.

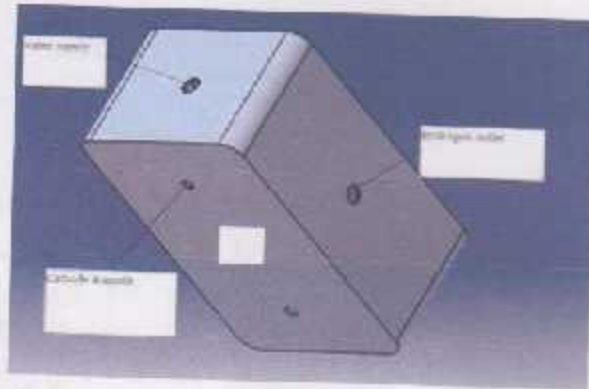


Figure (4-3) design of the extraction device container and its basic ports designed by CATIA.

- Water which doped with an amount of 0.05% NaOH for making the process faster.
- Electric module, the electric circuit built was as shown in the figure (4.4)

The variable resistance which marked as throttle is the controlling element of the hydrogen and it can be connected with the throttle pedal linkage or mechanism to take its position directly, the square wave pulse ratio determines the amount of current sent to the Generator electrodes by the circuit of figure (4-4). If the ratio is low (1:1), very little current arrives at the electrodes. So, very little hydrogen and oxygen are produced by the Generator. The pulse ratio also called duty cycle.



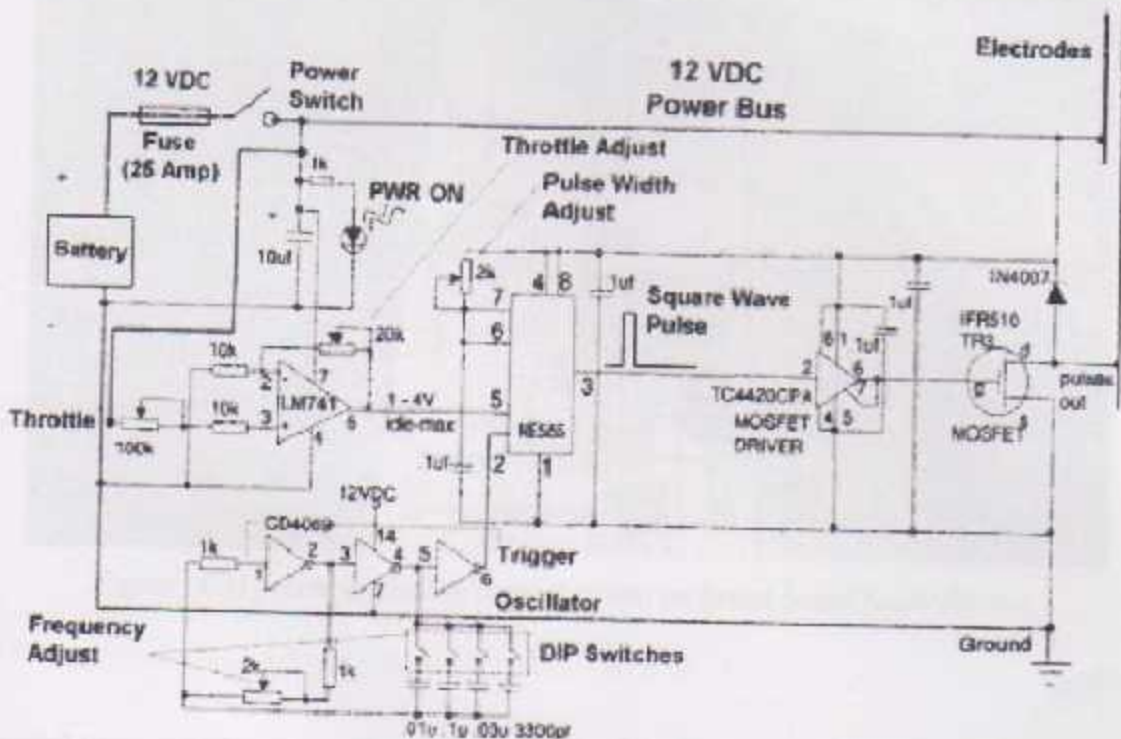


Figure (4-4).electric control circuit [4].

If the duty cycle is high (10:1), maximum current reaches the electrodes and the Generator produces maximum gas volume. Varying voltage input from a potentiometer connected via a 10KΩ resistor as shown in figure (4-4) to pin 3 of component LM741 causes the circuit to vary the pulse ratio, and therefore controls the amount of gases produced. The potentiometer shaft connects to the vehicle throttle linkage, enabling control of gas volume in direct response to voltage changes correlating with rotation of the potentiometer shaft in relation to throttle

positioning. A trimming potentiometer connects pins 2 and 6 of component LM741, enabling precise adjustment of the throttle input signal.

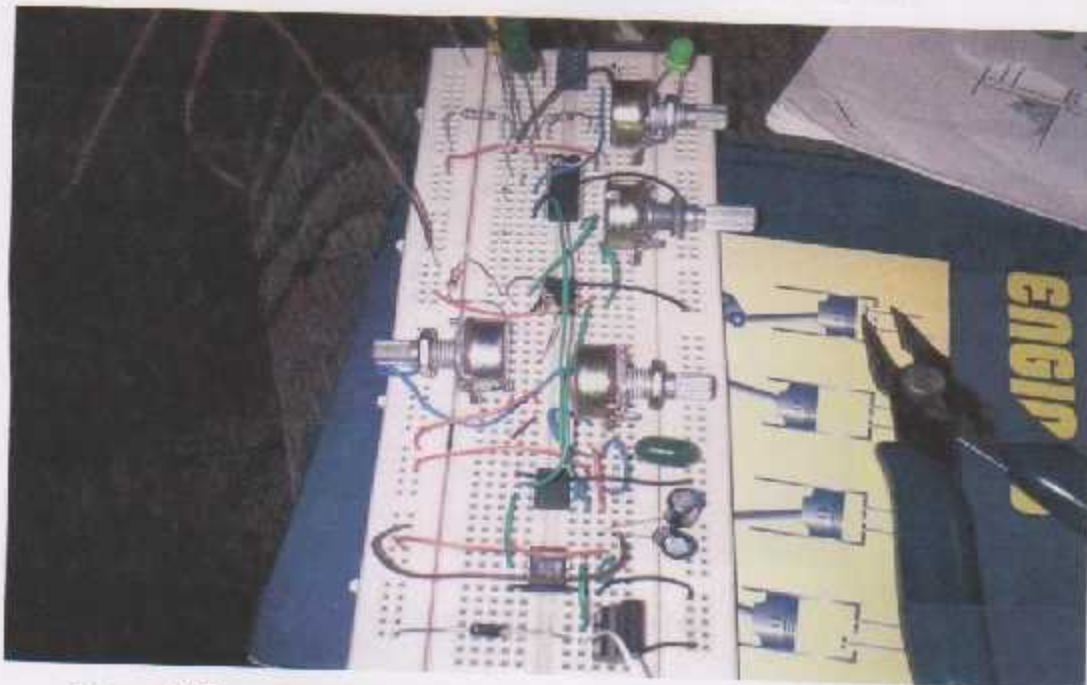


Figure (4-5) practical electric control circuit on bread board ready for test.

A second trimming potentiometer connects pins 4 and 7 of component NE555, enabling precise pulse width adjustment.

The electrode pairs of each Generator exhibit a unique frequency of electrical resonance at which optimum gas volume are created. This frequency often varies considerably among different Generators. Several factors determine resonance frequency such as: electrode size and shape, Generator chamber size and shape, spacing between electrodes, coil parameters and relative positioning, and pulse amplitude (voltage level). A trimming potentiometer connected between pins 1 and 2 of component CD4069 allows the precise frequency to be obtained. By selecting various combinations of dipswitch connections to a bank of four capacitors, pulse frequency can be varied between approximately 8 KHz and 260 KHz.

Safety valve which works on the density principle "Gas density is lower than water density so its tend always to move upward and the flam never dive in the water Figure (4.6).



Figure (4.6) Safety valve

4.3 The engine instrumentation and data collection

The test was performed on 1600 cm³ passenger vehicle SI engine with four cylinders in-line. The engine power and its torque were measured using a dynamometer. The exhaust gases were analyzed for CO, HC, CO₂, and O₂ by a Sun infrared gas analyzer, model SGA-9000, and for NO_x, by Hanatech gas analyzer, model 955.

All tests was made at 1800 rpm only, not for many engine speeds because of the complex of adjusting the 10% hydrogen at vary engine speed

Then the output from the safety valve was connected directly to the intake manifold as shown in the figure (4-7)

Initially the operation of the extraction device was from external electric source because the electric module was not ready which without the device would draw high current from the

engine battery, so the current was adjusted to have the amount of 8% of the intake air in the manifold and the flow rate of the hydrogen was measured by a gas flow meter also the calculation was made by the help of <http://www.stealth316.com/2-air-fuel-flow.htm> web site.

The air volume flow rate was measured and the area of the intake port then the amount of the hydrogen was adjusted to make the ratio of the enrichment 10%.

The total area of the manifold intake port is 4415.625 mm^2 and the area of the outlet of the hydrogen device is 441.5 mm^2 , then the air density calculated using the "stealth316" 1.1382 g/L .

Also the hydrogen flow rate is about 10% of the air volumetric flow rate which was about 2.5 L/minute .

Calculating the theoretical (maximum) volume of the hydrogen produced, also in cubic meters, from the other data for the current and the time, using "Faraday's First Law" is not enough because the method is not electrolysis only.

Practically there are two primary frequencies that produce the best results. They are: $14,372 \text{ Hz}$ and $43,430 \text{ Hz}$. The former is about 50% more efficient, but it seems that just about any frequency between 9 KHz and $143,762 \text{ KHz}$ works quite well. This is because the nature of the wave form (a spike) is rich in harmonics and one of them is bound to be close to one of the two primary frequencies [4].

Fuel consumption was measured with a set of calibrated burettes. The hydrogen was metered manually with a regulator. While it's volumetric flow rate was measured with a brook flow meter

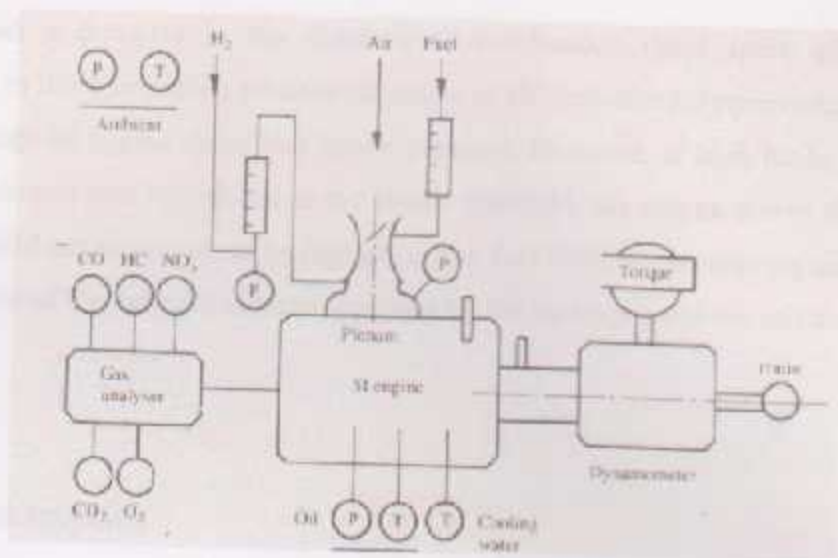


Figure (4-7) schematic diagram briefly shows the project parameters.

The current drawn was measured by a clamp meter.

4.4 Practical data

The effect of hydrogen enriched near stoichiometric operation

Present the effect of the amount of hydrogen enrichment on the improvement the effective b.s.f.c. of the engine. For this set of experiment the engine was first fuelled with gasoline and operated at particular engine speed and throttle position. Then the fuel consumption and the torque were recorded, in the next step hydrogen was introduced into the intake manifold (fig 4-7), while the fuel flow was regulated to maintain the same developed torque at the same engine speed and throttle position. Then, the fuel consumption m' as well as the hydrogen mass flow rate m'_{H_2} were recorded and the effective b.s.f.c. was calculated.

An increase in amount of hydrogen enrichment improves the b.s.f.c. A declining rate, depending mainly on the engine load above 8 per cent of hydrogen enrichment, the decrease in the b.s.f.c. seems to be marginal throughout the experimental range. These findings may suggest that at partial loads, an increase in the maximum temperature in the cycle (higher NO_x

emission), and a decrease in the duration of combustion (later spark advance) and an improvement in the combustion process (decrease in HC emission). Improvement was obtained for a wide range of engine speed and intake pressure. However, at high loads it was observed that when hydrogen was introduced to the intake manifold, the engine power deteriorated. The power loss could not be recovered by regulation the fuel flow, nor by altering the spark advance, a large portion of the cylinder volume occupied by the hydrogen and the mixture suffered from a lack of air.

4.5 Fuel consumption

Engine designers compare the fuel consumption of different engines or different fuels by the amount of fuel used in a period of one hour for each kilowatt developed. This is called brake specific fuel consumption (b.s.f.c), and depends on the calorific value of the fuel used.

The specific fuel consumption stated for the brake power of an engine. [9]

$$b.s.f.c = \frac{\text{fuel consumed in g/hour}}{\text{brake power in kw}}$$

Thus experiments was essentially different from the producer adopted for the case of near-stoichiometric operation. In the present case the engine was first fueled with gasoline and operation at a particular engine speed, equivalence ratio and throttle position. Under these conditions only the spark timing was adjusted automatically for best torque. Then the fuel consumption and the torque were recorded. In the next step, hydrogen was introduced into the manifold, while the fuel flow was regulated to maintain the same developed torque with a corrected MBT at the same engine speed and throttle position. Then the fuel consumption and the hydrogen mass flow rate were recorded and the effective b.s.f.c. was calculated. These figure that reduction in brake specific consumption, of the order 20-23 per cent, may be obtained with hydrogen-enriched gasoline. This is achieved by operating the engine under lean mixture condition below the lower flammability limit of gasoline /air mixture. Under these condition, which are achievable only at partial load, lower throttling is needed and pumping work is lowered. Here again it seems that an increase in the amount of hydrogen enrichment improves

the b.s.f.c. at a declining rate, and in a similar manner, as observed for the near stoichiometric operation case. The decrease in b.s.f.c. appears to be marginal above 10 per cent hydrogen addition throughout the experimental range of equivalence ratio.

Tables (4.1) brake specific fuel consumption

Hydrogen-mass ratio	b.s.f.c (at T=15.15 N.m , P=34 kpa)	b.s.f.c (at T=28.1 N.m , P=41 kpa)
0	1	1
0.01	0.91	0.91
0.02	0.89	0.895
0.03	0.87	0.89
0.04	0.86	0.88
0.05	0.85	0.87
0.06	0.84	0.865
0.07	0.835	0.86
0.08	0.83	0.855
0.09	0.825	0.85
0.1	0.82	0.845

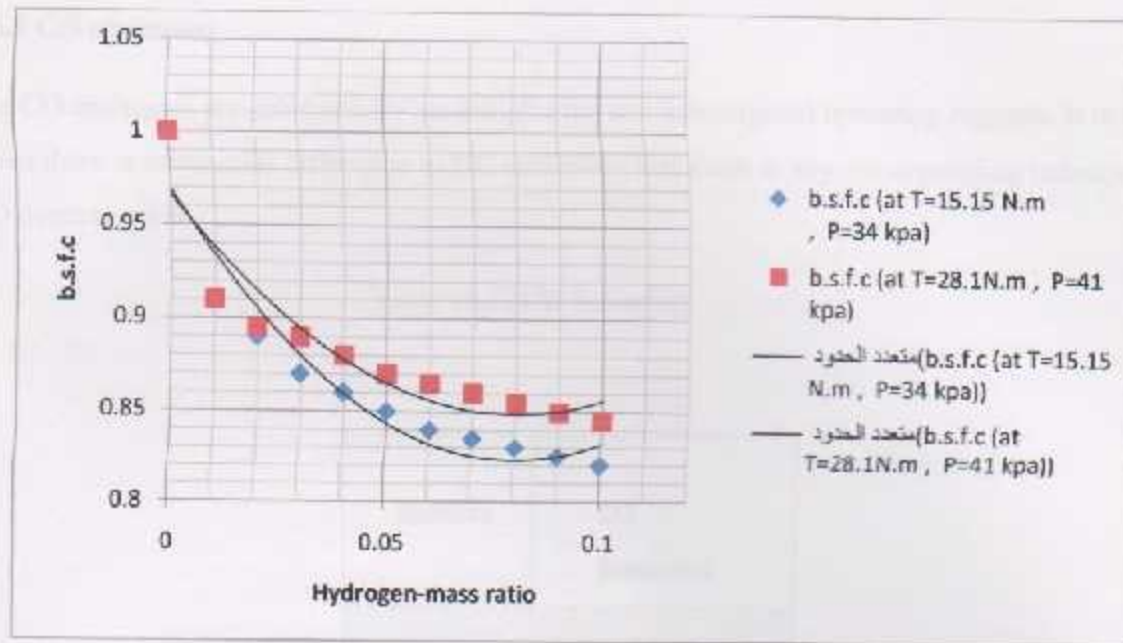


Figure (4-8)

4.6 Emission

Emission was measured by two different gas analyzers and the tow devices gives the same results, the measurements was made at the engine operation temperature, also as mentioned before all tests was made at engine speed of 1800 rpm for the same reason which controlling the amount of hydrogen.

4.6.1 CO emissions

The CO emissions are substantially similar, for the two investigated operating regimes. It is only when there is substantial difference in HC emissions that there is any corresponding reduction in CO concentration.

Table (4-2) CO Emission

lambda	CO Emission
1	0.262
1.2	0.26
1.25	0.255
1.4	0.235
1.5	0.2
1.6	0.15
1.92	0.05

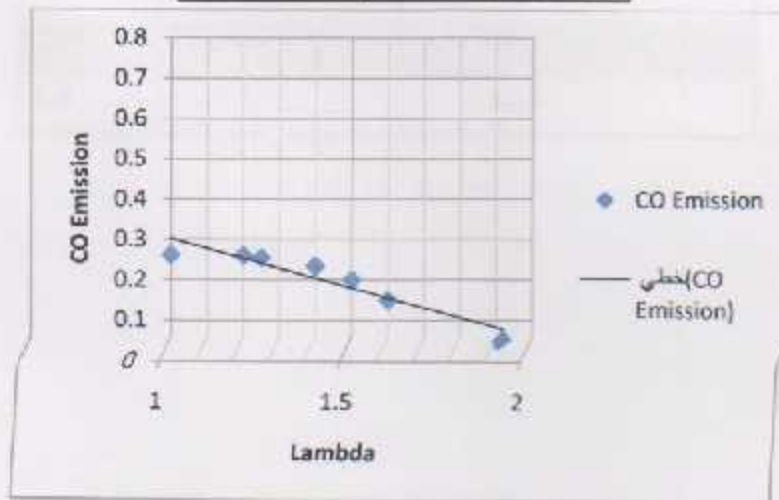


Figure (4-9) CO Emission

4.6.2 HC emissions

The following figure identifies the comparative specific HC exhaust emissions of the engine operating with straight gasoline and gasoline enriched with approximately 10% in volume hydrogen. In the domain of small excess of air the improvement by hydrogen addition is insignificant.

Table (4-3) HC Emission

Lambda	HC(GAS)(ppm)	HC(Gas+H ₂)(ppm)
0.95	8	7.9
1	6.8	6.5
1.05	6.1	6.2
1.1	6	6
1.15	7	6.3
1.2	9.5	6.8
1.25	13.2	8
1.3	-----	9
1.35	-----	10.3
1.4	-----	12.1

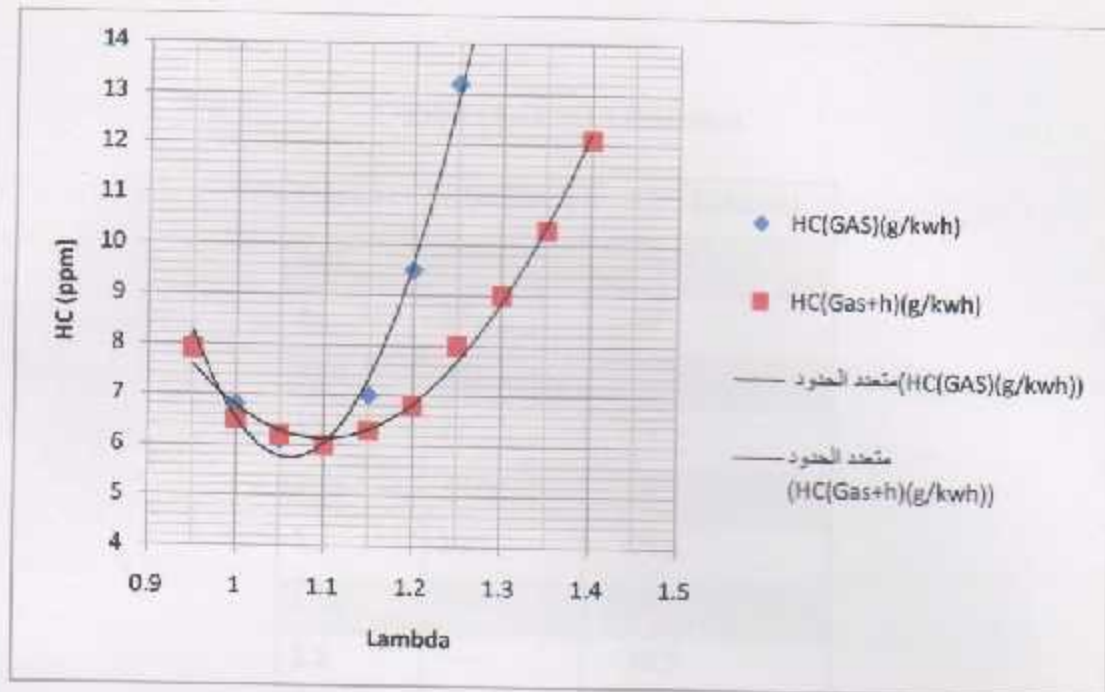


Figure (4-10) HC Emission

4.6.3 NOx emissions

The NOx emissions are compared in the following figure, because of the exponential relationship between NO formation and temperature, an increase of NOx concentration with the faster burning mixtures by addition of hydrogen, in the domain of small excess of air, confirms the expectation. NOx specific concentration drops only for higher air-fuel ratios, with stable combustion.

Table (4-4) NOX Emission

Lambda	NOX(GAS)	NOX(GAS+H)
0.95	25.5	7.9
1	28	28
1.05	30	27.5
1.1	27	27
1.15	24.5	26.5
1.2	15.5	25.5
1.25	5.5	24.5
1.3	----	16.5
1.35	----	13
1.4	----	6.5

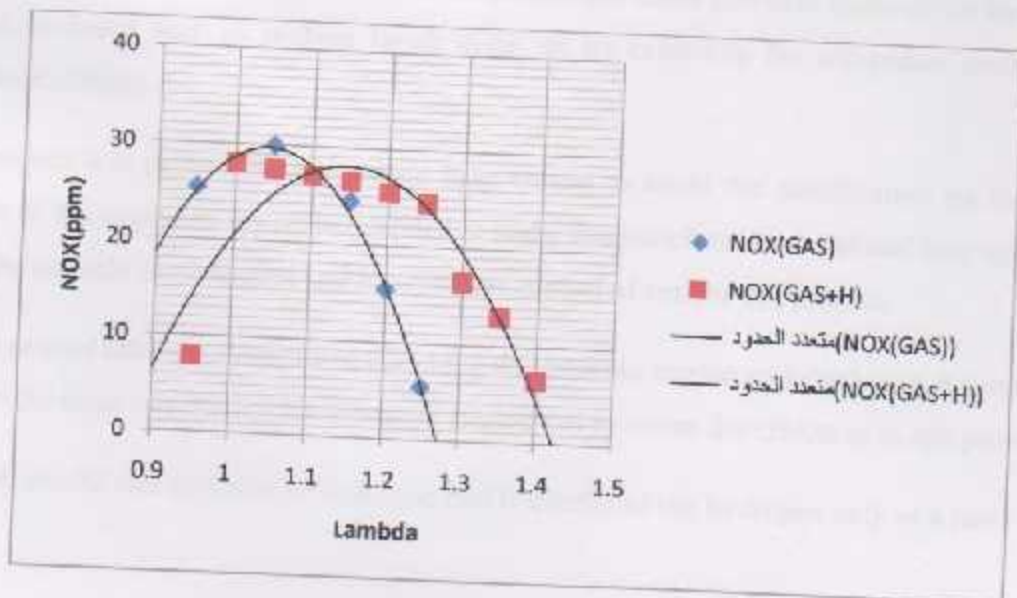


Figure (4.11) NOX Emission

4.7 Conclusion

An improvement of brake thermal efficiency up to 10% can be obtained by hydrogen addition, if coupled with favorable change of air fuel ratio and the throttle opening.

A significant decrease of HC emissions results by hydrogen addition only with leaner mixtures, reduction up to 35% were thus obtained. The NOx emissions tend to be increased at low excess air.

Finding the hydrogen-gasoline ratio, correlated with over all air-fuel ratios and the engine speed and torque with brake thermal efficiency and the emissions as optimized functions can be considered a problem of practical interest, even when small consumption of hydrogen is accepted.

4.8 Recommendation

The first difficulty in this project is to have the suitable current for the on-board hydrogen extraction process so it is important to make researches about practical methods for having high current on-board such as making faradi disks, or by extending the researches about electric resonance circuits.

This project was performed on an open loop system to avoid the modification on the electric module of the engine so it's recommended to make this enrichment on a closed loop system and make the suitable modification and improve the control of enrichment process.

As this project have good results in enriching the gasoline engine with hydrogen it recommends to make the same enrichment for the diesel engine and to assess the effects as in this project.

For good results and emission of hydrogen fuel it's better to use hydrogen only as a fuel.

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- [10] <http://www.omartalk.com/mech/?tag=hho>
- [11] <http://www1.eerc.energy.gov/hydrogenandfuelcells/>

Appendix A

The parameters which given for this engine.

Parameter	Symbol	Magnitude
Bore (mm)	D	
Stroke(mm)	S	
Condition rod length (mm)	L	
Engine speed (1/min)	N	
Compression ratio	ϵ	
Atmospheric pressure (Mpa)	Pa	
Ignition duration (CA)	H	
Ignition characteristic No.(-)	J	
Ignition starting (CA)	s	
Cylinder wall temperature(K)	Ts	
Ambient temperature (K)	To	

Appendix B

Vapor and Liquid Densities of Comparative Substances

Substance	Vapor Density (at 68 °F; 20 °C, 1 atm)	Liquid Density (at normal boiling point, 1 atm)
Hydrogen	0.005229 lb/ft ³ (0.08376 kg/m ³)	4.432 lb/ft ³ (70.8 kg/m ³)
Methane	0.0406 lb/ft ³ (0.65 kg/m ³)	26.4 lb/ft ³ (422.8 kg/m ³)
Gasoline	0.275 lb/ft ³ (4.4 kg/m ³)	43.7 lb/ft ³ (700 kg/m ³)

Appendix C

Heating values of comparative fuel

Fuel	Higher Heating Value (at 25 °C and 1 atm)	Lower Heating Value (at 25 °C and 1 atm)
Hydrogen	61,000 Btu/lb (141.86 kJ/g)	51,500 Btu/lb (119.93 kJ/g)
Methane	24,000 Btu/lb (55.53 kJ/g)	21,500 Btu/lb (50.02 kJ/g)
Propane	21,650 Btu/lb (50.36 kJ/g)	19,600 Btu/lb (45.6 kJ/g)
Gasoline	20,360 Btu/lb (47.5 kJ/g)	19,000 Btu/lb (44.5 kJ/g)
Diesel	19,240 Btu/lb (44.8 kJ/g)	18,250 Btu/lb (42.5 kJ/g)
Methanol	8,580 Btu/lb (19.96 kJ/g)	7,760 Btu/lb (18.05 kJ/g)

Appendix D

Engine Specification

Cylinders	4
Displacement	1600 cc
Fuel system	Carburctor
Manufacturer	Mazda
Bore mm	73
Horse Power Output	69hp @ 4800rpm
Stroke mm	77

