

11/10/2020

**TOPIC:** List at least 3 gaseous fuels that can be used as an alternate option. Compare the effects of using gaseous fuel for IC Engines. Define with chemical reactions of the selected gaseous fuels.

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# *ACKNOWLEDGEMENT*

*I cannot express enough thanks to VERZEO for their continued support and encouragement: My mentor Mr. Srujath. I offer my sincere appreciation for the learning opportunities provided by this internship programme.*

*My completion of this project could not have been accomplished without the support of my mentor. Thank you for allowing me to research and write. Thanks to my parents as well. The countless times you helped me won't be forgotten.*

*MY HEARTFELT THANKS TO EVERYONE!*

# **CONTENTS: -**

S. NO.	TOPIC	PAGE NO.
1.	<a href="#">Abstract</a>	3-4
2.	<a href="#">Gas fuels</a>	5-6
3.	<a href="#">CNG</a>	7-10
4.	<a href="#">LPG</a>	11-13
5.	<a href="#">Hydrogen</a>	14-17
6.	<a href="#">Conclusion</a>	18
7.	<a href="#">Reference</a>	19

## **ABSTRACT:**

Researchers have studied on alternative fuels that can be used with gasoline and diesel fuels. Alternative fuels such as hydrogen, acetylene, natural gas, ethanol and biofuels also uses in internal combustion engines. Hydrogen in the gas phase is about 14 times lighter than the air. Moreover, it is the cleanest fuel in the world. On the other hand because of its high ignition limit (4–75%), low ignition energy, needs special design to use as pure hydrogen in internal combustion engines. It is proved that hydrogen improves the combustion, emissions and performance, when is added as 20% to fuels. Natural gas is generally consisting of methane (85–96%) and it can be used in both petrol and diesel engines. Ethanol can be used as pure fuel or mixed with different fuels in internal combustion engines. In this section, the effects of natural gas, hydrogen, natural gas + hydrogen (HCNG), ethanol, ethanol + gasoline, ethanol + hydrogen, acetylene, acetylene + gasoline mixtures on engine performance and emissions have been examined.

For the purpose of reducing pollutant emissions resulting from internal combustion engines, the characteristics of hydrogen, natural gas, acetylene and ethanol, which are alternative fuels and can be used without requiring a structural change in SI and CI engines.

Oil is the undisputed largest source of energy for internal combustion engines (ICE). However, rapid depletion of the oil due to the increasing number of vehicles, the pollutant emissions within its combustion products that threaten the ecological system and the concerns about the security of supply due to the oil reserves unevenly distributed over the globe, of which about 50% is located in the Middle East, encourages the exploration of fuel sources that are more environmentally friendly and have widespread reserves in the world.

For the purpose of reducing pollutant emissions resulting from internal combustion engines, the characteristics of hydrogen, natural gas, acetylene and ethanol, which are alternative fuels and can be used without requiring a structural change in SI and CI engines, and their effects on engine performance and exhaust emissions are mentioned. The physical and chemical characteristics of gasoline, diesel fuel and alternative fuels are shown:

Properties	Acetylene	Hydrogen	CNG	Ethanol	Gasoline	Diesel
Formula	$C_2H_2$	$H_2$	$CH_4$	$C_2H_5O$ H	$C_4-C_{12}$	$C_8-C_{20}$
Density (1 atm, 20°C (kg/m <sup>3</sup> ))	1.092	0.08	0.65	809.9	720–780	820–860
Auto ignition temperature (°C)	305	572	540	363	257	254
Stoichiometric ratio (kg/kg)	13.2	34.3	17.2	9	14.7	14.5
Motor octane number	45–50	130	105	89.7	95–97	–
Flammability limits in air (% Vol.)	2.5–81	4–74.5	5.3–15	3–19	1.4–7.6	0.6–5.5
Adiabatic flame temperature (K)	2500	2400	2320	2193	2300	2200
Min. quenching diameter (mm)	0.85	0.9	3.53	2.97	2.97	–
Min. ignition energy (MJ)	0.019	0.02	0.29	0.23	0.23	–
Maximum flame speed (m/s)	1.5	3.5	0.42	0.61	0.5	0.3
Lower heating value (kJ/kg)	48.225	120.000	49.990	26.700	43.000	42.500

## ***GASEOUS FUELS***

Gas fuels are the most convenient requiring the least amount of handling and simplest and most maintenance free burner systems. Gas is delivered "on tap" via a distribution network and so is suited to a high population or industrial density. However large consumers do have gas holders and some produce their own gas.

The following is a list of the types of gaseous fuel:

(A) Fuels naturally found in nature:

- i. Natural gas
- ii. Methane from coal mines

(B) Fuel gases made from solid fuel

- i. Gases derived from Coal
- ii. Gases derived from waste and Biomass
- iii. From other industrial processes (Blast furnace gas)

(C) Gases made from petroleum:

- i. Liquefied Petroleum gas (LPG)
- ii. Refinery gases
- iii. Gases from oil gasification

(D) Gases from some fermentation process

When deciding whether an alternative gas can be used in an appliance, three factors must be considered:

- For the same pressure drop is the heat release roughly the same
- For the same air and fuel flows is the flame shape the same
- For the same heat release conditions are pollutants within a specified tolerance

The first criteria is best summarised by consideration of the Wobbe Index.

Consider the flow of gas through the control valve. It may be considered as an orifice of area,  $A$

The heat release  $Q$  is calculated knowing the CV of the gas

The pressure drop is calculated from Bernoulli's equation.

Continuity gives the volume flow rate:

The combination of these gives the heat release in terms of CV ( $\text{J/m}^3$ ), pressure drop, density and area

Now if the fuel gas is changed on the same burner (i.e. Area and pressure drop remain the same) the new heat release rate may be calculated as the ratio of the CV

multiplied by the square root of density.

Thus, a number may be derived which gives an indication of the interchangeability of the gases, the Wobbe number. In practice, the specific gravity with relation to air is used instead of density and  $W_o = CV/\bar{O} \text{ sp gr.}$  A second factor is used to define the propensity of the gas to react. This is called the Weaver flame speed factor. It is defined as the ratio between the laminar flame speed of the gas of interest with relation to hydrogen. Thus Hydrogen has a value of 100. The lower the number the lower the flame speed. Weaver speed factor is greatly influenced by the amount of hydrogen in the mixture. If the Wobbe number and flame speed factor are identical for two gases they are completely interchangeable. Unfortunately, this still doesn't guarantee the emissions will be the same.

Gases are classified according to Wobbe and Weaver numbers:

The international gas union assign the following gas families:

Family 1 -  $W_o = 17.8 - 35.8 \text{ MJ/Nm}^3$  - Coke Oven gas, Low CV gas

Family 2  $35.8 - 71.5$  - Natural gases, Town gas

Family 3  $71.5 - 87.2$  - Liquefied Petroleum Gas (LPG)

High flame speed gases  $We = 32$  to  $45$

Intermediate speed  $We = 25$  to  $32$

Low flame speed  $We = 13$  to  $25$

## **TYPES OF ALTERNATIVE GASEOUS FUELS FOR IC ENGINES:**

- I) Compressed natural gas( CNG)*
- II) Liquefied petroleum gas(LPG)*
- III) Hydrogen*

## **NATURAL GAS/COMPRESSED NATURAL GAS**

Natural gas is promising alternative fuel to meet strict engine emission regulations in many countries. Compressed natural gas (CNG) has long been used in stationary engines, but the application of CNG as a transport engines fuel has been considerably advanced over the last decade by the development of lightweight high-pressure storage cylinders. Engine conversion technology is well established and suitable conversion equipment is readily available. For spark ignition engines there are two options, a bi-fuel conversion and use a dedicated to CNG engine. For compression ignition engines converted to run on natural gas, there are two main options discussed, there are dual-fuel engines and normal ignition can be initiated. Natural gas engines can operate at lean burn and stoichiometric conditions with different combustion and emission characteristics. In this paper, the CNG engines research and development fueled using CNG are highlighted to keep the output power, torque and emissions of natural gas engines comparable to their gasoline or diesel counterparts. The high activities for future CNG engines research and development to meet future CNG engines is recorded in the paper.

The biggest disadvantage for the NGV transportation sector comes from the storage challenge of natural gas. Natural gas is a lighter gas than air. While the density of air at sea level at 15°C is 1.225 kg/m<sup>3</sup>, although the density of natural gas varies according to its composition, it is about 0.71 kg/m<sup>3</sup>. As natural gas is a light gas the energy density per unit volume is low and in order to ensure a reasonable driving distance the storage volume should be chosen large. Fortunately, technology has developed and the natural gas has been begun to storage in steel or carbon tubes at a pressure of 200 bar with high pressure compressors. Parking of natural gas vehicles in enclosed spaces is dangerous for safety reasons. Nowadays, cars with natural gas engines have a range of more than 300 miles with a single filling. Also, natural gas is not a renewable energy source, like other fossil fuels .

High knock resistance of natural gas allows it to be used in engines with higher compression ratios as compared to gasoline engines. Operation of natural gas vehicles at higher compression ratios than gasoline vehicles increases the thermal efficiency. As seen in Figure 10, in the tests carried out at different compression ratios with natural gas and natural gas-hydrogen mixtures (HCNG), the minimum fuel consumption for the compression ratio of 12.5 was obtained. Figure 11 shows that, THC emissions are lower than the Euro VI standards in all compression ratios . The experiments have been carried out using a modified diesel engine having 9.6, 12.5 and 15 different compression ratios at 1500 rpm under full load conditions fueled by hydrogen enriched compression natural gas blends (100% CNG, 95% CNG + 5% H<sub>2</sub>, 90% CNG + 10% H<sub>2</sub> and 80% CNG + 20% H<sub>2</sub>). Engine performances and emissions parameters have been realized at 10°C A BTDC ignition timing and different excess air ratios ( $\lambda = 0.9-1.3$ ).

## **CNG vs petrol vs diesel**

Here is the present cost of Fuels in India.\*

Petrol – Rs. 78.57 Per Litre

Diesel – Rs. 70.26 Per Litre

CNG – Rs. 40.61 Per Kg

\*Fuel prices vary from city to city. Hence, bear in mind to compare fuel prices of the same places and never mix the prices in two different areas.

Buying a diesel car is the most expensive. On an average, its cost would be approximately Rs. 2 Lakh higher in Ownership than a Petrol variant car.

**Not so frequent Driving:** If your car will run less than 500 Kms in a month (i.e. 5000 to 7000 kms in a year) then it is viable to buy a Petrol car.

**Normal or Average Driving:** If your car will run for about 800 – 1000 kms a month (i.e. 10,000 to 12,000 kms a Year) then CNG cars would prove to be more economical for you.

**For a little above average driving:** If your car will run in between 12000 to 14000 (i.e. 15,000 to 16,000 kms a year) then again, CNG would be an ideal fuel choice.

**For high road driving:** If your car will run for more than 2000 kms or more in a single month (i.e. 20000 kms in a year) then close your eyes and go for a diesel variant. It will help you save a lot on fuel costs and other upfront and maintenance costs.

**PROS:**

CNG Cars	Diesel Cars	Petrol Cars
Lowest running costs compared to Diesel and Petrol	Overall very low running cost	Priced lowest among CNG and Diesel (No fitment is required.)
Go Green Gas – best for the environment.	Long-term running as compared to Petrol or CNG	No degrading performance of Engine. Lowest Noise Vibration and Harshness (NVH)
Can run on both CNG and Petrol due to the presence of Retro Fitted CNG	Fuel combustion is fast leading to a stronger pickup	No alternate gas kit is required – thus low maintenance.

**CONS:**

CNG Cars	Diesel Cars	Petrol Cars
Small capacity of CNG Cylinders (Max 12 Kg with 85% usage)	Upfront payment is expensive.	High running cost, high fuel cost
Low pickup	Regular maintenance and spare parts are costlier	Lower Pep (Torque) in Engine Performance
Take a lot of Boot Space as the size of a CNG Kit is comparatively huge	Higher Noise and Vibration level compared to Petrol Cars	–
Lack of fuel stations and refueling is time-taking	–	–
Long-term reliability of ownership is less if CNG fitment is not Fitter in Branded Factory	–	–

## **MECHANISMS IN CNG ENGINE:**

Mechanism	Reactions	Normalized Rate of Production Coefficient
Mechanism-I	$\text{CO} + \text{N}_2\text{O} \rightleftharpoons \text{CO}_2 + \text{N}_2$	-0.139
	$\text{CO}_2 + \text{N} \rightleftharpoons \text{NO} + \text{CO}$	0.740
	$\text{HNCO} + \text{M} \rightleftharpoons \text{NH} + \text{CO} + \text{M}$	0.322
	$\text{NCO} + \text{M} \rightleftharpoons \text{N} + \text{CO} + \text{M}$	1.000
Mechanism-II	$\text{CO} + \text{N}_2\text{O} \rightleftharpoons \text{CO}_2 + \text{N}_2$	-0.013
	$\text{CO}_2 + \text{N} \rightleftharpoons \text{NO} + \text{CO}$	0.094
	$\text{HCN} + \text{O} \rightleftharpoons \text{NH} + \text{CO}$	0.044
	$\text{NCO} + \text{H} \rightleftharpoons \text{NH}_2 + \text{CO}$	0.119
	$\text{HNCO} + \text{M} \rightleftharpoons \text{NH} + \text{CO} + \text{M}$	-0.025
	$\text{H} + \text{NCO} \rightleftharpoons \text{NH} + \text{CO}$	0.304
	$\text{O} + \text{CN} \rightleftharpoons \text{CO} + \text{N}$	-0.017
	$\text{O} + \text{NCO} \rightleftharpoons \text{NO} + \text{CO}$	0.290
	$\text{OH} + \text{NCO} \rightleftharpoons \text{NO} + \text{CO} + \text{H}$	0.138
Mechanism-III	$\text{NCO} + \text{M} \rightleftharpoons \text{N} + \text{CO} + \text{M}$	-0.945
	$\text{CO} + \text{N}_2\text{O} \rightleftharpoons \text{CO}_2 + \text{N}_2$	-0.032
	$\text{CO}_2 + \text{N} \rightleftharpoons \text{NO} + \text{CO}$	-0.713
	$\text{HCN} + \text{O} \rightleftharpoons \text{NH} + \text{CO}$	0.020
	$\text{HNCO} + \text{H} \rightleftharpoons \text{NH}_2 + \text{CO}$	0.056
	$\text{H} + \text{NCO} \rightleftharpoons \text{NH} + \text{CO}$	0.250
	$\text{O} + \text{NCO} \rightleftharpoons \text{NO} + \text{CO}$	0.383
	$\text{OH} + \text{NCO} \rightleftharpoons \text{NO} + \text{CO} + \text{H}$	0.285
Mechanism-IV	$\text{NCO} + \text{M} \rightleftharpoons \text{N} + \text{CO} + \text{M}$	-0.246
	$\text{HNCO} + \text{M} \rightleftharpoons \text{NH} + \text{CO} + \text{M}$	0.975
	$\text{OH} + \text{NCO} \rightleftharpoons \text{NO} + \text{CO} + \text{H}$	0.022
	$\text{NCO} + \text{M} \rightleftharpoons \text{N} + \text{CO} + \text{M}$	1.000

## **LIQUEFIED PETROLEUM GAS:**

Liquefied petroleum gas, known as LPG, is used as an alternative fuel for vehicles with a combustion engine. LPG is a mixture of propane, butane and other substances of a small amount and it is obtained as a by-product of being manufactured during the refining of petroleum. The purpose of this article lies in the assessment of LPG as an alternative fuel. The article includes the classification of LPG from the economic and safety point of view. It also assesses liquefied petroleum gas as an alternative fuel in terms of emission production.

LPG is obtained during natural gas and oil extraction, or as a by-product of being manufactured during the refining of petroleum. The main components of LPG are propane and butane. Propane -  $C_3H_8$  is a saturated hydrocarbon with an energy value of  $46 \text{ MJ.kg}^{-1}$  and calorific value of  $11,070 \text{ kJ.kg}^{-1}$ . Butane -  $C_4H_{10}$  is highly inflammable and easily liquefiable gas with an energy value of  $45 \text{ MJ.kg}^{-1}$  and calorific value of  $10,920 \text{ kJ.kg}^{-1}$ . LPG is a mixture of propane, butane and other substances of a small amount. Propane and butane mixture is liquefied by cooling to a low temperature or by compressing. When being liquefied, the mixture's volume is reduced 260 times in comparison with gaseous phase. LPG is a fuel similar to petrol. Its energy value is  $45 \text{ MJ.kg}^{-1}$  and it has a density of  $0.55 \text{ kg.l}^{-1}$ . LPG is heavier than air in its gaseous form and lighter than water as liquid. When bearing in mind its effects on human health, LPG is not toxic, however, it is unbreathable with slightly toxic effects (Jemni et al., 2018). The mixture of propane and butane is colourless and odourless (Kapusta, Kalašová, 2015). In order to smell the LPG leakage, there are added components needed. Since LPG is used as a fuel, its value of octane number is very important. This number is 106 up to 110, so it is higher than an octane number of petrol and, thus, a higher resistance to detonation is guaranteed, since the ignition moment can be moved closer to the front of the piston's top dead centre. Liquefied petroleum gas (LPG) is made from butane and propane and generally cheaper than both petrol and diesel. LPG is also cleaner than petrol, emitting around 10 to 15 per cent less greenhouse gas and substantially less airborne toxins. Cars can be either factory-fitted with LPG tanks, or you can have your car converted to LPG, with a tank in the boot of the car, and you can switch between petrol and LPG fuel. It can't be used with diesel engines, however. LPG is not as fuel efficient as either petrol or diesel, and LPG engines aren't as responsive as petrol or diesel engines, and as a rule not as effective in larger vehicles.

**Advantages:**

- Cost: The main reason for driving LPG is the cost of the fuel. Of course very dependent on the country, but typically less than half the cost of petrol.
- You have both an LPG and petrol tank in your car. Meaning that you can really use all of the your LPG tank content, without worrying about running out of fuel. And if you don't care about running more expensive petrol, you can add that range to the LPG range.
- LPG is the cleanest fossil fuel available.

**Disadvantages:**

- Less range: LPG has less caloric content then petrol/gasoline, thus you typically have less range running LPG then petrol. Also, the tank never gets filled to more than 80%, again reducing effective range.
- In almost all cars, the LPG system is installed later... meaning that an additional petrol tank is installed in the back. This can take a lot of space. There are tanks that fit in the space of the reserve wheel, but those tank tend to be relatively small, and sometimes, you will have the situation that the floor of the truck gets a big higher. So you typically either have a relatively small tank, or loose trunk space.
- In many countries, LPG is not very common. Meaning that you have to search for tanking stations. The Netherlands has it at almost all stations, but Germany for example, has it in less then 5% of the cases.
- There are many different connectors for the refueling. In Europe, you need 3 different nozzles... Luckily, you can buy adapters, so if you prepare well it should be no problem.
- Some countries have a strong anti-LPG lobby, so you'll see nonsense like no parking allowed in parking garages... (Belgium is very anti-LPG for example) Also, there might be extra obstacles for the maintenance, where the normal car dealer is not allowed to certify it (Germany).
- Some cars do not handle the LPG system well, for a multitude of reasons. The Toyota dealer (at that time) claimed that somehow their electronics always got problems with the LPG systems, and advised strongly against it. Honda mentioned that their cylinder heads didn't handle the higher combustion temperature, and would need replacement. My Mitsubishi was perfect, and that brand was generally recognized as optimal for LPG. (Mercedes as well). My Mitsubishi Galant ran 330.000 km without any problems.

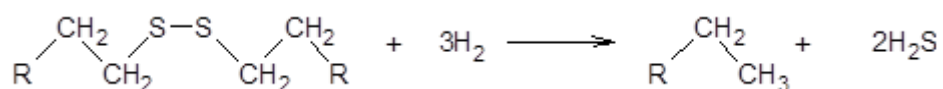
**Myths:**

- LPG being less safe. Yes, LPG is more volatile then petrol, and thus potentially more dangerous. However, because of that, it is stored in a thick-walled pressure tank, instead of the super fragile petrol tank. It has a pressure

safety release, that makes sure it will vent controlled in case of a fire. In reality, because of the extra safety precautions, it is actually safer than petrol.

- LPG being less powerful. That was true with the old LPG system (G). The modern G3 system is just as powerful as petrol. Indeed, you will not notice any difference when the car switches from petrol to LPG.

**LPG fuelled vehicle reaction:**

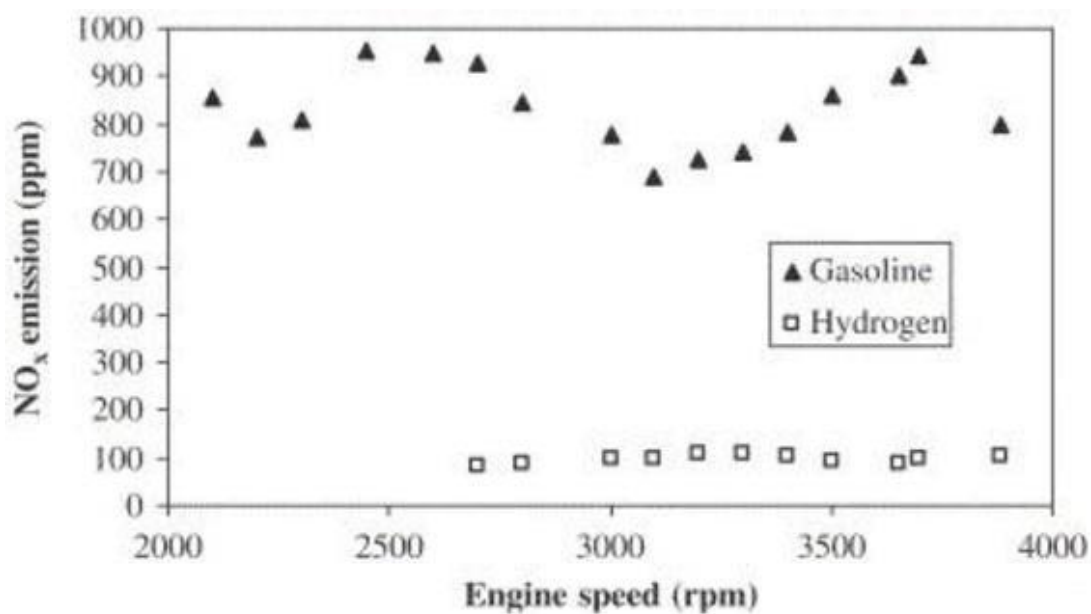


## **HYDROGEN:**

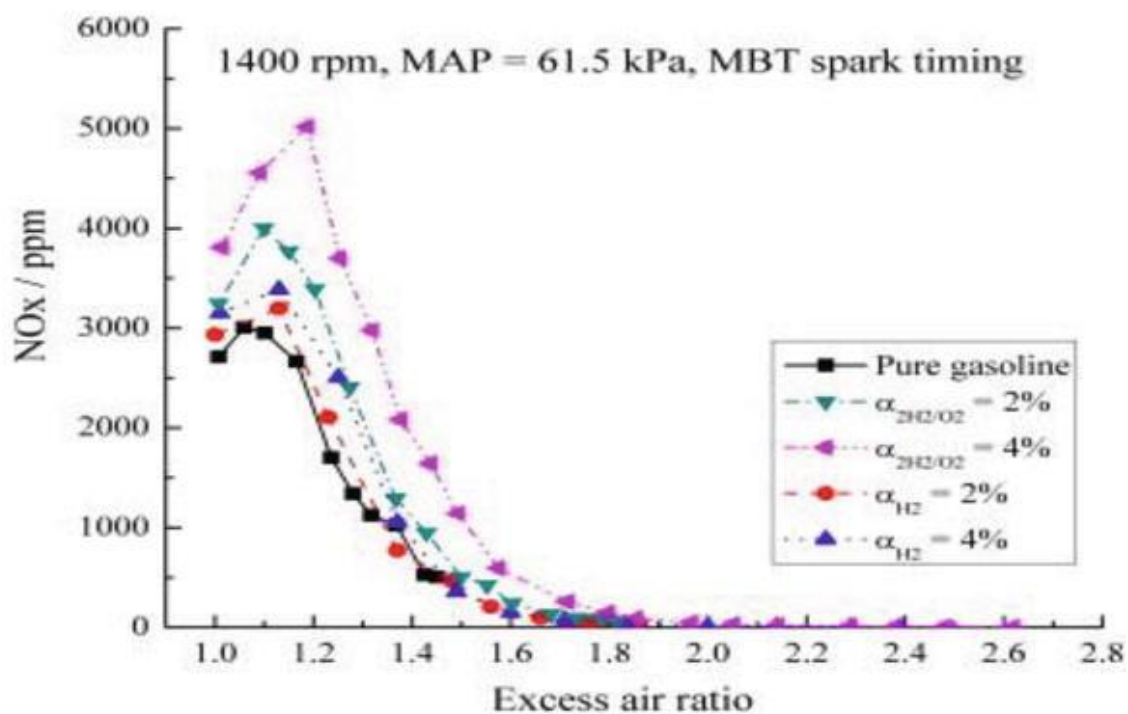
Although hydrogen the most common element in the world and it does not exist in nature in its pure state, so it has to be produced from sources like water and natural gas. The environmental impact and energy efficiency of hydrogen depends on how it is produced.

Hydrogen has been studied as an alternative gas fuel for a long time. Hydrogen has not some problems associated with liquid fuels, such as vapor lock, cold wall quenching, inadequate vaporization and lean mixing. Hydrogen has clean burning behaviors. As hydrogen is burned, it products mainly water. The combustion of hydrogen does not bring out toxic products such as hydrocarbons, carbon monoxide and carbon dioxide. The most important advantage of hydrogen is that it does not produce CO<sub>2</sub> gas, which is one of the most important sources of global warming. In addition, hydrogen has a wider limit of flammability than gasoline, diesel and natural gas. Moreover, hydrogen has high flame speed and it has high self-ignition temperature. Also, hydrogen can easily burn in ultra-lean mixtures. The energy required to ignite the hydrogen-air mixture is only 0.02 MJ. Therefore, it is ideal for poor mixed burns. Finally, hydrogen can be used at wide compression rates in internal combustion engines as the self-ignition temperature of hydrogen is too high. Due to these properties, many studies have been carried out on the use of hydrogen in internal combustion engines.

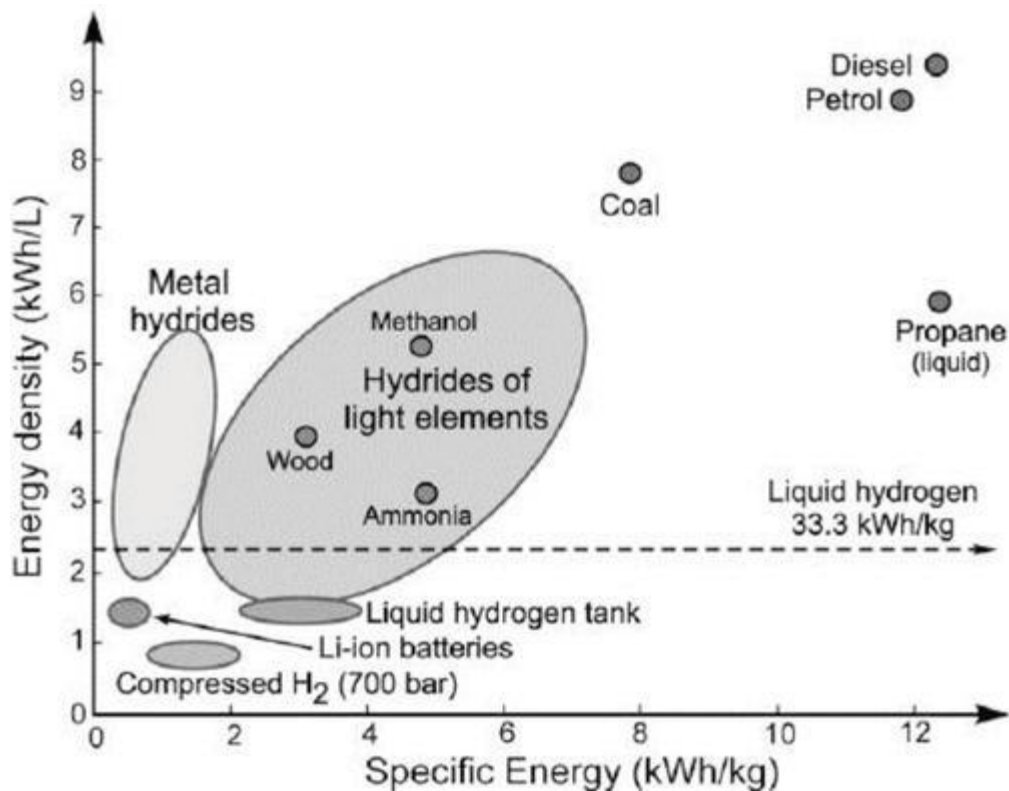
Due to the low energy required for the ignition of hydrogen, the mixture immediately ignites when it comes into contact with a hot spot in the cylinder. As a result, knock may occur. As can be seen from Figure another disadvantage of hydrogen is its low energy density. In addition, the formations of NO<sub>x</sub> emissions are increased by hydrogen combustion due to high flame temperature. The increasing of NO<sub>x</sub> with hydrogen can be seen from the table.



(a)



(b)



Because of hydrogen has some negative effects on internal combustion engine, it is used as a mixture rather than pure. The most widely mixture of hydrogen is HCNG. The mixture has been formed by the blending of natural gas. Natural gas-hydrogen mixtures (HCNG), which are considered as alternative fuels for conventional engines, are mixtures formed to combine the superior properties of natural gas and hydrogen. There are many studies [63, 64, 65, 66, 67, 68, 69, 70] using HCNG as an alternative fuel.

As can be seen in Figure 14, the hydrogen adding causes an increase in thermal efficiency and causes an expansion of the flammability limits. In addition, when the figures are examined, it is seen that the addition of hydrogen increases the stability of combustion and the value of brake power and reduces the specific fuel consumption.

Another mixture made using hydrogen is the ethanol-hydrogen mixture. In the literature, it can be found many studies on the use of hydrogen and ethanol in internal combustion engines

## **PROS AND CONS:**

One positive aspect to hydrogen-powered internal combustion engines (ICEs) is that engineers at car companies are already experienced in the construction of such engines. The engines are similar to gasoline-powered ICEs. These types of ICEs are more familiar to automotive engineers than the technology of fuel cell engines. These vehicles will also be simpler internally than gasoline-powered cars. The catalytic converters and related systems found on gasoline-powered ICEs to clean up the by-products of fossil fuel combustion are not needed if hydrogen is used.

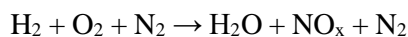
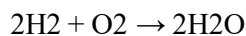
But hydrogen-powered ICEs have several disadvantages. The cars that use this type of engine are not as efficient as fuel cell-powered cars. Hydrogen ICEs can only extract about half of the chemical energy that is contained in a unit of hydrogen as compared to a fuel cell-powered vehicle. The vehicles also need more space to store fuel than gasoline-powered ICEs. These vehicles are built on current fuel tank sizes designed for gasoline or diesel fuel. Because hydrogen is not a very dense gas, the tanks cannot hold very much hydrogen. Therefore, the vehicles cannot travel as far.

Hydrogen fuel cells have many good aspects. Fuel cells are very easy to make. They contain no moving parts. This means that there is little maintenance that needs to be performed on each fuel cell. Because they have no moving parts, fuel cells are quiet. Fuel cells are also light and versatile. They can be manufactured big or small and used on a large or small scale. Because they are modular in design, one can work on its own or many can function together as one. Hydrogen fuel cell-powered cars are very efficient producers of power. They are more efficient than internal combustion engine cars. About 60 percent of the potential energy in hydrogen is made into electricity by a fuel cell. These fuel cell-cars can respond instantaneously to provide fuel when it is needed.

Yet there are several major drawbacks to the development and use of fuel cells. One is the lack of a worldwide standard for fuel cells between manufacturers or most governments. Only one standardization agreement was in place as of 2005. It was between Japan and the European Union. This agreement covered hydrogen fuel cells for automobiles. Because no standards are yet in place, the development of the infrastructure needed to support hydrogen technology has been delayed. Governments and businesses do not want to invest money in creating an infrastructure that could be useless if it does not match the standards that others use.

The cost of the energy produced by a fuel cell is also very high. It costs more per kilowatt produced when compared to a gasolinepowered combustion engine. In 2002 a fuel cell could cost anywhere from \$500 to \$2,500 per kilowatt produced, while the combustion engine only cost about \$30 to \$35 for the same amount of energy. The costs for fuel cells have been going down as technology has been developed and improved.

## **REACTIONS OF HYDROGEN POWERED IC ENGINE:**



## ***CONCLUSION***

Looking at today's applications, it is seen that natural gas fuel is a suitable fuel especially for SI engines having high compression ratio due to high knock resistance. Operation of natural gas vehicles at higher compression ratios than gasoline vehicles decreases the BSFC. On the other hand, natural gas, the cleanest fossil fuel due to having high H/C ratio, provides more reduction in THC emission values than Euro VI standard when suitable compression ratio is met. However, the storage problem must be eliminated in order to be used in all engines. Moreover, studies should also be done to increase the energy density. Hydrogen is a clean fuel and the mass energy density is very high. Fast burning characteristics of hydrogen permits high speed engine operation and less heat loss occurs for hydrogen than gasoline. NO<sub>x</sub> emission of hydrogen fuelled engine is about 10 times lower than gasoline fuelled engine if it works lean conditions. Because of hydrogen has some disadvantages such as very low ignition energy and volume energy density, it is mixed with other fuels especially natural gas to use in SI engines. Consequently, each fuel has positive and negative properties for use in internal combustion engines. There are differences in the effects of each alternative fuel on emissions and engine performance. The future studies could be carried out to obtain an appropriate hybrid fuel by making a comparison between these alternative fuels to reduce all emissions and to improve engine performance.

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