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AN OVERVIEW OF HYDROGEN FUELLED INTERNAL COMBUSTION ENGINES

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ABSTRACT: *This paper describes hydrogen technologies for the solution of long term internal combustion engine fuel problem with better reliability. A short overview about hydrogen is explained with some comparison among petrol and diesel. This report also includes some evaluations and discussions of implications of the combustion process of hydrogen systems in the following pages. The calculation of flame temperature for complete combustion and equilibrium and mixture pressure is explained in more detail. The general purpose of the article is to understand how efficiently hydrogen technology can be used as a fuel in the engine such as spark ignition and compression ignition and solve the World`s increasing engine fuel problem in our century.*

Keywords*: hydrogen, internal combustion engine, hydrogen fuelled internal combustion engine, H2ICE, lean burn, hydrogen engine, spark ignition engine, compression ignition engine.*

1. INTRODUCTION

With the increasing in technology, the reputation of energy production has risen around the world as a result of fast expanding consumption of fossil fuels and oils by increasing population and demanding industrial technologies. Additionally, these reasons cause to increase of CO_2 emissions and it is effect global warming. These factors lead to investigation of alternative energy sources for transportation and stationary production. Even though the major concern about the application of renewable energy sources is that the efficiency and the energy capacity of these systems which are not reliable and requires long time to have needed technological development for implementation and construction (Ganesh, 2008:2011). In this context, the energy storage and carrying system is needed that hydrogen energy system can be a perfect solution for this purpose. The purpose of this study is defining hydrogen fuelled internal combustion engine by giving information about design and operational structure as well.

2. In comparison among key properties of hydrogen, petrol and diesel and discussion of implications of the combustion process

2.1. Hydrogen

2.1.1. Some associated properties of hydrogen

Some important properties of hydrogen as an engine fuel are illustrated in comparison with methane and other gaseous on Table 1.

Table 1- Some comparative properties of hydrogen, methane and gasoline

Property	Hydrogen	Methane	Gasoline
Density at 1 ant and 300 K(kg/m^3)	0.082	0.717	5.11
Stoich. composition in air (% by volume)	29.53	9.48	1.65
Stoich fuel/air mass ratio	0.029	0.058	0.0664
No. of moles after combustion to before heat, mg values	0.85	1.00	1.058
Combustion energy per kg of stoic mixt.(MJ)	3.37	2.56	2.79
Kinematic viscosity at 300 K (mm^2/s)	110	17.2	1.18
Thermal conductivity at 300 K(mW/mK)	182.0	34.0	11.2
Diffusion coefficient into air at NTP (cm^2/s)	0.61	0.189	0.05

In comparison with other fuels, hydrogen has considerably high values of the significant features for transportations; for example, thermal conductivity, kinematic viscosity and diffusion coefficient. Hydrogen's low volumetric density and low luminosity affect to its unique diffusive and heat transfer quality directly. Table 2 shows the combustion features of hydrogen.

Table 2- Some comparative combustion properties of hydrogen, methane and gasoline

Property	**Hydrogen**	**Methane**	**Gasoline**
Flammability limits (% by volume)	4 – 75	5.3 – 15.0	1.2 – 6.0
Maximum ignition energy (mJ)	0.02	0.28	0.25
Laminar flame speed at NTP (m/s)	1.90	0.38	0.37 – 0.43
Adiabatic flame temp. (K)	2318	2190	~2470
Auto ignition temp.(K)	858	813	~500–750
Quenching gap at NTP (mm)	0.64	2.03	~2.0

2.1.2. Hydrogen as a fuel in engine system:

In comparison with other fuels, hydrogen engine operation contributes less undesirable exhaust emissions; for instance, there are no un-burnt CO and CO_2 gases (Das, 1990). Fast engine operation, which leads to high power output, can be provided due to the hydrogen’s fast burning properties. Moreover, these types of engines can be started easily in cold weather conditions because of hydrogen’s low boiling temperature characteristics (Shioji et al. 2002). In SI engine, hydrogen as an engine fuel provides high-power output efficiencies by over wide temperature and pressure ranges (wide range flammability) (Karim, 2003). Hydrogen might have high octane number, due to the hydrogen’s slow pre-ignition reactivity and fast burning rates. Unlike most other fuels, hydrogen can be used as a pure fuel which permits sustainable and better optimization for engine performance.

2.1.3. Some drawbacks of hydrogen engine applications

Most of the studies have been reported positive aspects of hydrogen engine applications. However, several limitations associated with hydrogen as an engine fuel. One of the most important negative features of hydrogen as a compressed gas is that it is obtained at 200atm and atmospheric temperature has only 5% of the energy of gasoline for the same volume. This is significant limitation especially for transport applications. Due to the low heating value of hydrogen based on volume in hydrogen engines, power output can be reduced. Hydrogen has high burning rates which cause to high pressure and temperatures during combustion in engines. Thus, oxides of nitrogen can release with high emission rates. Safety problems with hydrogen operation are always occurred (Hord, 1978 pp 157-176). Because of the high pressure rates, fast burning cause noise and vibrations. Uncontrolled pre-ignition problems are occurred because hydrogen need to very low ignition energy. Hydrogen engine requires almost 40-60% larger in size than a gasoline engine for the same power output. This causes to increase mechanical and motoring losses and decrease tolerance (Karim, 2003).

2.2. Petrol and Diesel

2.2.1. Some properties for petrol and diesel

Even there is different refining process, conventional petrol and diesel both formed from mineral/crude oil. The refinery process relatively easier for the diesel, which needs to be cleaned properly from the impurities, compared to petrol. On the other hand diesel quite has more energy that petrol with the high combustion efficiency and low carbon dioxide emissions (European Automobile Manufacturer Associations (ACEA)). The main properties is also shown in the table 3.

Table 3- The main properties of the petrol and diesel (adapted from Diffen, 2013)

Attributes	Diesel	Petrol
Uses	In diesel engines, heating systems	In petrol engines
Made from	Petroleum/ crude oil	Petroleum/ crude oil
Energy content	38.6 Mj/L	34.6 Mj/L
Made by	Fractional distillation	Fractional distillation
Torque (for 10L engine)	1000 Nm @ 2000 rpm	300 Nm @ 4000 rpm
Power (for 10L engine)	490 Hp @ 3500 rpm	600 Hp @ 5500 rpm
Power=torque*RPM	More torque at low speeds	Runs at higher RPM
Auto-ignition temperature	210 C^0	246 C^0
CO_2 emissions	More than gasoline (petrol). Diesel fuel produces approximately 13% more CO_2 gas per gallon fuel burned	Lower than diesel
US consumption	50 million gallons	148 million gallons

2.2.2. Petrol and Diesel as a fuel in engine system

This is comparatively new fuel application to obtain renewable biodiesel as a biofuel from different kinds of biomass such as vegetables oils, cane, sweat grain or animal fats for mainly use in diesel vehicles. Biodiesel technology can make significant contribution to greenhouse gas emission and national energy security (Fuel Economy Guide, 2013). Additionally it is also possible to use biodiesel as a mixture with petroleum diesel in a different blended rate that almost all manufacturers suggest that the high level blends affect the life time of the engine (Fuel Economy Guide, 2013). On the other hand, Diesel engine is considered to be more efficient than a spark-ignited petrol engine in a same power output conditions that the engines are installed in a vehicle having a similar mass in terms of combustion process efficiency. Even though the diesel has slight lower calorific value (45.5 MJ/kg) than petrol (45.8 MJ/kg), diesel fuel denser than petrol therefore it has higher energy per liter then petrol. As a result of this, the overall efficiency of the diesel is greater than petrol (ACEA, 2012). On the other hand, there are a significant increase in both diesel and petrol engine to obtain higher overall efficiency in terms of fuel consumption and performance. Homogeneous Charge Compression Ignition (HCCI) can be an example for the development of those fuel technology which can be used in both diesel and petrol engines technologies with considerably lower carbon dioxide emissions (ACEA, 2012).

3. The calculation of flame temperature for complete combustion

In the adiabatic and non-deformable vessel wall conditions, calculation the flame temperature for complete combustion was described as follows:

- A stoichiometric mixture of hydrogen and air in a closed vessel is initially at 298.13 K and 1 atm.

An example computation of adiabatic flame temperature for the reaction is;

$$H_2 + {}^1\!/_2\, O_2 \rightarrow H_2O$$

The adiabatic flame temperature;
For an adiabatic process;

$$\sum_R n_i(\overline{h}_f^\circ + \Delta\overline{h})_i = \sum_P n_e(\overline{h}_f^\circ + \underbrace{\Delta\overline{h}}_{\substack{\text{At adiabatic}\\ \text{flame temperature}}})_e.$$

Table 4- Enthalpy values at 298 K (Cengel, 2002 pp 928-955)

Substance	h_f° [kJ/kmol]	h_{298K} [kJ/kmol]
O_2	0	8682
H_2	0	8468
$H_2O_{(gas)}$	-241,826	9904

$$\rightarrow \quad 1\,\text{kmol}\, H_2O_{(gas)} \left[\left(-241820 + \overline{h_{H_2O_{(gas)}}} - 9904\right)\left[\frac{kJ}{kmol} H_2O_{(gas)}\right]\right] =$$

$$1\,\text{kmol}\, H_2 \left[(0 + 8468 - 8468)\left[\frac{kJ}{kmol} H_2\right]\right] + 0.5\text{kmol}\, O_2 \left[(0 + 8682 - 8682)\left[\frac{kJ}{kmol} O_2\right]\right]$$

$$\rightarrow \left(-241826 + \overline{h_{H_2O_{(gas)}}} - 9904\right) = 0$$

$$\overline{h_{H_2O_{(gas)}}} = 251730\text{ kJ}$$

Adiabatic flame temperature is specified by:

$$\sum_P n_g \Delta h_g = 251730kJ$$

Table 5- Different temperatures and he values for iteration (adapted from (Cengel, 2002) pp 928-**952)**

T/K	$\overline{h_{H_2O_{(gas)}}}$ **(kJ·mol^{-1})**
2300	240469.9
2400	252646.5
2500	264872.3
2600	277175
2700	289533.6
2800	301944.3
2900	314402.4

After this result, according to the table 5, the flame temperature for complete combustion must be between 2300 K and 2400 K. Thus,

$$\frac{Tp-2300}{2400-2300} = \frac{251726-240469.3}{252646-240469.3}\ ,\ \mathbf{T_p = 2392.4K}$$

⇨ Flame temperature for complete combustion is calculated about **2392.4K**

4. Equilibrium composition and mixture pressure

Once the above reaction reaches equilibrium at 2000 K, calculation of the equilibrium composition and mixture pressure as follows:

The stoichiometric reaction: $H_2 + {}^1/_2\, O_2 \longrightarrow H_2O$

The degree of reaction:

$$\varepsilon = \frac{n_i - n_{i,o}}{v_i^{II} - v_i^{I}} = \frac{n_{H_2} - 1}{0-1} = \frac{n_{O_2} - {}^1/_2}{0 - {}^1/_2} = \frac{n_{H_2O} - 0}{1-0}$$

$$n_{H_2} = 1 - \varepsilon\ ,\ n_{O_2} = {}^1/_2\,(1-\varepsilon)\ ,\ n_{H_2O} = \varepsilon$$

$$n_R = \sum_i n_{R,i} = 1 + 1/2 + 1.88 = 3.38\,, \quad n_p = \sum_j n_{p,j} = 1 - \varepsilon + {}^{1}/_{2}(1-\varepsilon) + \varepsilon + 1.88 = (3.38 - 0.5\varepsilon)$$

The equilibrium constant:

$$K_p = \prod_i \left(\frac{P_i}{P_o}\right)^{v_i^{ll}-v_i^{l}} = \prod_i \left(\frac{x_i P_p}{P_o}\right)^{v_i^{ll}-v_i^{l}} = \prod_i \left(\frac{n_i P_p}{n_p P_o}\right)^{v_i^{ll}-v_i^{l}} = \left(\frac{P}{P_o}\right)^{\sum_i (v_i^{ll}-v_i^{l})} . \prod_i x_i^{(v_i^{ll}-v_i^{l})}$$

The ideal gas low for the initial reactant mixture and equilibrium mixture;

$$P_R V = n_R R_u T_R\ ,\ P_p V = n_p R_u T_p$$

$$\frac{P_p V}{P_R V} = \frac{n_p R_u T_p}{n_R R_u T_R} \qquad => \quad \frac{P_p}{n_p} = \frac{P_p T_p}{n_R T_r} = \frac{P_o T_p}{n_R T_R}$$

$$K_p = \prod_i \left(\frac{n_i P_p}{n_p P_o}\right)^{v_i^{ll}-v_i^{l}} = \left(\frac{T_p}{n_R T_R}\right)^{\sum_i (v_i^{ll}-v_i^{l})} . \prod_i n_i^{(v_i^{ll}-v_i^{l})} = \left(\frac{T_p}{n_R T_R}\right)^{\sum_i (v_i^{ll}-v_i^{l})} . \frac{n_{H_2O}}{(n_{H_2} n_{O_2})^{0.5}}$$

$$K_p = \left(\frac{T_p}{3.38 * 298.13\ K}\right)^{0.5} * \frac{\varepsilon}{(1-\varepsilon) * [{}^{1}/_{2}(1-\varepsilon]^{0.5}}$$

$$\frac{\varepsilon}{(1-\varepsilon) * [{}^{1}/_{2}(1-\varepsilon]^{0.5}} = \frac{K_p}{\left(\frac{T_p}{3.38 * 298.13\ K}\right)^{0.5}}$$

After that point, the problem can be solved with iteration method. From the Janaf table, the equilibrium constant is taken for 2000 K which is given on Table 6 (Cengel, 2002 pp. 928-952).

Calculation for equilibrium constant;

$$\log_{10} K_{p,H_2O} = \log_{10} K_p$$

Table 6- Different temperature and equilibrium constant values (adapted from Cengel, 2002 pp 928-955)

T/K	$\log_{10} K_p$	K_p	$\dfrac{K_p}{\left(\dfrac{T_p}{1.5 * 298.13\ K}\right)^{0.5}}$
2000	3.540	3467.3	1639.551
2200	2.942	874.98	394.4893
2400	2.443	277.33	119.7126
2600	2.021	104.95	43.52555
2800	1.658	45.498	18.18284
3000	1.344	22.08	8.524853

Before calculate the equilibrium composition and mixture pressure. The degree of reaction has to be calculated at 2000 K.

Table 7- Iteration for degree of reaction

	$\dfrac{\varepsilon}{(1-\varepsilon) * [{}^{1}/_{2}(1-\varepsilon]^{0.5}}$
0.1	0.165634665
0.2	0.395284708
0.3	0.724417933
0.4	1.217161239
0.5	2
0.6	3.354101966
0.7	6.024640761
0.8	12.64911064
0.9	40.24922359
0.922	59.85549336
0.99	1400.071427
0.991	1641.43953
0.994	3024.645679
0.993	2397.823357
0.9931	2450.3851
0.99312	2461.127

- $$\frac{\varepsilon}{(1-\varepsilon)*[{}^{1}/_{2}(1-\varepsilon]^{0.5}} = \frac{K_p}{\left(\frac{T_p}{1.5*298.13\ K}\right)^{0.5}}$$

$$= \frac{\varepsilon}{(1-\varepsilon)*[{}^{1}/_{2}(1-\varepsilon]^{0.5}} = \frac{3467.3}{\left(\frac{2000}{3.38*298.13\ K}\right)^{0.5}}$$

- $$\frac{\varepsilon}{(1-\varepsilon)*[{}^{1}/_{2}(1-\varepsilon]^{0.5}} \sim 2461.14$$

Some different values, on Table 7, are used to compute almost exact degree of reaction that is about 0.99312. Hence

The equilibrium mixture composition;

$$X_{H_2O} = \frac{\varepsilon}{(3.38-0.5\varepsilon)} = \frac{0.99312}{(3.38-0.5*0.99312)} = 0.34442$$

$$X_{H_2} = \frac{1-\varepsilon}{(3.38-0.5\varepsilon)} = \frac{1-0.99312}{(3.38-0.5*0.99312)} = 2.386x10^{-3}$$

$$X_{O_2} = \frac{n_{O_2}}{n_{total}} = \frac{0.5(1-\varepsilon)}{3.38-0.5\varepsilon} = 1.193x10^{-3}$$

The equilibrium mixture pressure;

$$P_p = \frac{n_p T_p}{n_R T_R} = \frac{3.38 - 0.5 * 0.99312}{3.38} x \frac{2000\ K}{298.13\ K} = 5.7229$$

$$\mathbf{P_p = 5.69\ atm}.$$

5. Comparison between Spark Ignition (SI) and Ignition (CI) Engines

Both ignition engines are different in their principles operation; for instance, spark ignition (SI) engine, petrol or gasoline is used, is called petrol engine as a fuel. In compression engine (CI) diesel is used as a fuel, therefore these are called diesel engines (Spark engine, 2011).

Type of cycle; In SI engine, Otto cycle, where addition of fuel combustion and heat happens at a constant volume, is employed.

Fuel in the engine; In SI engine, both air and fuel are usually mixed before moving to the engine cylinder with utilizing a carburettor or fuel injection system. Unlike SI engine, CI engine uses highly compressed hot air to ignite the fuel using a spark plug.

Compression ratio for the fuel; In SI engine, the compression ratio of the fuel is approximately 6 to 10 depending on the size of engine. This ratio for diesel engine is the range of 16 to 20 which cause to high temperatures, as a result of this, diesel fuel might self-ignite.

Weight of the engine; as it is mentioned previously, diesel engine compression ratio is higher that creates high pressure inside the engine. Therefore, CI engines are heavier than SI engines.

Speed achieved by the engine; high engine speed conditions can be occurred due to the fuel is homogenously burned in SI. However, CI engine is heavier and the fuel is burned heterogeneously. These impacts cause low speed in CI engine (Korakianitis et al. 2010).

6. Spark Ignition (SI) or Compression Ignition (SI) Operation in Hydrogen Fuelled Internal Combustion Engine (H2ICE)

In contrast with other fuels such as diesel, gasoline and ethanol, there are great advantages to use hydrogen in ICE engine. For example, it is the most abundant component in the universe and potential of almost zero emissions of CO, NOx, and HC, and also greatly improved cold start capability. At this point, wide range flammability, low ignition energy, small quenching distance, high auto ignition temperature, high flame speed and stoichiometric ratios and very low density can be considered the main important properties of the hydrogen.

Wide range flammability: In comparison with all other fuels, hydrogen has a wide flammability range, thus it can be combusted in ICE over a broad range of fuel-air mixtures. Another significant benefit is that hydrogen can run on a lean mixture to provide engine starting easily especially in cold weather conditions.

High auto ignition temperature: Another important implication is that hydrogen has high auto ignition temperature when hydrogen-air mixture is compressed. In fact, auto ignition temperature provides to determine what suitable compression ratio an engine can utilize. The temperature increase is illustrated following equation;

$$T_2 = T_1 \left(\frac{V_1}{V_2}\right)^{\gamma-1}$$

Where; $\frac{V_1}{V_2}$ = compression ratio.

T_1 = absolute initial temperature

T_2 = absolute final temperature

γ= specific heat ratio

The maximum temperature cannot reach hydrogen's auto ignition temperature without being premature ignition. Hence, the absolute final temperature restricts the compression ratio. The high auto ignition temperature of hydrogen provides large compression ratios to be implemented in a hydrogen engine (hydrogen use in internal combustion, 2001).

7. General information about Ignition System:

As several combustion features are given at previous sections to decide a suitable ignition system. Numerous studies have been conducted to investigate the usage of hydrogen as a fuel in spark ignition engine and feasibility of hydrogen has been well reported and most of R&Ds focus on hydrogen application in conventional SI engines,. Hydrogen has low ignition energy limit, its ignition is easy and SI engine system can be preferred. Also, at very lean air/fuel ratios around 130:1 to 180:1 flame velocity decrease remarkable. Thus, double spark plug system can be also preferred, (hydrogen use in internal combustion, 2001).

Hydrogen's wide range flammability and high auto ignition temperature provide a great deal of flexibility to be used hydrogen in SI engine. On the other hand, ignition of hydrogen is difficult for compression or diesel engines because these types of ignition require relatively high temperatures. For instance, while self-ignition temperature is about 585 °C for hydrogen, that value is around 250 °C for diesel fuel (Verhelst and Wallner, 2009).Nevertheless, recently, some achieving studies about hydrogen fuelled ICE on compressive ignition have been reported. One of them is homogenous charge compression ignition (Verhelst and Wallner, 2009). There are several reasons for using hydrogen as an additional fuel with the diesel fuel in the ICE on CI. The most important reason is that it leads to increase the H/C ratio of the entire fuel. Secondly, heterogeneity of a diesel fuel spray can be reduced with addition small amounts of hydrogen due to the high diffusivity of hydrogen. This property leads to occur the combustive mixture better premixed. Moreover, due to the high flame speed, combustion duration can be reduced. For example, at normal temperature and pressure conditions laminar flame speed for hydrogen around 1.9 m/s while it is almost five times higher in comparison to 0.4 m/s for other hydrocarbon fuels (Karim, 2003). As a result, better homogeneity of the combustible fuels provides better conditions for the combustion sections. Furthermore, faster combustion with constant volume provides more efficiency (Szwaja and Grab-Rogalinski, 2009).

8. Operation of H2ICE in lean-burn mode (advantages and drawbacks)

SI engine performance effectively increases with lean-burn operation. Briefly, benefit of lean burn engines is its greater fuel efficiency due to its higher compression ratio. Furthermore, the CO emission level is very low during the combustion process. Additionally, lean burn engine provides higher power density. ICEs via lean combustion process have been improving their economic performance and decreasing toxic pollutants (Ji and Wang, 2010). Particularly, CO and HC emission are reduced considerably due to the using oxygen for the fuel to be burnt under lean conditions (Ma et al. 2008). In addition to this, increasing air ratio leads to reducing combustion temperature that prevents cooling losses. Hence, the engine thermally efficiency might be improved at lean conditions.

Also, NO_x emissions decrease with dropping in cylinder temperature. At that point although NO_x production level is very low in a lean burn engine; reducing this NO_x emission is very difficult and expensive after treatment system. However, there are several drawbacks associated with lean burn operating, some of them are; slower flame extension, growing cycle-by-cycle variation and undermined burning completeness (Ma, 2008). These difficulties lead to reduce engine performance especially in natural gas (NG) fuelled engines because of some effects of NG properties such as higher ignition energy and slower laminar combustion velocity. These issues can be solved utilising conventional ways; for example, strengthen cylinder turbulence, increasing spark energy or the amounts of spark plug. However, these ways are not completely solve the problems because their effects are always limited and sometimes cause significant damages. For instance, heavy cylinder turbulence can be harmful for volumetric efficiency. Moreover, spark plug life may be reduced when increasing ignition energy. As a result, some solutions require enhancing combustion of NG without above drawbacks. One of the most effective ways is addition fuels which have faster burning velocity and lower ignition energy features. Probably, hydrogen is the best choice for addition into NG because it has same properties for application in SI engines (Ma, 2008).

Furthermore, pure gasoline-fuelled SI engines are also exposed some issues at lean operation. For instance, narrow flammability of gasoline cause decrease engine thermal efficiency and increase carbon-related emissions at lean conditions (Ji and Wang, 2010).

CONCLUSION

There is no terrestrial free hydrogen as a fuel, which is its main property, in the atmosphere. Terrestrial hydrogen is commonly bound into other complex molecules such as water. Briefly, hydrogen gas must be produced from a broad variety of possible sources. For this reason, extracting hydrogen requires much energy and capital resources (Karim, 2003).Current times, hydrogen can be produced from fossil fuels such as NG, coal and oil with processing of steam or through partial oxidation. In addition, high purity hydrogen might be produced especially for fuel cells applications through the electrolysis of water during thermal efficiency around 60% to 75% (Kukkonen and Shelef, 1993).

The engine applications are not capable to solve storage and portability problem of hydrogen. However, hydrogen might be stored as a compressed gas in well-designed high pressure tanks which is require light-weight and compact in volume due to the hydrogen’s low volumetric density. However, both providing high pressure and setting up noble infrastructure for compression gas are high expensive process.Also, hydrogen can be transported with board vehicles but this method cause to increase undesirable emissions, much cost and bulk while decreasing the flexibility of the fuel system (Silva et al. 1993). However, recently many successful operations have been organised to provide mass transporting and distribution of hydrogen for long-distances by special pipelines and marines, rail and road transport in safety conditions.

Additionally, in comparison with gasoline and diesel, hydrogen is more preferable choices as a sustainable fuel source even its price quite higher than petrol and diesel in the near future. However, hydrogen is not a primary energy sources therefore it needs to be converted into a useful fuel which is a crucial issue in hydrogen technology. There are many methods to obtain hydrogen such as hydrolysis which is the most general process. It is quite difficult to generate high power from a hydrogen engine which is a main problem with hydrogen engines compared to traditional fuel engines. However, in terms of prices diesel and gasoline, which are nearly same prices, hydrogen is more expensive that such fuels. Consequently, with the increasing of the new technology, the cost of the hydrogen production can be decreased which cause an increase in production of the hydrogen (hydrogen fuel, 2010). There is an increasing demand for fuel cells technology which makes possible to use hydrogen to power electric motors or burned in internal combustion engines (ICEs). Even though there are several significant challenges need to overcome before it can be widely used. Additionally, hydrogen is an environmentally friendly fuel as well as it can dramatically reduce the dependence on imported oil. This is due to availability many kinds of domestic resources can be used for generating hydrogen (Energy efficiency and renewable energy, 2013).

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