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**Research Paper**

# Onboard Production of Hydrogen Gas for Power Generation

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***ABSTRACT:-*** Electrolysis is an electrochemical process in which electrical energy is the driving force of chemical reactions. Substances are decomposed, by passing a current through them in the presence of suitable substances, called electrolytes. Electric current causes positively charged hydrogen ions to migrate to the negatively charged cathode, where a reduction takes place in order to form hydrogen atoms. The atoms formed then combine to form gaseous hydrogen molecules (H2). On the other hand, oxygen is formed at the other electrode (the positively charged anode).

Hydrogen is a clean burning renewable fuel and does not produce any emissions such as smoke, CO which is major problem in fossil fuel operated engines. Hydrogen is one of the most promising alternative fuels. Its clean burning characteristics and better performance drives more interest in hydrogen fuel. The distinguished feature of hydrogen operated engine is that it does not produce major pollutants such as hydrocarbon (HC), carbon monoxide (CO), sulphur dioxide ($SO_2$), lead, smoke, particulate matter, ozone and other carcinogenic compounds. This is due to the absence of carbon and sulphur in hydrogen. The main objective of the project is to establish test facilities for the production of hydrogen on board generation. For this electrolysis process will be used and the established system will ensure 10 LPM of hydrogen. The hydrogen generated will then be used in a stationary engine for power generation.

***Keywords***:- Electrolysis, Electrolytes, LPM, Hydrocarbon

## I. INTRODUCTION

Faced with the ever increasing cost of conventional fossil fuels, researches worldwide are working overtime to cost- effectively improve internal combustion engine (ICE) fuels and emission characteristics. In recent years, many researchers have focused on the study of alternative fuels which benefit enhancing the engine economic and emissions characteristics. The main pollutants from the conventional hydrocarbon fuels are unburned/partially burned hydro-
carbon (UBHC), CO, oxides of nitrogen (NOx), smoke and particulate matter. It is very important to reduce exhaust emissions and to improve thermal efficiency. Among all fuels, hydrogen is a long term renewable, recyclable and non-polluting fuel. Hydrogen has some pecu-
liar features compared to hydrocarbon fuels, the most significant being the absence of carbon.

Besides, compared with traditional fossil fuels, hydrogen is a carbonless fuel whose combustion doesn't generate emissions such as HC, CO and CO2, The concept of using hydrogen as an alternative fuel for diesel engines is recent. The self ignition temperature of hydrogen is 858 K, so hydrogen cannot be used directly in a CI engine without a spark plug or glow plug. This makes hydrogen unsuitable as a sole fuel for diesel engines.

There are several reasons for applying hydrogen as an additional fuel to accompany diesel fuel in CI engine. Firstly, it increases the H/C ratio of the entire fuel. Secondly, injecting small amounts of hydrogen to a diesel engine could decrease heterogeneity of a diesel fuel spray due to the high diffusivity of hydrogen which makes the combustible mixture better premixed with air and more uniform.

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## II. HHO GAS

The HHO gas is nothing but the electrolyte form of water. It is also called as oxy-hydrogen or brown gas. It is produced by electrolysis process, where an electrical power source is connected to two electrodes and which are placed in a mixture of water and electrolyte. Oxyhydrogen appears to be a favourable alternative fuel on account of its high specific energy per unit weight, its all-time availability as a component of water, good combustion characteristics and eco-friendly, fast burning and higher flame propagation rates are the attractive features of HHO gas. HHO gas is a mixture of hydrogen and oxygen gases, typically in a 2:1 atomic ratio; the same proportion as water.

At normal temperature and pressure, oxyhydrogen can burn when it is between about 4% and 94% hydrogen by volume, with a flame temperature around $2000^0$C. Oxyhydrogen will combust (turning into water vapour and releasinging energy which sustains the reaction) when brought to its auto ignition temperature.

HHO is described to have the structure H-O-H where represents the new magnecular bond and the conventional molecular bond. The transition from the conventional H-O-H configuration to the new H-O-H species is explained as being a change of the electric polarization of water caused by the electrolyzes.

| Properties | Diesel | Unleaded gasoline | Hydrogen |
|---|---|---|---|
| Autoignition temperature (K) | 530 | 533–733 | 858 |
| Minimum ignition energy (mJ) | – | 0.24 | 0.02 |
| Flammability limits (volume % in air) | 0.7–5 | 1.4–7.6 | 4–75 |
| Stoichiometric air-fuel ratio on mass basis | 14.5 | 14.6 | 34.3 |
| Limits of flammability (equivalence ratio) | – | 0.7–3.8 | 0.1–7.1 |
| Density at 16 °C and 1.01 bar (kg/m$^3$) | 833–881 | 721–785 | 0.0838 |
| Net heating value (MJ/kg) | 42.5 | 43.9 | 119.93 |
| Flame velocity (cm/s) | 30 | 37–43 | 265–325 |
| Quenching gap in NTP air (cm) | – | 0.2 | 0.064 |
| Diffusivity in air (cm$^2$/s) | – | 0.08 | 0.63 |
| Research octane number | 30 | 92–98 | 130 |
| Motor octane number | – | 80–90 | – |

Water Electrolysis is a very simple process that takes water and passes a supply of electricity through it using immersed electrodes to split into positive hydrogen (H+) and negative oxygen (O-) ions. These hydrogen and oxygen ions migrate through the water towards the cathode and anodes respectively, where electron transfers allow for the diatomic H2 and O2 molecules to form at high purity.

Electrolysis of hydrogen is currently around 75% energy efficient and could be theoretically increased to more than 90 % in the future.Therefore this process appears to be an efficient method of producing high purity hydrogen in large quantities with little or no environmental impact. However the electrical energy required in running such a process would have to come from renewable power sources such as wind, photovoltaic,hydroelectric or geothermal generators for it to be truly environmentally friendly and sustainable in the future.

Alkaline water electrolysers usually use electrolyte that contains **aqueous potassium hydroxide (KOH)**, mostly with solutions of 20 - 30 wt% because of the optimal conductivity and require to use corrosion resistant stainless steel to withstand the chemical attack. The typical operating temperatures and pressures of these electrolysers are 70 – 100 °C and 1 – 30 bar respectively. The chemical reactions that take place in the operation of the alkaline electrolyser are mentioned below.

For the anode reaction it is:

$4H_2O + 4e \rightarrow 2H_2 + 4OH^-$

For the cathode reaction it is:

$4OH^- \rightarrow O_2 + 4e- + 2H_2O$

And finally the overall reaction is:

$2H_2O \rightarrow 2H_2 + O_2$

The electrolyser comprises of a positive terminal and a negative terminal where the power supply must be connected. A source of DC voltage connected to the electrodes so that an electric current flows through the electrolyte from anode to cathode. As a result, water in the electrolyte solution is decomposed into $H_2$ which is released at the cathode and oxygen at the anode

AC supply is not used because electrolysis needs some activation energy,it needs some energy for activation and its polarity changes.DC being uniploar after the activation energy continuous production of $H_2$ and $O_2$ takes place.

## III. DESIGN

Main Components of Process:

Electrodes: SS 316L 1mm thick sheet

Electrolyte: KOH + Distilled Water

Reactor: PVC

Bubbler: PET

The HHO generator is basically an electrolyte cell. Here the kit used is of simple in construction, whose reactor (container) is made of PVC pipe and the electrodes are made from SS 316L plate of thickness 1mm. The plate is cut into pieces 6”X2.5”. Now these arrangements are placed inside a reactor of diameter 3” and it’s both sides are sealed with end caps (PVC). The upper end cap houses the electrode terminals and also a hole for HHO gas outflow.

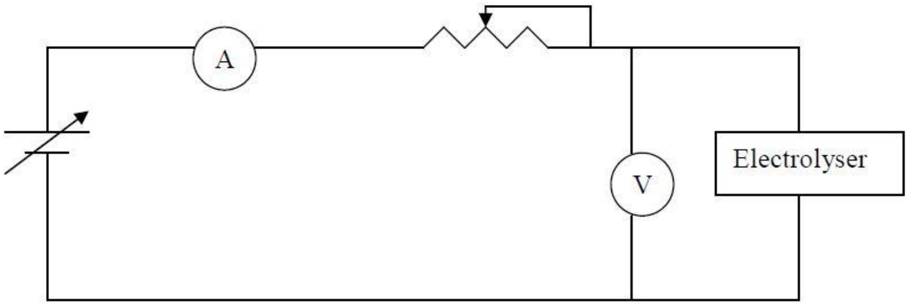
In the electrolysis process the oxygen is generated at anode & hydrogen is generated at cathode. A small free space at the top of the cylinder will allow the gases to mix together. The HHO gas generated from the kit is supplied to the engine via intake manifold. Since HHO gas is highly inflammable, the gas is passed through the water. The container of water (Bubbler) acts as a Back Fire Arrestor. This is for safety reasons. Then the gas is passed through the carburetor to run the engine.

## IV. CONCENTRATION LOSSES

Concentration loss relates to the reduction of the reactant’s concentration in the gas channels. The fuel and the oxidant are used at the surface of the electrodes and then the incoming gas must take the place of the used reactant. The concentration of the fuel is therefore reduced. The concentration loss can be neglected in some cases, but it is significant at higher currents and when the fuel and oxidant are used at higher rates and the concentration in the gas channel is at a minimum.

## V. METHODOLOGY

The units were assembled together as shown in the figure below.




The power supply unit is connected to the first multimeter, which will be used to measure the current in milliamperes, to the resistor, which is set to avoid high currents and connects to the electrolyser.

The second multimeter is used to measure the voltage in volts and is connected parallel to the electrolyser.

The polarity was double-checked to assure that the positive terminal of the power supply unit is connected to the positive terminal of the electrolyser and the negative terminal of the power supply unit to the negative terminal of the electrolyser

On this experiment, different amount of currents were applied for thirty seconds and then the volume of hydrogen produced in each current was measured.

The results from this experiment will show if the electrolyser produces the same amount of hydrogen when the same values of current are used and what is the loss of hydrogen volume each time using the same settings.

**Experimental Values:-**

| KOH(in grams) | Volume(ml) | Time | Current(A) | Discharge(LPH) |
|---|---|---|---|---|
| **50** | 600 | 6min 20sec | 6 | 5.68 |
| **150** | 600 | 3min38sec | 12 | 6.9 |
| **200** | 600 | 3min20sec | 13 | 3.8 |
| **250** | 600 | 3min55sec | 12.7 | 4.19 |
| **250** | 600 | 7min30sec | 6 | 6.8 |
| **250** | **600** | **2min57sec** | **16** | **7.2** |

**Performance characteristics of petrol and HHO gas when used as a fuel**

The performance of petrol engine with HHO up to 30% of full load, brake thermal efficiency will remain same for both the case (petrol and blended). Beyond this point brake thermal efficiency increase linearly for fuel mixture of petrol and HHO gas. And also up to 30% of full load for both cases the brake thermal fuel consumption increases linearly and reaches maximum value.

By comparing the results of above twocases the mixture of petrol and HHO gas gives better result for higher loads. Since HHO is highly combustible fuel, it ensures the complete combustion of the fuel mixture. Thus it results in the increased speed of the engine and in turn increases the power output.

**Water temperature**

The output voltage of battery or an alternator of a vehicle depends on the engine speed i.e. between 12 volts and 13.8 volts. If the source of power supply to the kit is car battery, the voltage and the current to the kit will always be fluctuating due to the varying engine speed.

The amount of gas produced in the setup depends on the voltage applied to the system i.e. at 12 volt the Hydroxyl production will be less however at 13.8 volts the Hydroxy production will be at peak.

The following are the design consideration for a HHO generating kit

- Compact in size
- Suitable for long operation
- Energy efficient
- Safe
- Easy to operate and maintenance free
- Leak proof

**Fuel consumption measurements**

The fuel consumption of an engine is measured by determining the volume flow in a given time interval and multiplied it by the specific gravity of the fuel which should be measured occasionally to get an accurate value.
Another method is to measure the time required for consumption of a given mass of fuel.
Accurate measurement of fuel consumption is very important in engine testing work.

The method selected was **"Burette method".**

## VI. CALCULATIONS

I= 2.5Amps

t = 60sec

N=12 (12plates)

Q= N*I*t

=12*2.5*60

= 1800 Coulomb

Number of moles of Hydrogen

= 1800/ (2*96485); (96485= F)

= 9.33 x $10^{-3}$ mole

Conversion to grams = mole * molecular mass

= 9.33 x $10^{-3}$ * 2

= 0.0187 gram

Conversion from gram to LPM:

1litre of hydrogen weighs - 0.082grams

X litres of H2 weighs - 0.0187grams

Therefore, X= 0.228 LPM

Considering KOH in calculations:

Concentration of KOH = (10/1lit)

56grams of KOH = 1mole

10grams of KOH = X

Therefore, X = 0.178mole

Diffusion $OH^-$ occurs starts after 7 seconds

From fix diffusion law

$J = -D\ (\Delta\phi / \delta x)$

$D = 5.3 \times 10^{-5}\ cm^2/sec$

$\Delta\phi = 178.57\ mol/m^3$

dX= 6 cm

$J = 1.571 \times 10^{-4}\ mol/cm^2 s^{-1}$

Number of moles of $OH^-$ produced in 1 minute.

= J x A x 60 (Area= 966.54 $cm^2$)

= 0.0915 mole

Total number of moles hydrogen gas produced $= 9.33 \times 10^{-3} + 0.04575$

$= 0.05508$ mole

No. of grams of hydrogen produced=0.05508*2

=0.1102 gram

Total hydrogen gas produced =0.1102/0.082

=1.34 LPM

$$\text{Brake Power, B.P} = \frac{(2\pi NWR*9.81)}{60000},\ kW$$

Where,

N is speed in RPM

W is load in kg

R is radius of brake drum in meters

$$BP = \frac{(2\pi*1500*13*0.16*9.81)}{60000}$$

= 3.2051 kW

$$\text{Total Fuel consumption, TFC} = \frac{10*\ \text{Specific gravity}*3600}{1000*t},\ kg/hr$$

Where,

Specific gravity of Diesel= 0.8275
T is time for 10cc of fuel consumption in seconds

$$TFC = \frac{10*0.8275*3600}{1000*25}$$

$= 1.1916$ kg/hr

Friction power, FP= 4.3KW
Indicated power, IP= FP+BP
=4.3+3.2051=7505

Brake thermal efficiency, $\eta_{bth} = \frac{BP*3600}{TFC*CV}*100$ %
Where,
CV is the calorific value of fuel = 45357 kJ/kgK

$$\eta_{bth} = \frac{3.2051*3600}{1.1916*45357}$$

$= 21.3$ %

Mechanical efficiency, $\eta_{mech} = \frac{BP}{IP}*100$
Where,BP is the brake power
IP is the indicated power

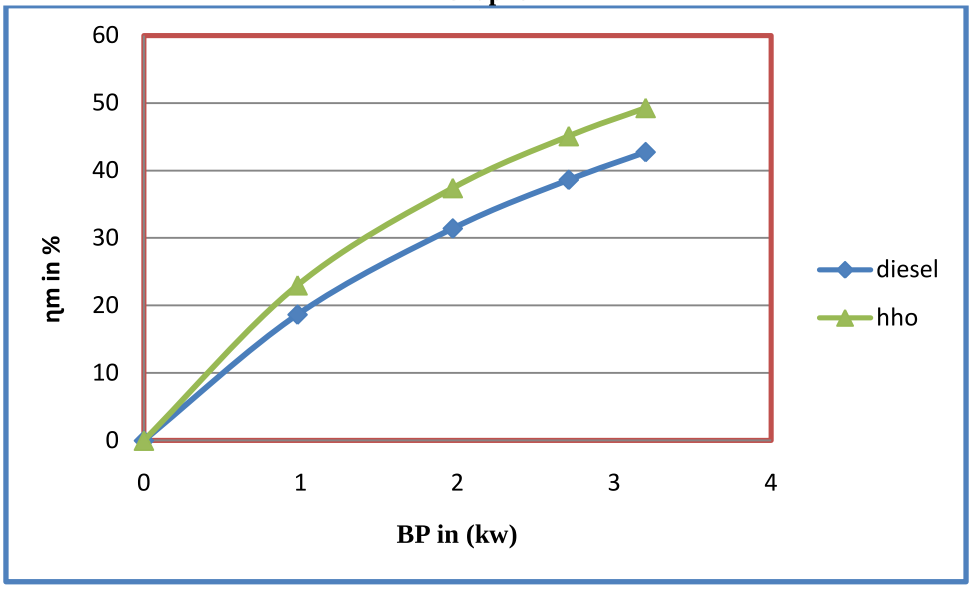
=3.2051/7.5051*100

=42.705%

Indicated thermal efficiency, $\eta_{ind.th} = \frac{IP*3600}{TFC*CV}$
= (7.505*3600)/(1.1916*45357)

= 49.98%

**Graphs**




**Mechanical efficiency (ɳ m) v/s brake power (BP)**

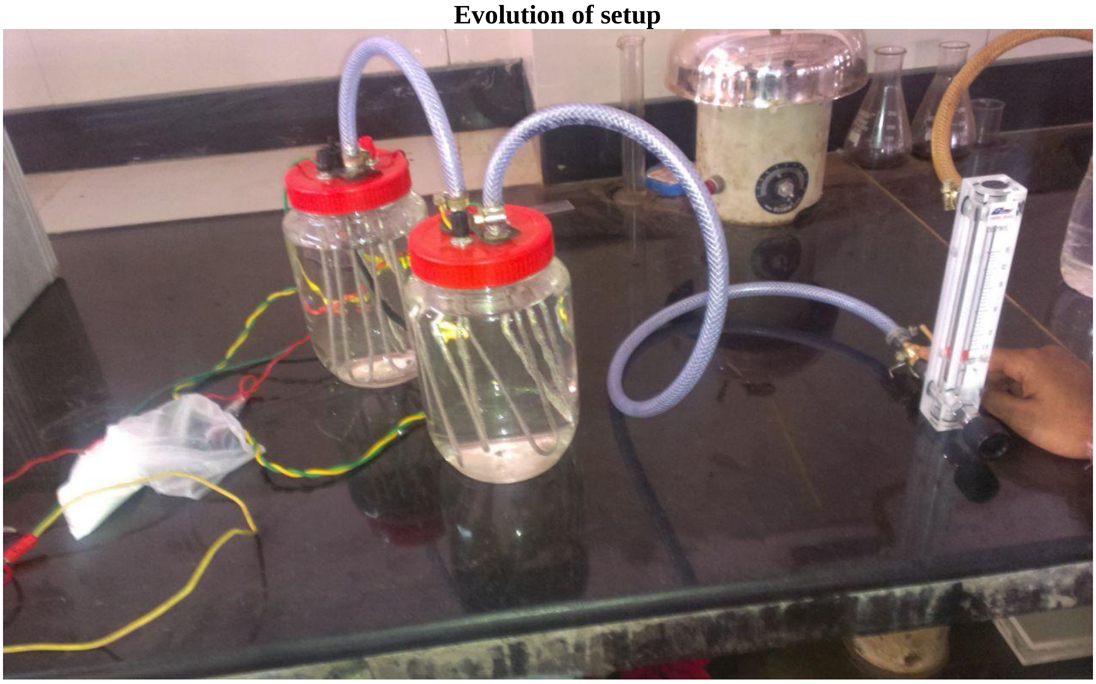
**Advantages of HHO gas as a fuel in Diesel engine**

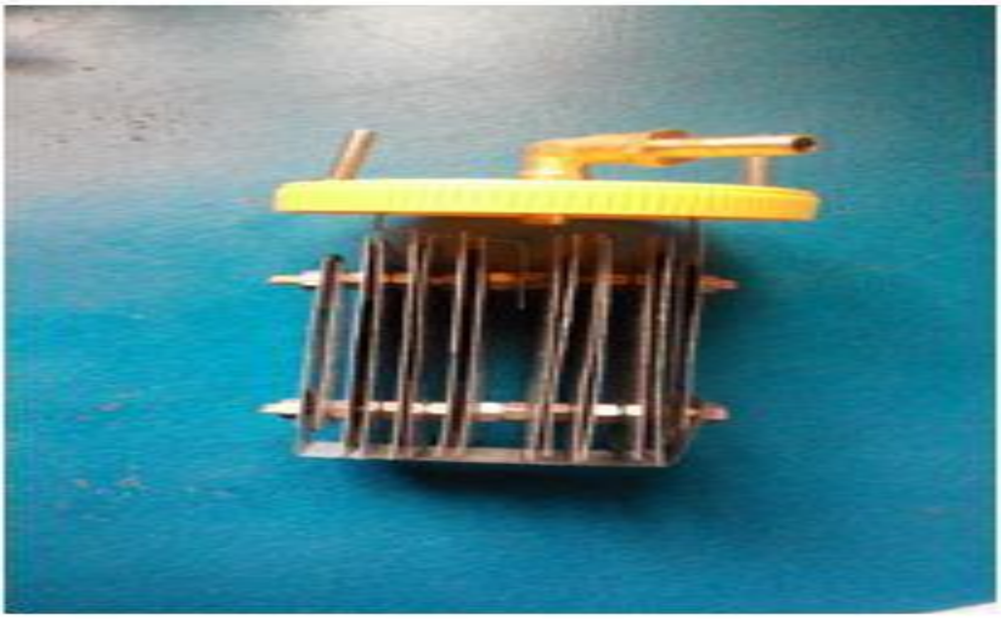
- HHO gas mixture burns nearly 10 times faster compared to gasoline air mixture.
- HHO ignition limits are much wider than gasoline's. So it can burn easily and give considerably higher efficiency.
- High self ignition temperature but very little energy is required to ignite it.
- Its clean exhaust is the most attractive feature of all.
- No green house effect.

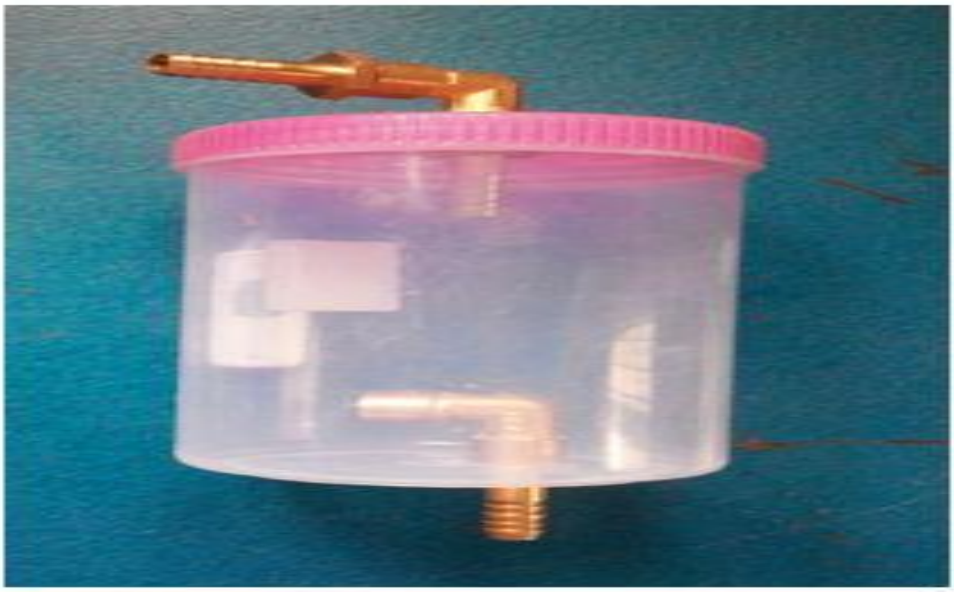
**Disadvantages of HHO gas as a fuel in Diesel engine**

- One of the major practical difficulties using HHO as car fuel is its very low density either in gas or liquid form.
- The handling of HHO gas is more difficult and storage requires high capital and running cost.

**Evolution of setup**







## VII. CONCLUSION

KOH solution produces lot of foams which leads to loss of concentration of electrolyte and in turn decrease the generation of HHO gas.

Therefore comparing the production, rate of change of electrolyte concentration and cost of KOH electrolyte solution is best suited for the generation of HHO gas.

From the experiment we came to know the volume of hydrogen produced is 1.5 LPM for 2.5Amps of current supply. With optimization in techniques of production of hydrogen and including five more junctions, this will yield 7.2LPM of hydrogen. Further the produced hydrogen gas can be an input to fuel cells, which is the major area of interest for researchers in automobile industry. Thus the method used for production of hydrogen is safe, efficient and clean for power generation and its future scope widely lies in the fuel cell.

| Property | Hydrogen | Diesel |
|---|---|---|
| **Density at 1 atm and 300 K (kg/m$^3$)** | 0.082 | **0.717** |
| **Stoichiometric composition of air (% by Volume)** | 29.53 | **9.48** |
| **Stoichiometric fuel air mass ratio** | 0.029 | **0.058** |
| **No. of moles after combustion to before** | 0.85 | **1.0** |
| **Higher heating value ( MJ/kg)** | 141.4 | **52.68** |
| **Lower heating value ( MJ/kg)** | 1119.7 | **46.72** |
| **Higher heating value ( MJ/m$^3$)** | 12.10 | **37.71** |
| **Lower heating value ( MJ/m$^3$)** | 10.22 | **33.95** |
| **Combustion energy per kg of Stoichiometric mixture (MJ)** | 3.37 | **2.56** |
| **Kinematic viscosity at 300K (mm$^2$/sec)** | 110 | **17.2** |
| **Thermal conductivity at 300K (mW/ mK)** | 182 | **34** |
| **Diffusion coefficient in to air at NTP (cm$^2$ /sec)** | 0.61 | **0.189** |
| **Flammability limits (%by Volume )** | 4-75 | **5.3-15** |
| **Property** | **Hydrogen** | **Diesel** |
| **Minimum Ignition energy (mJ)** | 0.02 | **0.28** |
| **Laminar Flame Speed at NTP (m/s)** | 1.90 | **0.38** |
| **Adiabatic Flame Temperature (K)** | 2318 | **2190** |
| **Auto Ignition Temperature (K)** | 858 | **813** |
| **Quenching gap at NTP (mm)** | **0.64** | **2.03** |

## REFFERENCE

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