Performance Analysis of 4-stroke SI Engine with HHO Generator by Morse Test

Prof. Mrs. Namrata V. Lotia[1], Zeeshan Jamal[2], Jafar Sadique[3], M. Mohsin Raza[4]

[1,2,3,4]*Anjuman college of Engg. and Technology, Rastrasant Tukdoji Maharaj Nagpur University, Maharashtra, India*

---***---

Abstract – *Earth today is facing the increasing cost of gasoline and other oil products. Automotive innovators and manufacturers are working to increase vehicle mileage while still meeting today's strict emissions and greater power requirements. An efficient way to increase the fuel economy and power of the engine is to add hydrogen to the air/fuel mixture in a conventional SI engine. In this work, the performance of an SI engine powered with petrol and HHO as fuel supplement was compared with only gasoline-fuelled engine using Morse Test. To study the effect we constructed a simple integrated HHO generation system and evaluated the effect of hydroxyl gas (HHO) addition, as an engine performance improver, into gasoline fuel on engine. HHO cell was designed, fabricated and for appropriate HHO gas productivity per input power. The performance was measured in terms of the engine torque (T), brake power (BP), thermal efficiency (η_{th}), brake specific fuel consumption (BSFC) by utilizing Morse Test Method*

The Hydroxyl gas (HHO) was produced by the process electrolysis using Potassium hydroxide (KOH) in a leak proof cylindrical chamber. Utilizing an on board integrated generation system of the gas reduces the risk of storage (hydrogen is highly inflammable and its leak is undetectable). At economy and higher engine speeds the HHO system with petrol fuel yields higher engine efficiency and reduced fuel consumption compared to pure petrol fuelled engine operation.

Key Words: Morse Test, 4-Storke SI Engine, HHO Generator, Heat Balance Sheet, Thermal and Mechanical Efficiency.

1. INTRODUCTION

There are different possible solutions for the problem of using fossil fuels, but most of them would require years of development and research. This method involves burning hydrogen gas along with hydrocarbon fuels in engine. Combustion of fossil fuels has caused serious problems to the environment and most adverse effect of combustion on environment by fossils fuel combustion are emission of NO_x, CO, CO_2, and unburned hydrocarbons which leads to ozone depletion.

Hydrogen has long been considered as a fuel entirely from the plethora of renewable resource water with some unique and desirable properties, for application as a fuel in engines. It is the only fuel that can be produced, through the expenditure of relatively much energy. Hydrogen combustion in oxygen produces only water. These attributes makes it an excellent fuel to significantly meet the increasing strict environmental controls of exhaust emissions from combustion engines, including the reduction of greenhouse gases that are emitted. The use of H_2 with conventional fuels offers reduction in exhaust gas emission and also opportunities of optimizing engine performance. The use of Hydrogen helps to reduce their use and hence prevent the depletion of these non-renewable fossil fuels.

The principle of this type of combustion is to add a proportion of hydrogen gas to the combustion reactions of spark ignition engines. The theory of this concept is that the addition of hydrogen as a supplement to the fuel can increase lean operation limit, improve the lean burn ability, and decrease burn duration. Thus the use of hydrogen in IC engines not only help in increasing the efficiency of it but also to reduce pollution and suppress the toxic gases like carbon monoxide, nitrous oxide emission etc..

1.1 MORSE TEST

The Indicated Power (IP) and the mechanical efficiency of a multi-cylinder SI engine is calculated by this method. During the test the engine is run at a constant speed (3000 rpm in our test) and at the same throttle opening. First the Brake Power (BP) of the engine with all cylinders operative is measured with the help of a dynamometer. Now, the Brake power of the engine is measured with each cylinder rendered in cut off position one by one by shorting the spark plug of that particular cylinder.

When any cylinder is cut off, the speed goes down. Before taking any reading, the initial speed must be restored by adjusting the load. Consider the case of a 4-cylinder engine. Let,

BP= Brake power of the engine with all cylinder in operation

BP_1= BP of the engine with cylinder no. 1 cut off

BP_2= BP of the engine with cylinder no. 2 cut off

BP_3= BP of the engine with cylinder no. 3 cut off

BP_4= BP of the engine with cylinder no. 4 cut off

IP_1, IP_2, IP_3 and IP_4 = IP of the engine 1, 2, 3, 4 cut off

FP_1 FP_2 FP_3 and FP_4 = Frictional power loss of cylinder 1, 2, 3, 4 respectively

Therefore when all cylinder are operative then,

$$BP = (IP_1 - FP_1) + (IP_2 - FP_2) + (IP_3 - FP_3) + (IP_4 - FP_4)$$

$$= (IP_1 + IP_2 + IP_3 + IP_4) - (FP_1 + FP_2 + FP_3 + FP_4)$$

When cylinder No.1 is cut off, it does not develop any power on the contrary; some power is lost due to friction between cylinder and piston. Then,

$$BP_1 = (IP_2 + IP_3 + IP_4) - (FP_1 + FP_2 + FP_3 + FP_4)$$

From the above equations, $BP - BP_1 = IP_1$

Similarly, $BP - BP_2 = IP_2$

$BP - BP_3 = IP_3$

and $BP - BP_4 = IP_4$

Therefore, total IP of the engine= $IP_1 + IP_2 + IP_3 + IP_4 = IP$ and mechanical efficiency is **BP/IP.** When the Morse test is carried out following precautions must be taken:

- The Brake Power(BP) should be measured as soon as possible after making cylinder cut off
- The dynamometer load should be adjusted to bring the speed to its constant value.

2. HHO GENERATOR

A HHO Generator is a device that uses the process of electrolysis to convert water into two moles of Hydrogen and one mole of Oxygen (HHO). This gas, also known as Brown's Gas, is a very cheap and clean, powerful fuel. Efficient HHO Generators are capable of using Distilled Water only, but most HHO Generators used an electrolyte, or catalyst in addition to the distilled water. The most easily available and cheap catalyst is potassium hydroxide KOH.

Water + KOH +Electric current = clean, cheap fuel

Through the simple process of running electric current through the water, the atoms 'split' back into their original elemental forms. This process is known as electrolysis. Electrical current runs through the water and all the Hydrogen atoms run towards the negatively charged electrode. Any HHO generator simply adds 'free' hydrogen and oxygen in a gaseous state to the combustion process. The mixture of this burns so hot, and so fast, it helps to COMPLETE the combustion process of the original gasoline.

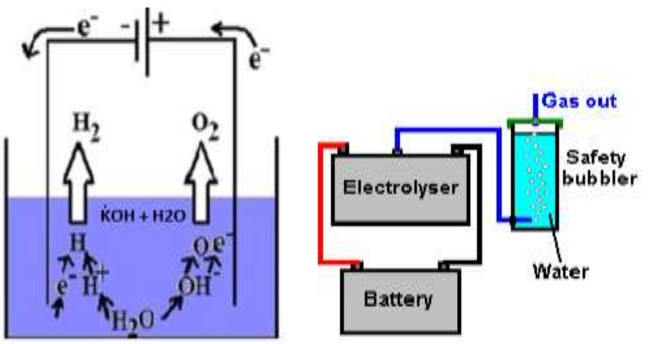

Fig 1: HHO Generator with bubbler arrangement

When water is introduced with electrical current/voltage it has a tendency to become excited and divides into its primary elements of Hydrogen and Oxygen. The produced Hydrogen and Oxygen are now in a gaseous state from the liquid water. It's been said by others that the two elements have been split apart from one another into their sub-diatomic molecular state.

The process is as follows, you start with water and Potassium Hydroxide. DC current is passed through the solution, the H_2O breaks into H_2 and O (we call it HHO). HHO is introduced into the engine by use of the engines vacuum. The HHO combines with the gasoline and air in the carburetor and is burnt in the combustion chamber. After combustion, it converts to H_2O.

Since, the hydrogen gas is highly inflammable, odorless and colorless, it becomes difficult to detect its leak. As a preventive measure, we installed a bubbler just after the electrolytic cell. The bubbler is filled with regular water and works as a shield between gas source and possibility of any spark from the engine, which may lead to any fire and explosion in the electrolytic cell. It also useful in controlling the amount of HHO gas to the engine. The actual HHO generator is shown in Fig 2.

Fig 2: Actual HHO generator

3. EXPERIMENTAL SETUP

The Experimental setup consists of a 4-Stroke four-Cylinder Maruti Esteem VXI Engine. The carburetor of the engine is connected with HHO intake hose pipe which comes directly from the electrolytic generator. Fuel is supplied from the petrol tank to a burette to measure the quantity of fuel supplied to the engine. The line diagram of the experimental Kit can be seen in fig 3.

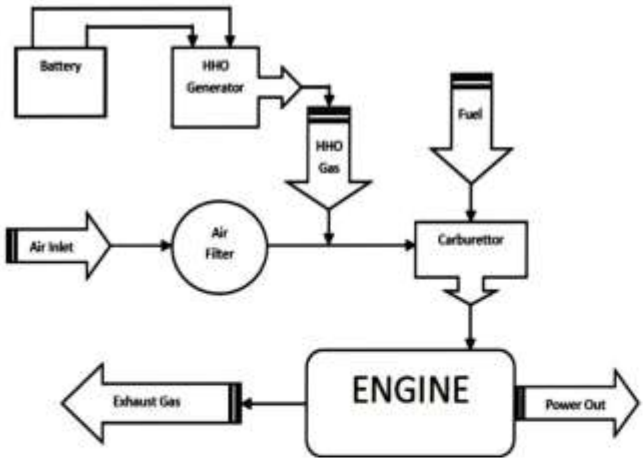

Fig 3: Line diagram of experimental setup

ENGINE SPECIFICATION:

Engine	: Maruti Esteem VXI
Type	: 4stroke, 4-Cylinder, SI Engine
Cubic Capacity	: 1298cc
Max Power	: 85bhp at 6000rpm
Max Torque	: 110Nm at 4500rpm

Rope brake dynamometer is used to measure the Torque of the engine. Two spring balances are attached to the rope at the tight side and one at the slack side and are tangential to brake drum. The speed is measured with the help of a Digital Tachometer. Readings are taken with and without HHO input to the engine and calculations are tabulated in the table

Fig 3: Actual experimental setup

4. OBSERVATION TABLE AND CALCULATIONS

The test was carried out in the Heat Engine Lab of Anjuman College of Engineering and Technology. The readings were tabulated with the conventional cycle (without HHO) as well as with the addition of HHO with Petrol. Rpm of the shaft was measured with the help of a digital Tachometer and the temperature at the inlet and outlet of cooling water and gases were measured with the help of Thermocouples. The dynamometer has the following dimensions;

Dynamometer drum radius (R_d) = 0.118m
Thickness of the rope (t) = 0.01m

Morse test Sample Calculations:

- **Torque(T) : $T = (W-S)\times 9.81\times(R_d + t\backslash 2)$**

a) Torque when all cylinders are working
$T = (133.3-44.2) \times 9.81 \times 0.123$
$T = 107.6$ Nm

b) Torque when 1st cylinder is cut off
$T_1 = (93.1-30.7) \times 9.81 \times 0.123$
$T_1 = 75.2$ Nm

c) Torque when 2nd cylinder is cut off
$T_2 = (92.4 - 28.7) \times 9.81 \times 0.123$
$T_2 = 76.7$ Nm

d) Torque when 3rd cylinder is cut off
$T_3 = (91.1 - 29.9) \times 9.81 \times 0.123$
$T_3 = 74.3$ Nm

e) Torque when 4th cylinder is cut off
$T_4 = (93.1 - 30.8) \times 9.81 \times 0.123$
$T_4 = 75.5$ Nm

- **Brake Power (BP) = $2\pi NT/60$**

Where; N=3000rpm

i) Brake power when all cylinders are operating
$BP = (2\pi\times3000\times107.6)/60$
BP = 33.8 Kw

ii) Brake power when 1st is cut off
$BP_1 = (2\pi\times3000\times75.2)/60$
$BP_1 = 23.6$ Kw

iii) Brake power when 2nd is cut off
$BP_2 = (2\pi\times3000\times76.7)/60$
$BP_2 = 24$ Kw

iv) Brake power when 3rd is cut off
$BP_3 = (2\pi\times3000\times74.3)/60$

BP_3= 23.3 Kw

v) Brake power when 4th is cut off

BP_4= (2π×3000×75.5)/60

BP_4= 23.7 Kw

- **Indicated Power (IP)**

Utilizing Morse Test for calculation of Indicated Power;

$IP_1 = BP - BP_1 = 33.8 - 23.6 = 10.2$ Kw

$IP_2 = BP – BP_2 = 33.8 – 24 = 9.8$ Kw

$IP_3 = BP – BP_3 = 33.8 – 23.3 = 10.5$ Kw

$IP_4 = BP – BP_4 = 33.8 – 23.7 = 10.1$ Kw

Therefore, the total Indicated power is given as

IP = $\mathbf{IP_1 + IP_2 + IP_3 + IP_4}$

IP = 10.2+9.8+10.5+10.1

IP = 40.6 Kw

Table: 1 Calculation table of BP and IP with conventional cycle (Only Petrol)

Petrol						
Sr. No	W (kg)	S (kg)	W-S (kg)	Torque (Nm)	BP (Kw)	IP (Kw)
1	133.3	44.2	89.2	107.6	33.8	40.6
2	93.1	30.7	62.4	75.2	23.6	10.2
3	92.4	28.7	63.7	76.7	24	9.8
4	91.3	29.9	61.4	74.3	23.3	10.5
5	93.1	30.8	62.3	75.5	23.7	10.1

- **Mechanical Efficiency (η_{mech})**

η_{mech} = B.P/I.P

=33.8/40.6

= 83.25%

- **Fuel Air Ratio (m_f/m_a)**

Fuel Air Ratio = m_f/m_a

Where;

$m_a = \rho_{air} \times C_d \times A_o \times (2 \times g \times h_m \times ((\rho_m/\rho_{air}) - 1))^{1/2}$

Where;

ρ_{air} = Density of Air (1.16Kg/m^3)

C_d = Co-efficient of discharge of orifice = 0.65

A_o = Area of Orifice = 1.539×10^{-3} m^2

h_m = Manomeric pressure head (0.03m)

ρ_m = Density of Manometric fluid

= 1000 Kg/m^3

Hence, ρ_m/ρ_{air} = 1000/1.16 = 862.06

Therefore,

$m_a = 1.16\times0.62\times1.539\times10^{-3}\times(2\times9.81\times0.03\times((862.06) - 1)^{1/2}$

$\mathbf{m_a = 25\times10^{-3}}$ **Kg/s**

$m_f = 10cc \times \rho_f/T_f$

Where;

ρ_f = Density of Fuel (0.78 Kg/m^3)

T_f = Time for 10cc Fuel Consumption = 3.65sec

$m_f = 0.01 \times 0.78/3.65$

$\mathbf{m_f = 2.14 \times 10^{-3}}$ **Kg/sec**

Hence;

Fuel Air Ratio = m_f/m_a

$\mathbf{m_f/m_a = 0.085}$

- **Thermal Efficiency**

$\eta_{th} = Power/(m_f \times C_v)$

Where C_v is the calorific value of fuel (48000 KJ/Kg)

$\eta_{th} = 33.8/(2.14 \times 10^{-3} \times 48000)$

$\mathbf{\eta_{th} = 32.8\%}$

- **Brake Specific Fuel Consumption(BSFC)**

BSFC = $m_f \times 3600$/BP

= $2.14 \times 10^{-3} \times 3600/33.7$

= **0.227 Kg/Kw-hr**

- **Heat Balance Sheet (Without HHO)**

The inlet temperature (t_1) and outlet temperature (t_2) of the cooling water is measured with the help of Thermocouple. Similarly t_3 and t_4 are the inlet and outlet temperature of the exhaust gases when all cylinders are in operating condition.

IP = 40.6 Kw

BP = 33.8 Kw

$m_f = 2.14 \times 10^{-3}$ Kg/sec

$m_a = 25\times10^{-3}$ Kg/s

I. **Heat Supply (Q_s) =** $m_f \times C_v$

= $2.14 \times 10^{-3} \times 48000$

= 102.72 Kw

II. **Heat Equivalent to BP**

= 33.8 Kw

III. **Heat Carried by Cooling Water**

= $m_w \times C_p \times (t_2-t_1)$

= $0.109 \times 4.187 \times (83.6-72.8)$

= 4.93 Kw

IV. Heat Carried by exhaust gases(Q_g)

$Q_g = m_g \times CP_g \times (t_4 - t_3)$

Where; $m_g = m_f + m_a$

$m_g = 2.14 \times 10^{-3} + 25\times10^{-3}$

$m_g = 0.027$ Kg/sec

Hence,

$Q_g = 0.027 \times 1.005 \times (184.8 - 32)$

= **4.14 Kw**

V. Un-accounted Heat Loss

$Q_a = Q_s -$ (Sum of losses)

= 102.72 – (33.8+4.93+4.14)

= **59.85 Kw**

HEAT BALANCE SHEET (Without HHO)

Table: 2 Heat Balance Sheet for petrol (Without HHO)

Energy Input			
Sr. no	Particular	Quantity (Kw)	%
1	Heat Supplied	102.7	100%
Energy Output			
Sr. no	Particular	Quantity (Kw)	%
1	Heat Equivalent to BP	33.8	32.91%
2	Heat Carried By Cooling Water	4.93	4.8%
3	Heat Carried By Exhaust gases	4.14	4.03%
4	Un-accounted heat losses	59.85	58.2%

Similarly the whole calculation can be obtained for the cycle with HHO as supplement. Below is the calculation table and heat balance sheet for the combustion cycle with HHO.

Table: 3 Calculation table of BP and IP with HHO as supplement

Petrol + HHO						
Sr. No	W (kg)	S (kg)	W-S (kg)	Torque (Nm)	BP (Kw)	IP (Kw)
1	147.8	48.2	99.6	120.1	37.7	45.4
2	100.9	31.8	69.1	83.3	26.1	11.6
3	100.1	30.4	69.7	84.1	26.4	11.3
4	101.1	31.2	69.9	84.3	26.4	11.3
5	100.7	30.7	70.0	84.4	26.5	11.2

➢ **Mechanical Efficiency (η_{mech})**

η_{mech} = B.P/I.P

= 37.7/45.4

= 83.04%

➢ **Fuel Air Ratio (m_f/m_a)**

$m_a = 1.16\times0.62\times1.539\times10^{-3}\times(2\times9.81\times0.03\times((862.06) - 1)^{1/2}$

$\mathbf{m_a = 25\times10^{-3}}$ **Kg/s**

$m_f = 10cc \times \rho_f/T_f$

Where; ρ_f = Density of Fuel (0.78 Kg/m^3)

T_f = Time for 10cc Fuel Consumption (4sec)

$m_f = 0.01 \times 0.78/4$

$\mathbf{m_f = 1.95 \times 10^{-3}}$ **Kg/sec**

Hence;

Fuel Air Ratio = m_f/m_a

$\mathbf{m_f/m_a = 0.0755}$

and $m_g = m_f + m_a$

$\mathbf{m_g = 26.95 \times 10^{-3}}$ **Kg/sec**

➢ **Brake Specific Fuel Consumption(BSFC)**

BSFC = $m_f \times 3600$/BP

= $1.195 \times 10^{-3} \times 3600/37.7$

= **0.186 Kg/Kw-h**

HEAT BALANCE SHEET (With HHO)

Table: 4 Heat Balance Sheet for petrol (With HHO)

Energy Input			
Sr. no	Particular	Quantity (Kw)	%
1	Heat Supplied	93.6	100%
Energy Output			
Sr. no	Particular	Quantity (Kw)	%
1	Heat Equivalent to BP	37.7	40.2
2	Heat Carried By Cooling Water	5.93	6.33
3	Heat Carried By Exhaust gases	4.29	4.5
4	Un-accounted heat losses	45.68	48.8

5. GAS ANALYSIS GRAPHS:

The following charts shows the emission of hydrocarbons and carbon monoxides against the Brake power of the engine. The emission of CO before and after addition of HHO to the fuel is shown in chart 1. It is clear that using a blend of HHO gas reduces the presence of carbon monoxide in the exhaust gas emitted. This is due to reduction in the gasoline consumption.

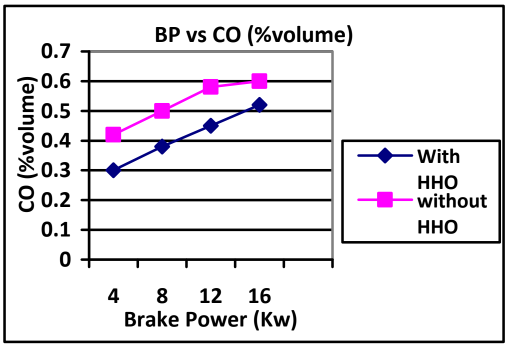

Chart: 1 Brake power vs CO

In Chart:2, it is clear that, the unburned hydrocarbons increases with the load. This increase in the hydrocarbons is due to the increase in introduction of fuel in the combustion chamber. Hence, more HC remains unburned and is emitted as exhaust. When HHO is added to the fuel as supplement enhances the fuel oxidation process and result in the complete combustion of the hydrocarbons in the fuel.

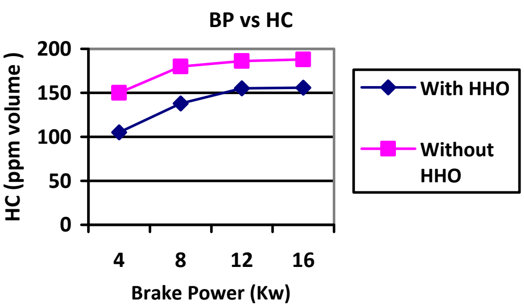

Chart: 2 Brake power vs HC

6. CONCLUSIONS:

The effect of adding proportionate amount of HHO mixture on the performance of the given 4-stroke four cylinder SI engine was evaluated. The following improvements in the parameters can be observed

- Complete combustion was achieved by adding the HHO to petrol leading to less emission of hydrocarbons and Carbon monoxides.
- The fuel consumption reduced by 8.87%
- The Thermal efficiency of the system decreased because of the increase input of heat due to addition of Hydrogen. The Mechanical efficiency however remained approximately same.
- The BSFC was also from 0.227 Kg/Kw-hr to 0.186 Kg/Kw-hr.

REFERENCES

[1] Suryakant Sharma, Deepak Bhardwaj and Vinay Kumar, “Effect on performance of engine by injecting hydrogen” International Journal of Mechanical Engineering and Robotics Research July 2013.

[2] Sebastian Verhelst, Thomas Wallner, “Hydrogenfueled internal combustion engines”, Progress in Energy and Combustion Science, Vol. 35 (2009), Page no. 490–527.

[3] A text book of ‘Internal Combustion Engines’ by V. Ganeshan, Tata McGraw Hill Education Private Limited .

[4] Ammar A. Al-Rouson, 2010. An International Journal on ‘Reduction of fuel consumption in gasoline engines by introducing HHO gas into intake manifold’, Published by Elsevier Ltd.

AUTHORS

Prof. Mrs. Namrata V. Lotia
Assistant Professor,
Anjuman College of Engineering and Technology, Nagpur, India. Nagpur University (RTMNU)

Zeeshan Jamal.
Student of B.E Anjuman College of Engineering and Technology, Nagpur, India. Nagpur University (RTMNU)

Jafar Sadique.
Student of B.E Anjuman College of Engineering and Technology, Nagpur, India. Nagpur University (RTMNU)

Mohammad Mohsin Raza.
Student of B.E Anjuman College of Engineering and Technology, Nagpur, India. Nagpur University (RTMNU)