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Effect of Hydroxy (HHO) gas addition on the air-fuel ratio, mileage and fuel consumption of a motorbike equipped with 4 stroke SI engine through theoretical calculations

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ABSTRACT

This research aims to compare the mileage and fuel consumption of a BAJAJ Pulsar 150 equipped with a 4 stroke SI Engine with and without the assistance of Hydroxy (HHO) gas through theoretical calculations and derive suitable conclusions. HHO gas consists or Hydrogen (H_2) and Oxygen (O_2) which are liberated during water electrolysis. The hydrogen gas produced by electrolysis of water is injected through a small opening in the engine intake manifold while the carburettor, fuel pipeline, and engine cylinder being unaltered. Topics from elementary Chemistry, Engineering Thermodynamics and IC Engines were used in the calculations. The specifications of SI Engine used in the Bajaj Pulsar 150 were also taken into account. The following results were obtained from the calculations when the engine was run with the aid of HHO gas: (a) 4.54% increase in mileage of the bike when operating the engine under maximum power condition. (b) 4.71% increase in mileage of the bike when operating the engine under maximum torque condition. (c) 74.2% decrease in fuel consumption, (d) No change in Air-Fuel(A/F) ratio

Keywords— *HHO, SI Engine, mileage, fuel consumption, Air-Fuel ratio, Electrolysis*

1. INTRODUCTION

1.1 Hydrogen as a fuel

As a potential fuel, hydrogen is appealing because it has a high energy density by weight. This results in a 38% efficiency for a combustion engine, compared to 30% when gasoline was used as a fuel. In addition, it provides an environmentally clean source of energy that does not release pollutants. However, there are several obstacles for the use of hydrogen as a fuel, including the purity requirement of hydrogen and difficulties that arise with its storage. Hydrogen production is a large and growing industry. Globally, 50 million metric tons of hydrogen (equivalent to 170 million tons of oil) were produced in 2004. There are two primary uses for hydrogen today. Half of the hydrogen produced is used to synthesize ammonia in the Haber process. The other half is used to convert heavy petroleum sources into lighter fractions which can be used as fuels. Currently, global hydrogen production is 48% from natural gas, 30% from oil, 18% from coal and 4% from water electrolysis.

1.2 Combustive Properties of Hydrogen

- Low Ignition Energy
- High Octane number
- High autoignition temperature
- High flame speed
- High Calorific value
- Low freezing point

1.3 Comparison of petrol and hydrogen

Table 1: Properties of petrol and hydrogen

Property	Petrol	Hydrogen
Molecular mass, [kg/kmol]	114	2.016
Theoretical air-fuel ratio, [kg/kg comb]	14.5	34.32
Density, at 0°C and 760 mmHg, [kg/m3]	0.735-0.760	0.0899

Flame velocity in air (λ=1), at 20 °C and 760 mm Hg [m/s]		0.12	2.37
Octane Number		90-98	>130
Min. ignition energy in air [mJ]		0.2-0.3	0.018
Autoignition temperature, [K]		753-823	848-853
Lower Calorific Value (gas at 0°C and 760mmHg)	stoichiometric fuel-air mixture [kJ/kg]	42690	119600

From Table 1.1 the Following observations can be made:

- Hydrogen's calorific value is 2.8 times larger than petrol which indicates that the energy produced by burning 1 kg of hydrogen is greater than petrol and hence can be more powerful fuel.
- Hydrogen's octane number and autoignition temperature are higher than petrol which leads to lower knocking tendency.
- Hydrogen requires less energy to ignite since its ignition energy is lower than petrol.

1.4 Electrolysis of water

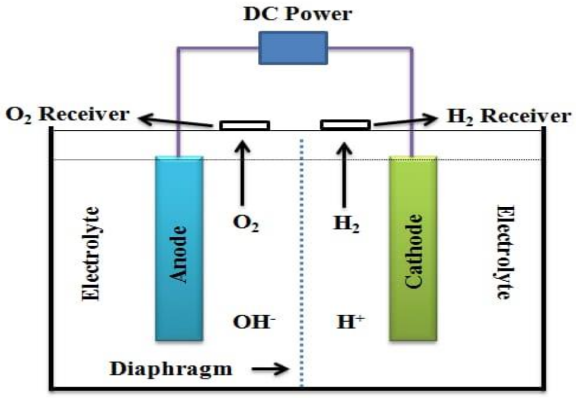

Fig. 1: Parts of the water electrolysis system (source: Google)

Water can be decomposed by passing an electric current through it. When this happens, the electrons from the electric current cause an oxidation-reduction reaction. At one electrode, called the cathode, electrons pass into the solution and cause a reduction. At the other electrode, called the anode, electrons leave the solution completing the circuit, and cause oxidation as shown in Figure 1. In order to carry out electrolysis, the solution must conduct an electric current. Pure water is a very poor conductor. To make the water conduct better we can add an electrolyte to the water. This introduces another problem though. Many electrolytes that we add electrolyze more easily than water. Sulphate ions do not electrolyze as easily as water, so sulphates are often used to enhance the conductivity of the water. At one of the electrodes, electrons (from a current source like a battery) are added to the water molecules (since electrons are added, this is the negative terminal of the battery). The following reduction takes place at the cathode, producing hydrogen gas.

$$2H_2O + 2e^- \longrightarrow H_2\,(g) + 2OH^- \qquad \text{Reduction = Cathode}$$

At the other electrode, electrons are removed from the water (so it is the positive end of the battery) and enter the electrode. This completes the circuit so current can flow. At this electrode, called the anode, water is oxidized:

$$H_2O \longrightarrow \tfrac{1}{2}\,O_2\,(g) + 2H^+ + 2e^- \qquad \text{Oxidation = Anode}$$

Since oxidation cannot occur without a reduction, these two reactions must occur at the same time. If we add them together and cancel out the similar terms, we will get the net overall reaction.

$$2H_2O + 2e^- \longrightarrow H_2\,(g) + 2OH^-$$
$$H_2O \longrightarrow \tfrac{1}{2}\,O_2\,(g) + 2H^+ + 2e^-$$
$$3H_2O + 2e^- \longrightarrow H_2 + \tfrac{1}{2}\,O_2\,(g) + 2H_2O + 2e^-$$

Which is the same as

$$H_2O \longrightarrow H_2 + \tfrac{1}{2}\,O_2\,(g)$$

2. THEORETICAL CALCULATIONS

The aim of this section is to determine the air-fuel ratio, mileage and fuel consumption theoretically. The engine specifications are given in table 2.

Table 2: Specifications of Bajaj Pulsar 150cc engine

Engine	4 Stroke, Single Cylinder, Air Cooled
Displacement	149.01 cc
Bore and Stroke	57mm X 56.4mm
Compression Ratio	9.5:1
Max. Power	14.09 PS (10.35 KW) @ 8500rpm
Max. Torque	12.76 Nm @ 6500rpm
Transmission	5 Speed, constant mesh
Clutch	Multiplate Wet
Ignition	CDI
Fuel Supply	Carburettor UCAL Mikuni BS29
Engine to drive wheel sprocket ratio	44:15

2.1 Determination of Air-Fuel ratio

We consider the following data from the specifications of the Pulsar 150 engine:

Given: 4 stroke
Bore D = 0.057 m
Stroke L = 0.0564 m
Compression ratio = 9.5
Max power = 10.35 KW @ 8500 rpm
Max torque = 12.76 Nm @ 6500 rpm

2.1.1 Without HHO gas: Considering petrol to consist of only octane (C_8H_{18}), the balanced combustion equation for the petrol and hydrogen mixture is as follows:

$$C_8H_{18} + 12.5O_2 \rightarrow 8CO_2 + 9H_2O$$

Mass of the reactants: C_8H_{18} = 114g

O_2 = 400g

We know that 100g air contains 23g of O_2 by mass

Therefore 400g of O_2 is contained in $\frac{100}{23} \times 400 = 1739.13$g of air.

Therefore air-fuel ratio A/F is $\frac{1739.13}{114} = 15.25$

2.1.2 With HHO gas: Considering petrol to consist of only octane (C_8H_{18}), the balanced combustion equation for the petrol and hydrogen mixture is as follows:

$$C_8H_{18} + 13.5O_2 + 2H_2 \rightarrow 8CO_2 + 11H_2O$$

Mass of the reactants: C_8H_{18} = 114g
O_2 = 432g
H_2 = 4g

The balanced chemical equation for water electrolysis is

$$2H_2O \rightarrow 2H_2 + O_2$$

Mass of the products: H_2 = 4g
O_2 = 32g

Since 32g of O_2 is supplied by the HHO gas, the net requirement of O_2 from the atmosphere is 432g – 32g = 400g

We know that 100g air contains 23g of O_2 by mass

Therefore, 400g of O_2 is contained in $\frac{100}{23} \times 400 = 1739.13$g of air.

Therefore, air-fuel ratio A/F is $\frac{1739.13}{114} = 15.25$

Hence there is no change in air-fuel ratio for both cases.

2.2 Determination of mass flow rate of Hydrogen, fuel consumption and distance traveled per litre of petrol (mileage)

Assuming volumetric efficiency of the engine to be 100%, we calculate the mass flow rate of H_2 and mileage for two different operating conditions of the engine.

2.2.1 For Maximum power of 10.35 KW @ 8500 rpm

(i) Without HHO Generator

$$\text{Volumetric flow rate } Q = \frac{\pi}{4} \times D^2 \times L \times \frac{N}{60} \times k \qquad (3.1)$$

Where D = Bore (m)
L = Stroke length (m)
N = Engine speed (rpm)
K = 1 for 2 stroke engine

And 0.5 for 4 stroke engine

Substituting the values in (3.1) we get

$$Q = \frac{\pi}{4} \times 0.057^2 \times 0.0564 \times \frac{8500}{60} \times 0.5$$

$$Q = 0.0102 \text{ m}^3/\text{s}$$

Assuming that temperature T = 303K and pressure P = 101.3 KPa

$$\text{The specific volume of air} \quad \vartheta_a = \frac{RT}{P} \qquad (3.2)$$

Where R = characteristic gas constant

$$\vartheta_a = \frac{0.287 \times 303}{101.3}$$

$$= 0.86 \text{ m}^3/\text{kg}$$

From reference [1] we have specific volume of petrol (C_8H_{18})

$$\vartheta_f = 0.27 \text{ m}^3/\text{kg}$$

Applying conservation of mass to the control volume at intake manifold junction as shown in figure 2 we have

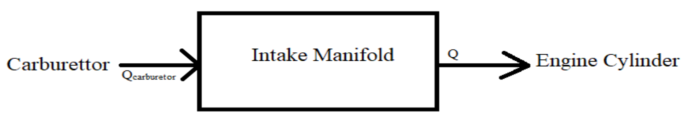

Fig. 2: Control volume at intake manifold junction

$$Q_{carburetor} + Q_{HHO\ generator} = Q \quad (3.3)$$

$$Q = m \times \vartheta \quad (3.4)$$

Where m = mass flow rate (kg/s) and ϑ = specific volume (m^3/kg)

Since HHO generator is absent → $Q_{HHO\ generator} = 0$

$$m_a \vartheta_a + m_f \vartheta_f = 0.0102$$

$$m_f [(m_a/m_f) \times \vartheta_a + \vartheta_f] = 0.0102$$

$$m_f [15.25(0.86) + 0.27] = 0.0102$$

$$\mathbf{m_f = 0.76\ g/s}$$

Density of octane (C_8H_{18}) = 0.69 kg/L, which means mass of 1L of C_8H_{18} is 690g.

Time required to consume 690g $C_8H_{18} = \frac{690}{0.76}$ = 907.9 s = 15.13 min

No. of rotations of crankshaft for 15.13 min = N×15.13
= 8500×15.13
= 128605 rotations

No. of rotations of the drive wheel for 15.13 min = crankshaft rotations × sprocket ratio
= 128605 × 15/44
= 43842.6 rotations

Diameter of Bajaj pulsar 150 wheel 'd' = 0.432 m

Distance covered by the bike = Rotations of drive ×π×d (3.5)
= 43842.6×π×0.432
= 59501.8 m
= **59.5 km/L of petrol**

(ii) With HHO gas

$$\text{Volumetric flow rate } Q = \frac{\pi}{4} \times D^2 \times L \times \frac{N}{60} \times k$$

Where D = Bore (m)
L = Stroke length (m)
N = Engine speed (rpm)
K = 1 for 2 stroke engine
And 0.5 for 4 stroke engine

Substituting the values in (.1) we get

$$Q = \frac{\pi}{4} \times 0.057^2 \times 0.0564 \times \frac{8500}{60} \times 0.5$$

$$Q = 0.0102\ m^3/s$$

Assuming that temperature T = 303K and pressure P = 101.3 KPa

$$\text{The specific volume of air} \quad \vartheta_a = \frac{RT}{P}$$

Where R = characteristic gas constant

$$\vartheta_a = \frac{0.287 \times 303}{101.3}$$

$$= 0.86\ m^3/kg$$

Similarly specific volume of H_2,

$$\vartheta_H = \frac{4.157 \times 303}{101.3}$$

$$= 12.435\ m^3/kg$$

Similarly specific volume of O_2,

$$\vartheta_O = \frac{0.26 \times 303}{101.3}$$

$$= 0.777\ m^3/kg$$

From reference [1] we have specific volume of petrol (C_8H_{18}) ϑ_f = 0.27 m^3/kg

Applying conservation of mass to the control volume at the HHO generator and intake manifold junction as shown in Fig 3.2 we have

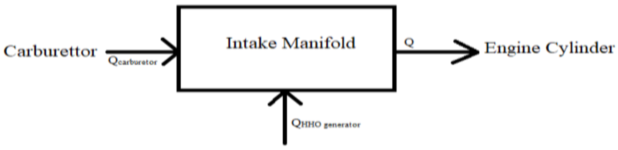

Fig. 3: Control volume of intake manifold junction with HHO generator

$$Q_{carburetor} + Q_{HHO\ gas} = Q$$

$$m_a \vartheta_a + m_f \vartheta_f + m_o \vartheta_O + m_h \vartheta_H = 0.0102$$

$$m_h \left[\frac{1739.13*0.86}{4} + \frac{114*0.27}{4} + \frac{32*0.777}{4} + 12.435\right] = 0.0102$$

$$\mathbf{m_h = 2.55x10^{-5}\ kg/s}$$

$$m_o = (m_o/m_h) \times m_h$$

$$m_o = 2.04 \times 10^{-4}\ kg/s$$

$$m_f = (m_f/m_h) \times m_h$$

$$\mathbf{m_f = 0.196\ g/s}$$

$$m_{hho} = m_o + m_h$$

$$m_{hho} = (0.255 + 2.04) \times 10^{-4}$$

$$m_{hho} = 2.295\times10^{-4}\ kg/s$$

$$\text{Time consumed to utilize 36g } H_2O \text{ from HHO generator} = \frac{\text{Mass of water}}{\text{Mass flow rate of HHO}} \quad (6.6)$$

$$= \frac{0.036}{0.0002295}$$

$$= 156.86\ s$$

$$\text{Mass of water} = \rho_{water} \times \text{volume} \quad (6.7)$$

$$\text{Mass of 1L of water} = 1g/ml \times 1000ml$$

$$= 1000g$$

$$\text{Time consumed to utilize 1000g } H_2O \text{ from HHO generator} = \frac{156.86\times1000}{36}$$

$$= 4357.3\ s$$

$$= 1hr\ 12min/L \text{ of water}$$

Density of octane (C_8H_{18}) = 0.69 kg/L, which means mass of 1L of C_8H_{18} is 690g.
Referring to the combustion equation we have
114g of C_8H_{18} requires 36g of H_2O
Therefore 690g of C_8H_{18} requires $\frac{36}{114} \times 690 = 217.9$g of H_2O
Time required to consume 217.9g H_2O from HHO generator = $\frac{0.2179}{0.0002295} = 949.45$ s
= 15.82 min

No. of rotations of crankshaft for 15.82 min = N×15.82
= 8500×15.82
= 134470 rotations

No. of rotations of the drive wheel for 15.82 min = crankshaft rotations × sprocket ratio
= 134470 × 15/44
= 45842.04 rotations

Diameter of Bajaj pulsar 150 wheel 'd' = 0.432 m

Distance covered by the bike = Rotations of drive wheel×π×d
= 45842.04×π×0.432
= 62215.36 m
= 62.2 km/L of petrol

Therefore, percentage increase in distance per litre petrol (mileage) = $\frac{62.2-59.5}{59.5}\times100\%$
= **4.54%**

2.2.2 For Maximum torque of 12.76 Nm @ 6500 rpm

(i) Without HHO Generator

$$\text{Volumetric flow rate } Q = \frac{\pi}{4}\times D^2\times L\times\frac{N}{60}\times k$$

$$Q = \frac{\pi}{4} \times 0.057^2 \times \frac{0.0564}{2*60}\times6500$$

$$Q = 7.8\times10^{-3}\ m^3/s$$

Applying conservation of mass to the control volume at the HHO generator and intake manifold junction we have

$$Q_{carburetor} + Q_{HHO\ generator} = Q$$

Since HHO generator is absent → $Q_{HHO\ generator} = 0$

$$m_a\,\vartheta_a + m_f\,\vartheta_f = 7.8\times10^{-3}\ m^3/s$$

$$m_f\,[15.25(0.86) + 0.27] = 0.0078\ m^3/s$$

$$\mathbf{m_f = 0.582\ g/s}$$

Density of octane (C_8H_{18}) = 0.69 kg/L, which means mass of 1L of C_8H_{18} is 690g.
Time required to consume 690g $C_8H_{18} = \frac{690}{0.582} = 1185.56$ s = 19.76 min
No. of rotations of crankshaft for 19.76 min = N×19.76
= 6500×19.76
= 128440 rotations
No. of rotations of the drive wheel for 19.76 min = crankshaft rotations × sprocket ratio
= 128440 × 15/44
= 43786.4 rotations
Diameter of Bajaj pulsar 150 wheel 'd' = 0.432 m
Distance covered by the bike = Rotations of drive wheel×π×d
= 43786.4×π×0.432
= 59425.5 m
= 59.4 km/L of petrol

(ii) With HHO Generator

$$\text{Volumetric flow rate } Q = \frac{\pi}{4}\times D^2\times L\times\frac{N}{60}\times k$$

$$Q = \frac{\pi}{4} \times 0.057^2 \times \frac{0.0564}{2*60}\times6500$$

$$Q = 7.8\times10^{-3}\ m^3/s$$

Applying conservation of mass to the control volume at the HHO generator and intake manifold junction we have

$$Q_{carburetor} + Q_{HHO\ generator} = Q$$

$$m_a \vartheta_a + m_f \vartheta_f + m_o \vartheta_O + m_h \vartheta_H = 7.8\times10^{-3}\ m^3/s$$

$$m_h \left[\frac{1739.13*0.86}{4} + \frac{114*0.27}{4} + \frac{32*0.777}{4} + 12.435\right] = 0.0078$$

$$\mathbf{m_h = 1.95\times10^{-5}\ kg/s}$$

$$m_o = (m_o/m_h) \times m_h$$

$$m_o = 1.56\times10^{-4}\ kg/s$$

$$m_f = (m_f/m_h) \times m_h$$

$$\mathbf{m_f = 0.15\ g/s}$$

$$m_{hho} = m_o + m_h$$

$$m_{hho} = (0.195 + 1.56) \times10^{-4}$$

$$m_{hho} = 1.754\times10^{-4}\ kg/s$$

Time consumed to utilize 36g H_2O from HHO generator $= \frac{\text{Mass of water}}{\text{Mass flow rate of HHO}}$

$$= \frac{0.036}{0.0001754}$$

$$= 205.246\ s$$

$$\text{Mass of water} = \rho_{water} \times \text{volume}$$

$$\text{Mass of 1L of water} = 1g/ml \times 1000ml$$

$$= 1000g$$

Time consumed to utilize 1000g H_2O from HHO generator $= \frac{205.246*1000}{36}$

$$= 5701.277\ s$$

= 1hr 35min/L of water

Density of octane (C_8H_{18}) = 0.69 kg/L, which means mass of 1L of C_8H_{18} is 690g.
Referring to the combustion equation we have
114g of C_8H_{18} requires 36g of H_2O
Therefore 690g of C_8H_{18} requires $\frac{36}{114} \times 690 = 217.9$g of H_2O

Time required to consume 217.9g H_2O from HHO generator $= \frac{0.2179}{0.0001754}$

$$= 1242.3s = 20.7\ min$$

No. of rotations of crankshaft for 20.7 min = N×20.7

= 6500×20.7

= 134550 rotations

No. of rotations of the drive wheel for 20.7 min = crankshaft rotations × sprocket ratio

= 134550 × 15/44

= 45869.3 rotations

Diameter of Bajaj pulsar 150 wheel 'd' = 0.432 m

Distance covered by the bike = Rotations of drive wheel×π×d

= 45869.3×π×0.432

= 62252.4 m

= 62.2 km/L of petrol

Percentage increase in distance travelled per litre of petrol (mileage) $= \frac{62.2-59.4}{59.4}\times100\%$

= 4.71%

3. RESULTS

The calculated values are tabulated in table 3 and 4 on the next page.

Table 3: Calculated values of A/F ratio, H_2 flow rate and mileage

Condition	Air-fuel ratio	Mass flow rate of H_2 (kg/s)	Mileage (km/L)		% increase in Mileage
			Without HHO kit	With HHO kit	
Maximum Power Of 10.35 kW @ 8500 rpm	15.25	2.55×10^{-5}	59.5	62.2	4.54
Maximum Torque of 12.76 Nm @ 6500 rpm	15.25	1.95×10^{-5}	59.4	62.2	4.71

Table 4: Calculated values of fuel consumption

Condition	Fuel consumption, m_f (g/s)		% decrease in Fuel consumption
	Without HHO kit	With HHO kit	
Maximum Power Of 10.35 kW @ 8500 rpm	0.76	0.196	74.2
Maximum Torque of 12.76 Nm @ 6500 rpm	0.582	0.15	74.2

Since there is an increase in the mileage and decrease in fuel consumption of the engine when equipped with HHO generator for both the cases of maximum power and maximum torque, hence it is proved theoretically that the HHO kit increases the mileage and decreases the petrol consumption of the engine.

4. CONCLUSION

We observe from the calculations that the addition of H_2 and O_2 gas from the HHO generator does improve the mileage and fuel consumption of the SI engine.

Based on theoretical calculations it was proved that there would be 4.54% increase and 4.71% increase in the mileage of the engine operated under maximum power and maximum torque conditions respectively. It was calculated that there would be a 74.2% decrease in petrol fuel consumption for both the conditions whereas the air-fuel ratio remained the same.

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