Effect of Hydroxy (HHO) Gas Addition on Performance and Exhaust Emissions in Spark Ignition (SI) Engine

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Abstact- In this study, hydroxy gas (HHO) was produced by the electrolysis process of different electrolytes (KOH(aq), NaOH(aq), NaCl(aq)) with various electrode designs in a leak proof plexiglass reactor (hydrogen generator). Hydroxy gas was used as a supplementary fuel in a four cylinder, four stroke, compression ignition (CI) engine without any modification and without need for storage tanks. Its effects on exhaust emissions and engine performance characteristics were investigated. Experiments showed that constant HHO flow rate at low engine speeds (under the critical speed of 1750 rpm for this experimental study), turned advantages of HHO system into disadvantages for engine torque, carbon monoxide (CO), hydrocarbon (HC) emissions and specific fuel consumption (SFC). Investigations demonstrated that HHO flow rate had to be diminished in relation to engine speed below 1500 rpm due to the long opening time of intake manifolds at low speeds. This caused excessive volume occupation of hydroxy in cylinders which prevented correct air to be taken into the combustion chambers and consequently, decreased volumetric efficiency was inevitable. Decreased volumetric efficiency influenced combustion efficiency which had negative effects on engine torque and exhaust emissions. Therefore, a hydroxy electronic control unit (HECU) was designed and manufactured to decrease HHO flow rate by decreasing voltage and current automatically by programming the data logger to compensate disadvantages of HHO gas on SFC, engine torque and exhaust emissions under engine speed of 1750 rpm. The flow rate of HHO gas was measured by using various amounts of KOH, NaOH, NaCl (catalysts).

These catalysts were added into the water to diminish hydrogen and oxygen bonds and NaOH was specified as the most appropriate catalyst. It was observed that if the molality of NaOH in solution exceeded 1% by mass, electrical current supplied from the battery increased dramatically due to the too much reduction of electrical resistance. HHO system addition to the engine without any modification resulted in increasing engine torque output by an average of 19.1%, reducing CO emissions by an average of 13.5%, HC emissions by an average of 5% and SFC by an average of 14%.

Keywords-- *Renewable Energy Resources, Fuel Cell, SI Engine, Combustion.*

I. NEED OF ALTERNATIVE FUEL

Global increasing consumption of fossil fuel is primary reason for search for alternative fuel. Reserve of fossil fuel is limited. Price of the petroleum has been increasing over span of time. Hence in past efforts have been taken to improve fuel efficiency were limited by the increased use of heavy vehicles such as sport utility vehicles and light trucks for personal use. On the other hand, fossil fuel combustion releases large amounts of greenhouse gases, the most significant being carbon dioxide. Greenhouse gases trap heat in the earth's atmosphere. Increased concentrations of carbon dioxide in the atmosphere contribute to global warming, which has been receiving world-wide attention as a significant environmental problem. This problem allows researchers and scientist community to seek interest in search of alternate fuel. HHO can be additive to the SI engine. Problem can be raised on production, storage and utilization.

II. ABOUT HHO OR HYDROXY

Basically HHO is a mixture of 2/3 of hydrogen and 1/3 of oxygen bonded together molecularly and some water vapour . It is generally produced by dissociation of water [1]. When electric current passed through water, it divides into hydrogen and oxygen. The hydrogen and oxygen rise from the liquid water as gas. This gas is called HHO Gas or Brown gas. At the instant that the water splits, the hydrogen and oxygen are in their mono-atomic state, this is H for hydrogen and O for oxygen. Normal electrolyzers encourage the hydrogen and oxygen to drop to their di-atomic state. The di-atomic state is a lower energy state, the energy difference shows up as heat in the electrolyzer. This energy is now available to the flame. HHO gas is odorless, colorless and lighter than air. The HHO gas is highly flammable due to presence of hydrogen much more than gasoline. The Oxy-hydrogen explosion is so quick that it fills the combustion chamber at 3 times faster than gasoline explosion. At one atom. Pressure auto ignition of hydroxy occurs at about 570^0. Hydroxy gas has very high diffusivity. This ability allows to disperse in the air is considerably greater than gasoline. At normal temperature and pressure hydroxy gas can burn when it is between about 4% to 94% hydrogen by volume. Oxy-hydrogen is 0.535 kg/m³ this results in a storage problem. When ignited, the gas converts to water vapors and release energy of about 241.38 KJ of energy (LHV) for every mole of H_2 burned.

III. EXPERIMENTATION PROCEDURE

The main pollutants from the conventional hydrocarbon fuels are unburned/partially burned hydrocarbon (UBHC), CO, oxides of nitrogen (NOx), smoke and particulate matter. It is very important to reduce exhaust emissions and to improve thermal efficiency. The higher thermal efficiency of gasoline engines certainly has advantages for conserving energy and also solving the greenhouse problem. Among all fuels, hydrogen is a long term renewable, recyclable and non-polluting fuel. Hydrogen has some peculiar features compared to hydrocarbon fuels, the most significant being the absence of carbon. Very high burning velocity yields very rapid combustion and the wide flammability limit of hydrogen varies from an equivalence ratio (f) of 0.1e7.1, hence the engine can be operated with a wide range of air/fuel ratio. The properties of hydrogen are given in Table 1 [1]. Due to the low ignition energy and wide flammable range of hydrogen, hydrogen engines are quite suitable to run at lean conditions which are helpful for the enhanced engine economic and emissions performance [2,3]. All regulated pollutant emissions, except nitrogen oxides, can be simply reduced by using a carbon-free fuel. This is true whatever the alternative fuel source if the production of this carbon-free fuel in large plants is more efficient and therefore produces less CO_2 than the direct conversion of the fuel source into mechanical power in the internal combustion engine. The combination of its molecular composition and some of its peculiar properties (high laminar flame speed, wide flammability

range, etc.) reveals hydrogen as an attractive fuel for ICEs [4]. Besides, compared with traditional fossil fuels, hydrogen is a carbonless fuel whose combustion doesn't generate emissions such as HC, CO and CO_2 [5]. The concept of using hydrogen as an alternative fuel for gasoline 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 gasoline engines [1]. There are several reasons for applying hydrogen as an additional fuel to accompany gasoline fuel in CI engine. Firstly, it increases the H/C ratio of the entire fuel. Secondly, injecting small amounts of hydrogen to a gasoline engine could decrease heterogeneity of a gasoline fuel spray due to the high diffusivity of hydrogen which makes the combustible mixture better premixed with air and more uniform. It could also reduce the combustion duration due to hydrogen's high speed of flame

propagation in relation to other fuels [6]. Throughout history, there have been many studies regarding hydrogen as a fuel in ICEs. First, Reverend Cecil in England planned to use hydrogen as fuel in 1820. Bursanti and Matteucci in Italy improved the hydrogen engine with a free piston in 1854. Rudolf Erren conducted studies with the hydrogen engine in Germany in 1920. Ricardo achieved high efficiency when working with hydrogen in an engine in 1924 [7]. In 1992, as a result of the Second World Renewable Energy Congress held in Reading, the world renewable energy network (WREN) has been formed. The first author of this paper is the founder member of WREN. This network is dedicated to promoting renewable energy throughout the world [8]. Also, there have been many investigations on hydrogen-enriched fuel operation in ICEs. Saravanan and Nagarajan [9] experimentally investigated the hydrogen enriched air induction in a gasoline engine system. The test results showed that an efficiency of 27.9% was achieved without knocking over the entire load range with 30% hydrogen enrichment. Also, they observed that specific fuel consumption decreased with increase in hydrogen percentage over the entire range of operation. Saravanan et al. [10] did an experimental investigation on hydrogen as a dual fuel for gasoline engine system with exhaust gas recirculation (EGR) technique. The test results demonstrated that the SFC decreased without EGR with 20 L/min of hydrogen flow and they concluded that the reason for reduction in SFC is due to the operation of hydrogen fueled engine under lean burn conditions. Masood et al. [11] studied on experimental verification of computational combustion and emission analysis of hydrogenegasoline blends and the test results showed that the hydrogen gasoline co-fueling solved the drawback of lean operation of hydrocarbon fuels such as gasoline, which were hard to ignite and resulted in reduced power output, by reducing misfires, improving emissions, performance and fuel economy. Saravanan and Nagarajan [12] studied on an experimental investigation on optimized manifold injection in a direct-injection gasoline engine with various hydrogen flow rates.

Table 1: Physical properties of hydrogen and gasoline

Property	Hydrogen	Gasoline
Densityat1atm.and300K(kg /m^3)	0.082	5.11
Stoichiometry Compositionin air (% by	29.53	1.65
Number of molesafter combustion to before	0.85	1.058
LHV(MJ/kg)	119.7	44.79
Combustion energy per kg of Stoichiometry mixture	3.37	2.79

Table 2: Engine specification

Manufacture	**FIAT**
No. of cylinders	4
Bore	80.5mm
Stroke	78.4mm
Brake Horse Power	98.63 bhp @5500 rpm
Compression ratio	9.5:1
Torque	14.1 kg-m
Cooling	Water cooling
Fuel injection	Carburetor
Fuel tank capacity	10 L

Figure 1: General View of Engine

IV. RESULT AND DISSCUTION

Description of the experimental rig and measurements techniques as follows

A four cylinder, air cooled spark ignition engine is used for testing purpose. The motor specification is shown in table above. A constant load test and variable speed (1500 rpm) has been performed on this motor. A gas analyzer has been used to estimate the concentrations of NOX, HC, CO, CO_2, and O_2 in the exhaust stream. Tachometer was used to measure the engine speed.

V. HHO INJECTION INSIDE ENGINE SYSTEM

Adding HHO gas to the fuel/air mixture has the immediate effect of increasing the octane rating of any fuel. ''Octane Rating'' means how much that fuel can be compressed before it ignites. More efficient combustion translates to less fuel being consumed. An earlier study by Al Rousan demonstrates the enhancements associated with the use of a blend of HHO gas on both the break efficiency and fuel consumption.

VI. EMISSION PARAMETERS

The effect of adding HHO gas to the air/fuel mixture on the carbon monoxide concentration is presented in fig. Using a blend of HHO gas reduces significantly the presence of carbon monoxide in the exhaust. CO has to do with the efficiency of the combustion in the engine and also is highly affected by the fuel to air ratio of the engine. It has been shown that introducing HHO gas to the combustion enhances the combustion efficiency and enhancement in thermal efficiency and specific fuel consumption will be evident. HHO is extremely efficient in terms of fuel configuration; its hydrogen and oxygen exist as tiny independent clusters of no more than two atoms per combustible unit. Comparatively, a gasoline droplet consist many thousands of large hydrocarbon molecules. This diatomic configuration of HHO gas (H2, O2) results in efficient combustion because the hydrogen and oxygen atoms interact directly without any ignition propagation delays due to surface travel time of the reaction. On ignition, its flame front flashes through the cylinder at a much higher velocity than in ordinary gasoline/air combustion . The heat and pressure wave HHO generates crushes and fragments the gasoline droplets, exposing fuel from their interior to oxygen and the combustion reaction. This effectively enriches the air/fuel ratio since more fuel is now available to burn. Simultaneously, the HHO flame front ignites the crushed fragments thereby releasing more of their energy, more quickly. Fig. shows the reduction in nitrogen oxide emission due to the existence of HHO in the combustion chamber. As well as shows the reduction in NOX concentration in exhaust. High NOX emission is usually noticed with highly heated and compressed air that has nitrogen in it. Adding HHO to gasoline increases the octane ratting. This fact causes the gasoline to ignite before TDC (Top Dead Center, the point where the piston is at thehighest point of its motion), making it less efficient because the explosion of gas fumes pushes the piston down and out of sequence (it is too early so it goes a bit in reverse) and therefore the ‘‘pinging’’ noise and less power from regular gasoline. Brown’s gas or water vapor causes regular low-grade fuel to ignite more slowly, making it perform like a high octane gasoline. A higher octane rating means stronger horse power due to combustion occurring much closer to TDC, where it has a chance to turn into mechanical torque (rotary push) the right way and without pinging. Each piston transfers more energy during its combustion cycle, so combustion becomes more efficient as well as. More efficient combustion translates to less fuel being consumed. The variation of oxygen concentration and carbon dioxide concentration in the exhaust with engine speed is presented in given figs. One can notice that the result shows two segments. The first is up to 1900 rpm engine speed, oxygen presence increased by about 20% when HHO gas has been introduced to the system, whereas carbon dioxide is reduced by 40%. The second segment shows no significant difference in either oxygen or carbon dioxide concentrations. This is related to the time available to combustion reactions to take place; higher engine speed is directly related to shorter combustion time.

HC’s are usually the worst problem for vehicle engines. HC which refers to hydrocarbons, are simply another term for unburned fuel that makes it way through the engine and out the exhaust.The variation of hydrocarbon concentration with engine speed is shown in Fig. 9. One can notice that HC concentration in the exhaust is reversely related to the engine speed. This is due to an increase in turbulence intensity mixing process of burnt and unburnt gases which increases oxidation rate of HC. Also a reduction in HC concentration in the exhaust as a result of introducing HHO is noticed. This reduction in HC emission is increased with engine speed. At 2300 rpm engine speed, Fig. 9 reveals a reduction in HC concentration to about 40% due to thepresence of HHO in the fuel mixture. Fig. 10 shows the variation of exhaust gas temperature with engine speed. The exhaust gas temperature is almost directly related to the engine speed. Introducing HHO to the intake manifold reduces the exhaust gas temperature. This leads to lower NOX emissions as shown in Figs. 5 and 6. The variation of k (A/Ftheoretical/ A/Factual) with engine speed is shown in Fig. 11. The results reveals that introducing HHO gas shifts the curve downward, since it enhances the combustion characteristics and consequently reduces the fuel consumption at any speed.

CONCLUSION

Experimental tests to investigate the effect of HHO gas on the emission parameters of a four stroke four cylinder engine have been carried out. HHO gas has been generated by an electrolysis process in a Plexiglas box (fuel cell). The generated gas is mixed with a fresh air just before entering the carburettor. The exhaust is sampled by a gas analyser and the exhaust constituents have been identified and their concentrations have been evaluated.

The following conclusions can be drawn.

1. HHO cell may be integrated easily with existing engine systems.
2. The combustion efficiency has been enhanced when HHO gas has been introduced to the air/fuel mixture, consequently reducing fuel consumption.
3. The concentration of nitrogen oxide has been reduced to almost 50% on average when HHO is introduced to the system.
4. When HHO is introduced to the system, the average concentration of carbon monoxide has been reduced to almost 20% of the case where air/fuel mixture was used (no HHO).
5. The NOX average concentration has been reduced to about 54% of the case where HHO was not introduced.
6. HC concentration is highly affected by the engine speed and the presence of HHO gas.

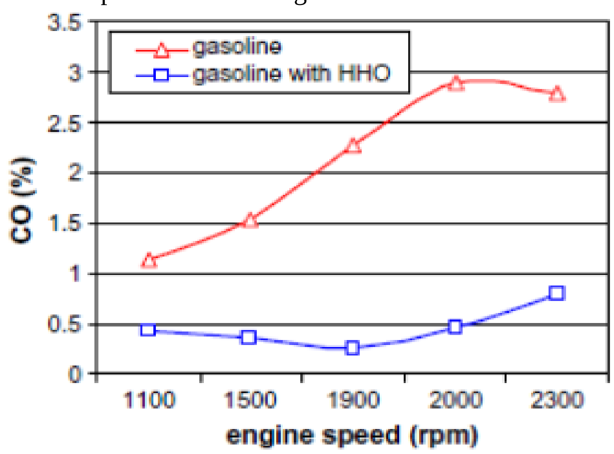

Figure 2: Engine speed vs CO

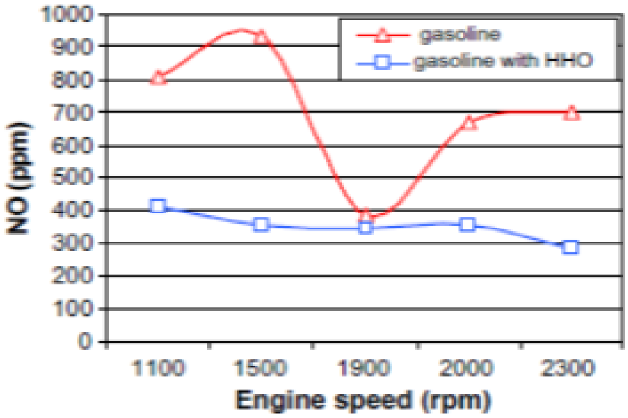

Figure 3: NO Vs Engine Speed

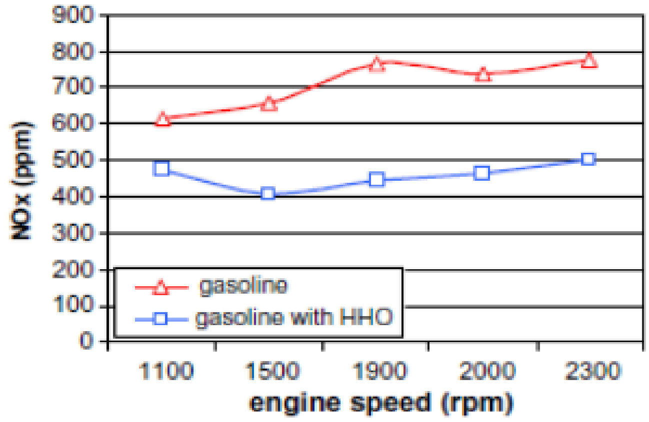

Figure 4: NOx Vs Engine speed

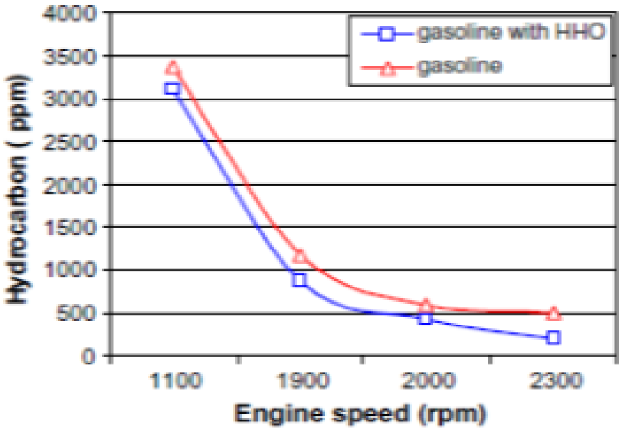

Figure 5: HC Vs Engine Speed

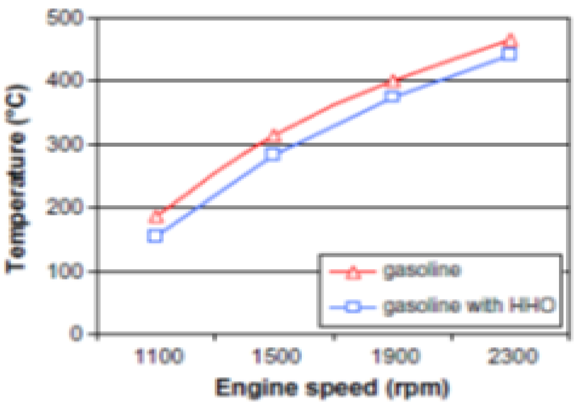

Figure 6: Temp Vs Engine Speed

References

[1] A.M. Falahat, M.A.Hamdan, J.A.Yamin, "Engine Performance Powered by a Mixture of Hydrogen and oxygen fuel obtained by water Electrolysis".International Journal of Automotive Technology,Vol.15 No.1,pp.97-101(2014).

[2] A.Vamshi Krishna Reddy, T.Sharath Kumar, D.K. Tharun Kumar, B. Dinesh, Y.V.S. Saisantosh "Improving the efficiency of IC engine Using Secondary Fuel " .International journal of technology enhancements and emerging engineering research, vol 2, issue 652 , 2347-4289

[3] Tuan Le Anh, Khanh Nguyen Duc, Huong Tran Thi Thu and Tai Cao Van,"Improving performance and reducing pollution emission of a carburetor gasoline engine by adding HHO gas into the intake manifold".SAE International,2013-01-0104,2013.

[4] Santilli RM, "A new gaseous and combustible form of water". International Journal of Hydrogen Energy 2006; 31, 111-128.

[5] M. B. King, "Water Electrolyzers and the Zero-Point Energy". Space, Propulsion & Energy Sciences International Forum Physics Procedia 20 (2011) 435–445.

[6] Daniel M. Madyira, Wayne G. Harding, "Effect of HHO on Four Stroke Petrol Engine Performance". 9th South African Conference on Computational and Applied Mechanics Somerset West 14 – 16 January 2014.

[7] G.Venkateswara Rao,"Performance Characteristic of Oxy Hydrogen Gas on two stroke Petrol Engine". International Journal of engineering Trends and Technology-volume 6 Dec 2013.

[8] Sa'ed A. Musmar, Ammar A. Al-Rousan, "Effect of HHO gas on Combustion emission in gasoline engines". International Journal of Hydrogen Energy, Fuel 90,3066-3070,2011.

[9] S.M. Sawant, M .Yadav,"Investigation on generation method for oxy-hydrogen gas, its blending with conventional fuels and effect on the performance of internal combustion engines". Journal of Mechanical Engineering Research, Vol.3(9), pp.325-332, 21 september, 2011.

[10] AmmanA.Al-Rousan, "Reduction of fuel consumption in gasoline engines by introducing HHO gas into intake manifold". International Journal of Hydrogen Energy, Fuel 90 (2011) 3066–3070.

[11] Ali Can Yilmaz, "Effect Of Hydroxy (Hho) Gas Addition On Performance And Exhaust Emissions In Compression Ignited Engines" Int J Hydrogen Energy(2010),

[12] S. Bari And M.M. Esmaeil, "Effect Of H2/O2 Addition In Increasing The Thermal Efficiency Of A Diesel Engine". Fuel 89:378-383, 2010.

[13] W.Hsin-Kai , C. Chia-Yu , L.Yuan-Chung , and C.Kang-Shin , "Emission reductions of Air Pollutants from a Heavy-duty Diesel Engine Mixed with Various Amounts of H2/O2" .Aerosol and Air Quality Research, vol. 12, pp. 133-140, 2012.

[14] C. M. White, R. R. Steeper, and A. E. Lutz, "The hydrogen-fueled internal combustion engine: a technical review," International Journal of Hydrogen Energy, vol. 31, pp. 1292-1305, 2006.

[15] K. S. Varde and G. A. Frame, "Hydrogen Aspiration in a Direct injection Type Diesel Engine- Its Effects On Smoke and Other Engine Performance Parameters,"

International Journal of Hydrogen Energy, vol. 8, no. 7,pp. 549-555, 1983.
[16] C. Ji, and S. Wang, "Experimental study on combustion and emission characteristics of a sparkignition engine fueled with gasoline–hydrogen blends". Energy Fuels 23, 6, 2930−2936, 2009.
[17] C. Ji, and S. Wang, "Effect of hydrogen addition on the idle performance of a spark ignited gasoline engine at stoichiometric condition". Int. J. Hydrogen Energy34, 8, 3546−3556, 2009.
[18] C. Ji, S.Wang, and B.Zhang,"Combustion and emissions characteristics of a hybrid hydrogen–gasoline engine under various loads and lean conditions". Int. J. Hydrogen Energy 35, 11, 5714−5722,2010.
[19] D.R. Gabhane, S.S. Deshmukh, "effect of oxyhydrogen (HHO) gas addition on performance of internal combustion engine". International Journal for Scientific Research & Development Vol. 3, Issue 04, 2015,2321-0613
[20] K. M. Senthil, , A. Ramesh, and B. Nagalingam, ,"Use of hydrogen to enhance the performance of vegetable oil fuelled compression ignition engine". International Journal of Hydrogen Energy, 28, 1143-54.2003.
[21] B. S. Romdhane, "Hydrogen production by water electrolysis effects on electrode Materials Nature on the Solar Water Electrolysis Performances". Natural Resources, 2013, 4, 1-7
[22] Wall J, "Effect of Hydrogen Enriched Hydrocarbon Combustion on Emissions and Performance". Panacea University (2008), Retrieved May 26, 2009.
[23] S. D. Allan, "OS: Self-Looped Anton HHO Cell System". peswiki.com, 2010.
[24] K.W. Harrison, R. Remick, and G.D. Martin. "Hydrogen Production: Fundamentals and Case Study Summaries" Conference Paper NREL/CP-550-47302 January 2010.
[25] M.Kumar , "Use of Hydrogen to Enhance the Performance of a Vegetable Oil Fuelled Compression Ignition Engine". Int J Hydrogen Energy (28) (2003) 1143-1154
[26] P Van Blarigan , J O Keller, "A hydrogen fuelled internal combustion engine designed for single speed/power operation" .Int J Hydrogen Energy 1998;23:603–9
[27] JB Heywood. Internal combustion engine fundamentals. New York: McGraw-Hill Book Company; 1988.