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Hydrogen-methanol blending as renewable energy and alternative fuel source for conventional spark-ignition engines - Performance study

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Abstract
The energy crisis and pollution are vital issues today, which have led to researchers investigating non-petroleum, renewable, sustainable, and non-polluting fuels to reduce fuel consumption and reduce toxic compounds in combustion products. Hydrogen and methanol can be alternatives to conventional energy sources such as natural gas, oil, and coal since they can be coupled with renewable and sustainable sources. The purpose of this study is to investigate the engine performance and pollutant emission of a spark ignition engine using hydrogen-methanol blended fuels with various blended rates for hydrogen (0%, 2%, 4%, 6%, 8%, 10% 12% by mass). The usage of hydrogen as supplementary fuel to the methanol-air mixture for spark ignition engine results in considerable improvement of the engine performance and in the reduction of the toxic components in the exhaust gases in comparison with the conventional spark ignition gasoline engine. The important improvement of hydrogen addition is to reduce the s.f.c and CO emission of methanol engines. The Possibility of the engine power quality adjustment has also been studied.

Keywords: Hydrogen; Methanol; Alternative fuels; SIE; Renewable energy.

1. Introduction

The present energy situation has stimulated active research interest in non-petroleum, renewable, and non-polluting fuels. The world reserves of primary energy and of raw materials are obviously limited. The enormous growth of the world population during the last decades, the strongly increased technical development and standard of living in the industrial nations have led to an intricate situation in the field of energy supply. Here might be mentioned that many of the present world’s energy demand be still supplied by the exhaustible fossil fuels (natural gas, oil, and coal), which on the other hand are also the material basis for the chemical industry. It is well know that combustion of fossil fuel degrades the human condition: air pollution in cities, acid rains very damaging for our forests, build up of carbon dioxide changing the heat balance of the earth, etc…

Everything, which can be done to save our environment, is important. The fossil fuel can be substituted, by a number of alternative energy sources, such as hydrogen and methanol. These fuels are very attractive substances for the role of the energy vector in many practical applications. While conventional energy sources such as natural gas, oil and coal are nonrenewable, hydrogen and methanol can be coupled to renewable energy sources.

Methanol has been used as a fuel for automotive engines in many countries [1, 2]. With methanol fuel, compared to gasoline at the same operation conditions, a carbureted methanol engine generally has higher specific fuel consumption (s.f.c) compared to an equivalent gasoline engine, because of methanol's low heat of combustion [3, 4]. Hydrogen is characterized by having the highest energy-mass coefficient of the chemical fuels and in terms of mass energy consumption, the hydrogen exceeds the conventional methanol fuels by about 6 times [5]. Therefore, the hydrogen addition reduces the specific fuel consumption of the methanol engine. The advantage of the hydrogen-supplemented fuel lies in the requirement for a smaller quantity of hydrogen, which considerably reduces the problems connected with hydrogen storage in the automobile [6, 7].

In the present work, hydrogen has been used as a supplementary fuel to the methanol-air mixture for spark ignition engines to improve the engine performance and to reduce the toxic components in the exhaust gases.

2. Availability and Suitability of Methanol as an S.I. Engine Fuel

Methanol is a likely alternative automotive fuel in that it has properties, which would allow its use in present engines with minor modifications. Methanol fuel has high heat of vaporization, therefore, it is reduce the peak temperature inside the cylinder and hence reduce the NOx emissions and increase the engine power [5]. It has a high octane number than gasoline [3]. A fuel with a higher-octane level can endure a higher compression rate before exploding, giving the engine the ability of delivering more power and thus being more powerful and economical. Methanol fuels burn cleaner than regular gasoline and produce less carbon monoxide and nitrogen oxides [2-4]. Its power and safety benefits have prompted its use in the racing industry; its low emissions characteristics have generated considerable interest, from the Environmental Protection Agency (EPA), and from state and local air quality agencies in many countries [3]. The other most important characteristic of methanol is that it is undoubtedly the cheapest liquid alternative fuel per calorific unit, which can be produced from the widely available fossil raw material. Current research is investigating the possibility of producing it from biomass and municipal solid waste as potential feedstock. This essentially means that many countries can solve their energy imbalance problems due to petroleum shortage by using methanol as a source of energy.

3. Using Hydrogen as a Supplementary Fuel

The use of hydrogen as a supplemental automotive fuel appears to promise a significant improvement in the performance of a gasoline spark ignition engine [8-10]. Besides being the cleanest burning chemical fuel [11, 12], hydrogen can be produced from water (using non-fossil energy) and conversely, on combustion forms water again by closed cycle [13]. The self-ignition temperature of the hydrogen/air mixture is greater than that of the other fuels and, therefore a small amount of hydrogen addition produces an antiknock quality of fuel [9, 10]. Hydrogen is characterized by having the highest energy-mass coefficient of the chemical fuel and in terms of mass energy consumption it exceeds the conventional gasoline fuel by about 3 times, methanol 6 times. Therefore the results clearly establish that the supplemental hydrogen can increase the effective efficiency of the engine and reduce the specific fuel consumption [6-10].

A small amount of hydrogen mixed with air produces a combustible mixture, which can be burned in a conventional spark ignition engine at an equivalence ratio below the lean flammability limit of methanol/air mixture. The resulting ultra lean combustion produces low flame temperature and leads directly to lower heat transfer to the walls, higher engine efficiency and lower exhaust of NOx [14].

The burning velocity of hydrogen/air mixture is about six times higher than that of the methanol/air mixture [6, 7, and 15]. As the burning velocity rises, the actual indicator diagram approaches closer to the ideal diagram and a higher thermodynamic efficiency is achieved. The high molecular diffusivity of the hydrogen into the air improves the mixture uniformity and hence the combustion efficiency and cycle-to-cycle variation [15]. The using of gaseous fuel (rather than a liquid fuel) for short periods during cold start and warm-up, avoids problems of cold fuel evaporation, uneven distribution of the fuel to the different cylinders due to the presence of a liquid film on the walls of the intake manifold and to unwanted large variations in supplied air-fuel ratio during transient conditions such as acceleration and deceleration [15]. Table 1 shows the properties of hydrogen and methanol fuels [16].

Hydrogen appears to pose risks of the same order of magnitude as other fuels. In spite of public perception, in many aspects hydrogen is actually a safer fuel than gasoline and natural gas. Table 2 compares hydrogen properties with other fuels and ranks their effect on safety [16].

Table 1. Comparison properties of hydrogen and methanol fuels.

Property	Hydrogen	Methanol	Gasoline
Chemical Formula	H_2	CH_3OH	C_8H_{18}
Molecular Weight	2.02	32.04	102
Molar carbon to hydrogen ratio	0.000	0.250	0.444
Stoichiometric air/fuel ratio, mass	34.32	6.45	15.11
Latent heat of vaporization (kJ/kg)	446	1176	348
Lower heating value (MJ/kg)	119.93	19.93	44.50
Flammability limits (% by volume)	4.1-74	7.3-36	1.4-6.7
Self-ignition temperature (oK)	855	737	530
Combustion speed in air (m/s)	2.933	0.455	0.356
Octane number (R+M)/2	130+ (R)	100	86-94

Table 2. Summary of hydrogen safety related properties compared with other fuels.

Property	Compare with other fuels	Risk
Leak probability	Higher than other fuels	Dangerous
Volume of fuel released in leak	Higher than other fuels	Same as other fuels
Energy of fuel released in leak	Lower than other fuels	Safe
Diffusivity and buoyancy	Higher than other fuels	Safe
Lower flammability limit in air	Higher than other fuels	Same as other fuels
Minimum ignition energy	Lower than other fuels	Same as other fuels
Ignition energy at LFL	~Same as other fuels	Same as other fuels
Flame velocity	Higher than other fuels	Dangerous
Lower detonability fuel/air ratio	Higher than other fuels	Safe
Explosive energy per energy stored	Lower than other fuels	Safe
Flame visibility	Lower than other fuels	Dangerous
Flame emissivity	Lower than other fuels	Safe
Flame fumes toxicity	Lower than other fuels	Safe
Fuel toxicity	Lower than other fuels	Safe

4. Fuel Supply to the Engine

The Ricardo E6/US carbureted single cylinder research engine has been used in this research. The technical details of the engine are given in Table 3.

Table 3: The Technical Details of the Engine.

Type:	Ricardo E6/US, spark ignition engine
Cycle:	Four stroke
Number of Cylinder:	1
Cylinder Bore:	76.2 mm
Stroke:	110.0 mm
Connecting Rod Length:	241.3 mm
Compression Ratio:	variable
Engine Speed:	1500 rpm
Ignition Timing:	Variable

The methanol enters the air stream through the liquid fuel discharge tube in the carburetor body and is atomized and convicted by the air stream past the throttle plate and into the intake manifold (Figure 1). Methanol evaporation starts within the carburetor and continues as fuel droplets move with the air stream. Hydrogen mixed with methanol-air mixture before throttle valve to enter the intake manifold. The engine power has been measured using an electrical dynamometer. The exhaust gas was analyzed for CO by non-dispersive infrared analyzer NDIR and for NOx by chemluminescet analyzer, CUSSONS equipment's. A

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high-pressure transducer, type AVL-8QP was used to record the cylinder pressure. The transducer signal has been amplified by a CUSSONS-PIEZO channel amplifier, and is then stored and presented on the display of a CRT kikusui-COS5020-ST oscilloscope. A pick-up for an angle marker has been installed and its signal is also presented on the oscilloscope display.

Whereas blends of methanol in gasoline are commonly used in vehicles designed to operate on gasoline [3, 4], vehicle modification is required for methanol fueling because its properties are different from those of gasoline. Methanol has low stoichiometric air-fuel ratio and high heat of vaporization require carburetor re-calibration and increased heating of the air-fuel mixture to provide satisfactory drivability.

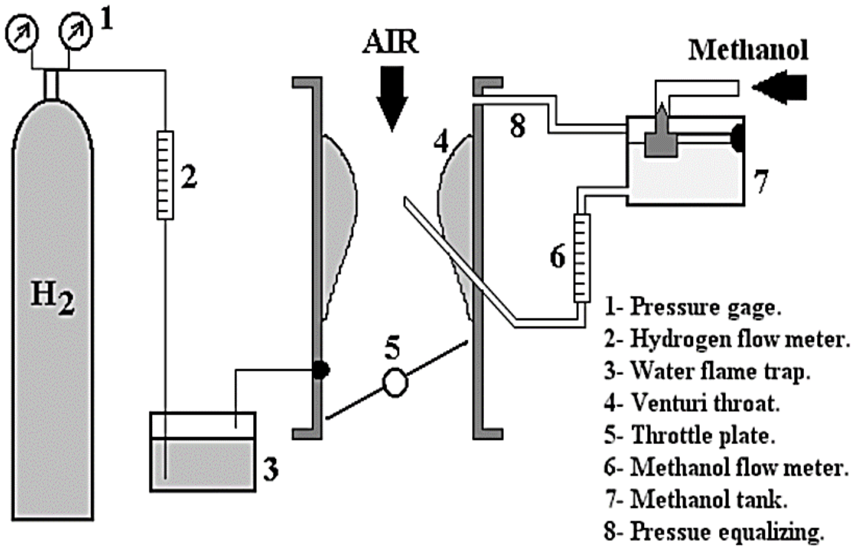

Figure 1: Schematic of Fuel Supply to the Engine

5. Results

The blending of hydrogen and methanol has been used as an alternative renewable fuel in a carbureted spark ignition engine. All measurements were performed under wide-open throttle.

Figures 2-5 show the effect of hydrogen addition on the performance and emission of a Ricardo E6/US, spark ignition engine. The hydrogen-methanol fueled engine operates with a stoichiometric mixture and optimum spark timing for best torque with 7 compression ratio and 1500 rpm. Gasoline fuel has been used as a base fuel for comparisons. Each parameter studied was made dimensionless by relating it to its value when the engine was fueled with a pure gasoline at 7 compression ratio, 1500 rpm, stoichiometric mixture and optimum spark timing for best torque.

Figure 2 shows the effect of hydrogen blending on the NOx emission. It could be noted that NOx concentration with methanol fueled engine were about 40 percent lower than the corresponding with gasoline. This is probably a result of the higher heat of vaporization of methanol, which reduces the peak temperature inside the cylinder. The increasing of hydrogen mass ratio with methanol fuel caused an increase in NOx emissions. This is due to higher peak temperature and pressure in addition to the reduction of the time required for dissociating NO to N_2 and O_2.

As shows in Figure 3, CO concentration decreases as the percentage of hydrogen addition increases. This decrease contributes to the reduction in carbon atom concentration in the blended fuel and the high molecular diffusivity of hydrogen which improves the mixing process and hence combustion efficiency. A CO emission with methanol was 2.3 percent lower than with gasoline.

Figure 4 shows the effect of hydrogen blending on the specific fuel consumption. The specific fuel consumption was poorer with methanol fuel because of its low heating value. When compared at the same compression ratio and equivalence ratio, methanol fuel consumption was about 57 percent greater than that of gasoline. The specific fuel consumption decreases as the percentage of hydrogen blending is increased. Achieving low fuel consumption is definitely of major importance in the development of methanol engines; however, reductions in exhaust emissions must also be considered.

Figure 5 shows the effect of hydrogen blending on the engine power. The engine power increases as the percentage of hydrogen blending increases because of the high rate of mass burning of hydrogen, which leads to improve the combustion efficiency. When the percentage of blending is more than 2-3 percent, the power decreases due to the reduction in mixture density and engine volumetric efficiency. High compression ratios were possible because of methanol's high octane quality and hydrogen's high self-ignition temperature. The increasing of compression ratio giving the engine the ability of delivering more power and thus being more powerful and economical.

Figure 6 show the effect of hydrogen blending and equivalence ratio on the NOx emission. The hydrogen-methanol fueled engine operates with 7 compression ratio, optimum spark timing for best torque and 1500 rpm. Each value of NOx emission was made dimensionless by relating it to its value when the engine was fueled with a pure gasoline at 7 compression ratio, 1500 rpm, stoichiometric mixture and optimum spark timing for best torque. Hydrogen-methanol fueled engine may have either higher or lower levels of NOx emissions than their gasoline counterparts, depending on the equivalence ratio and hydrogen mass ratio. The increasing of hydrogen mass ratio in fuel mixture caused an increase in the peak burned-gas temperatures, promoting NOx formation. However, exhaust NOx concentrations are also influenced by decomposition reactions, which occur more readily at rich mixtures than at lean mixtures. Thus, with rich mixtures, higher burned-gas temperatures is increased the NOx formation, but also increase NOx decomposition. At leaner mixtures, decomposition reactions become less important so the increasing of NOx formation leads an increasing in exhaust concentrations of NOx.

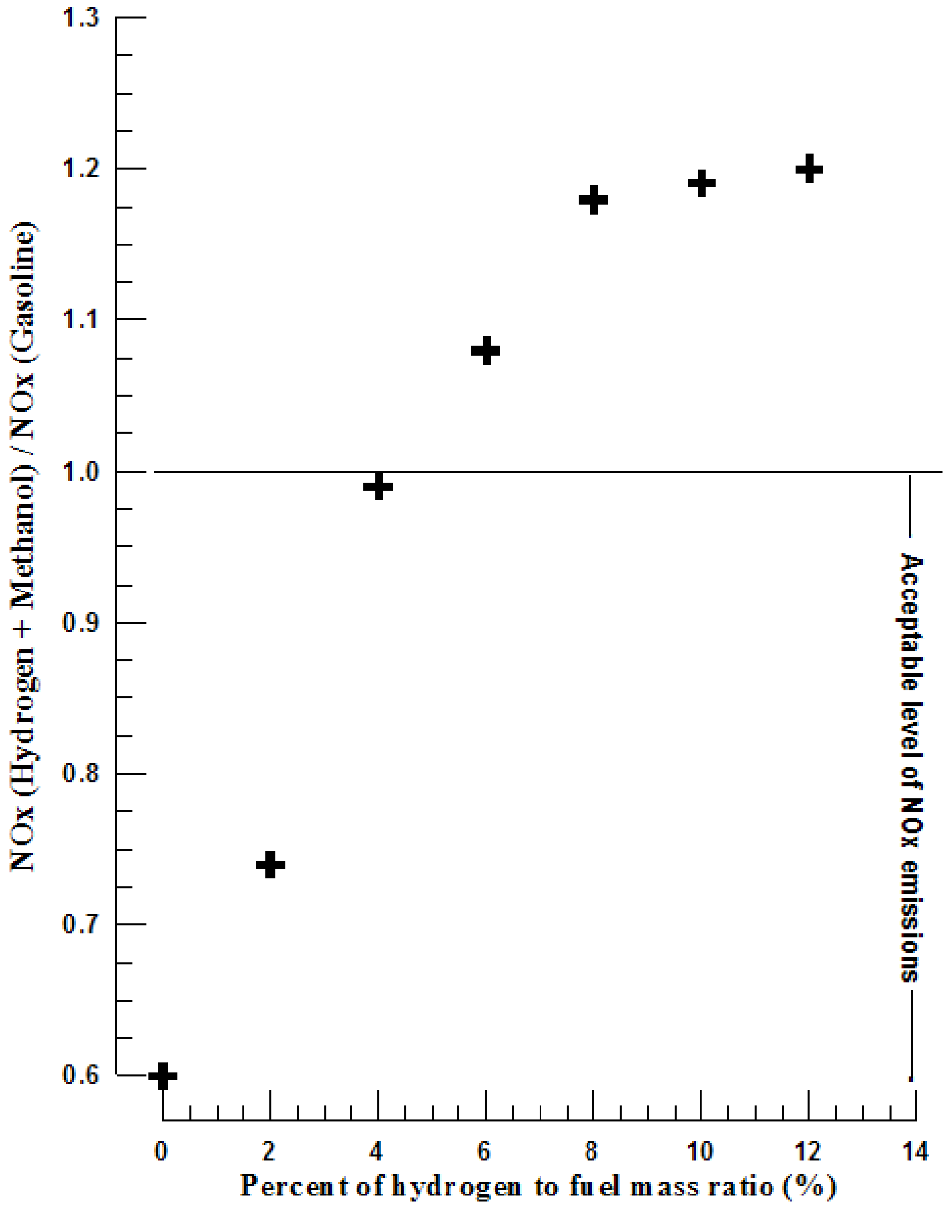

Figure 2: Effect of Hydrogen Addition on the NOx Emission

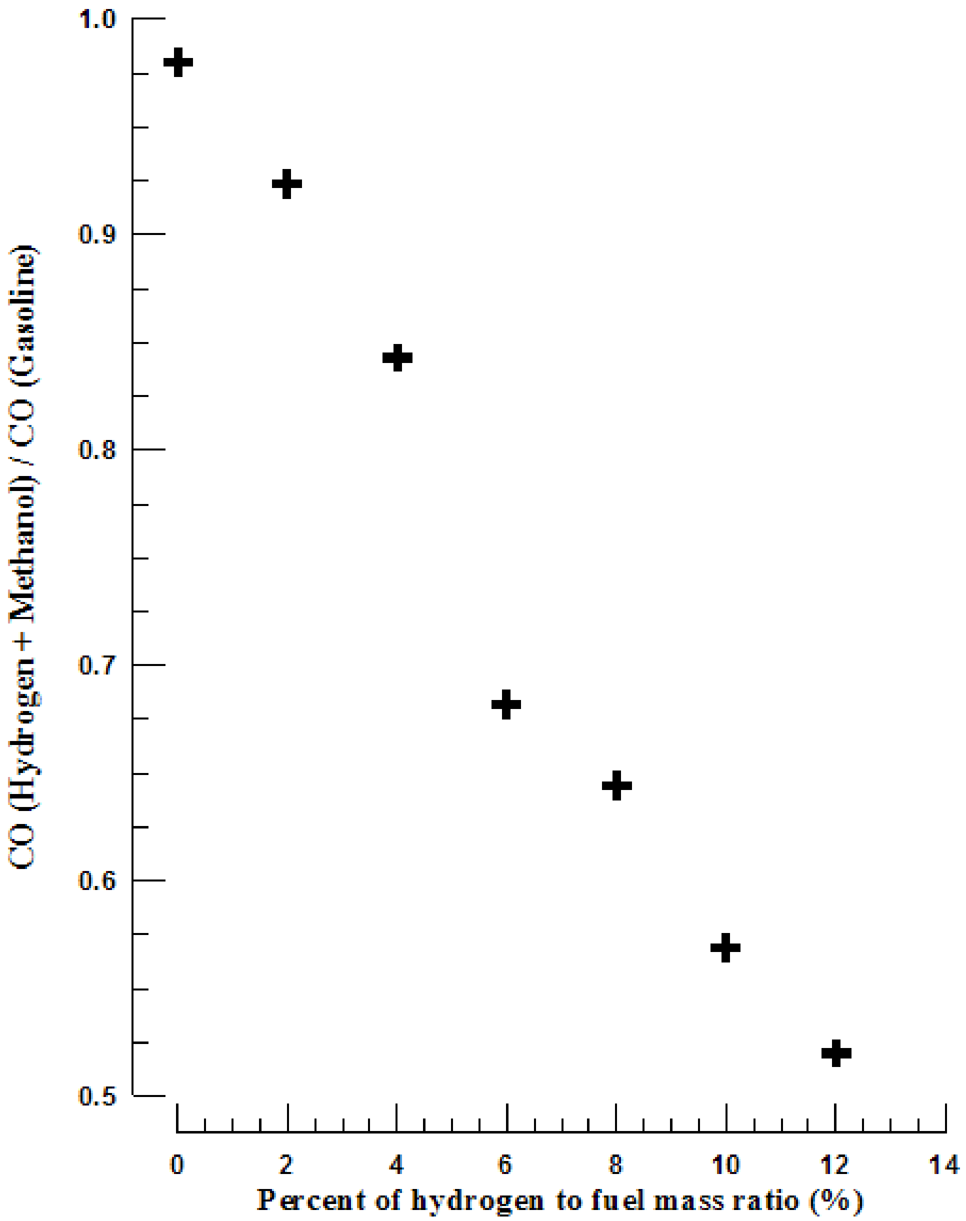

Figure 3: Effect of Hydrogen Addition on the CO Emission

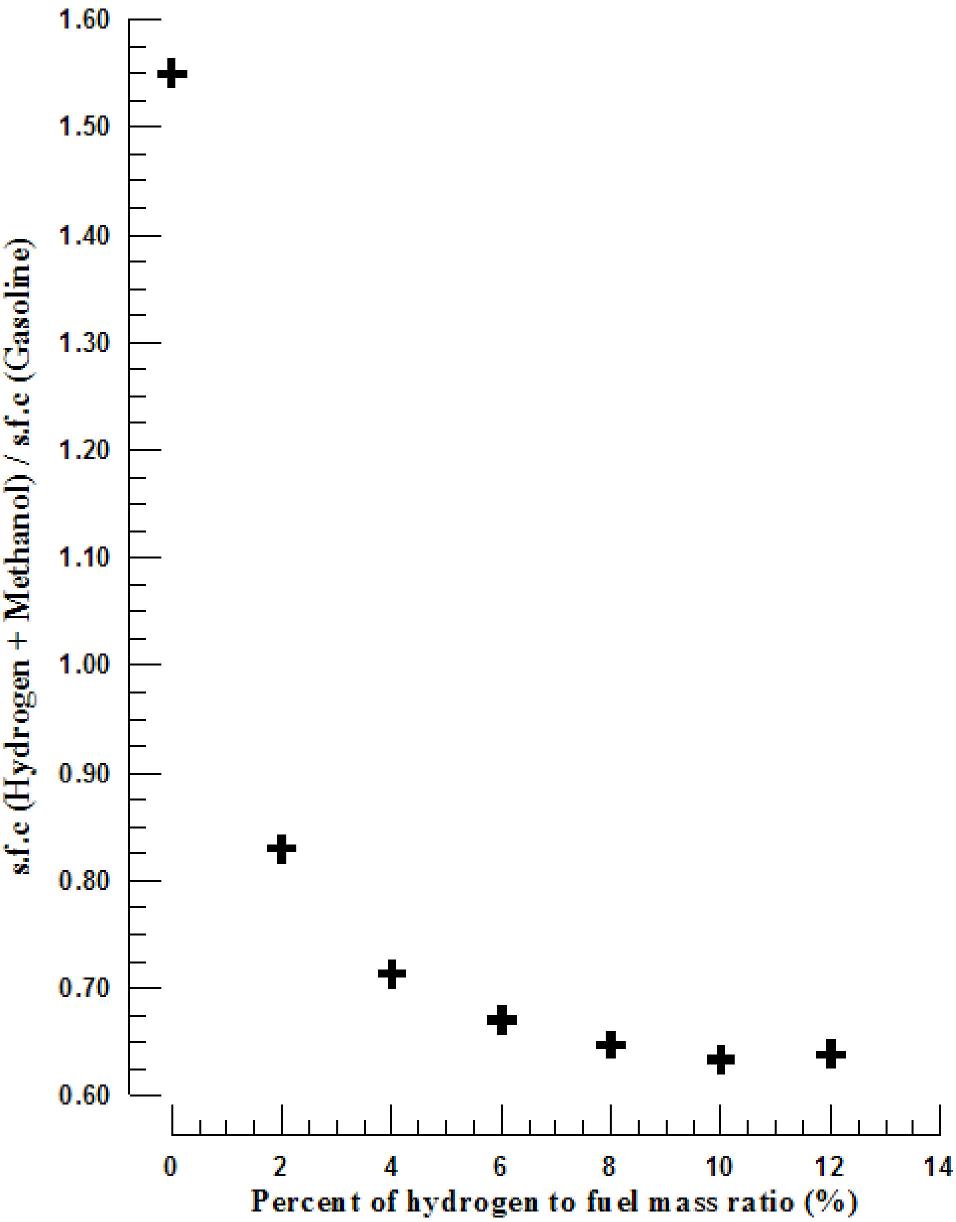

Figure 4: Effect of Hydrogen Addition on the s.f.c.

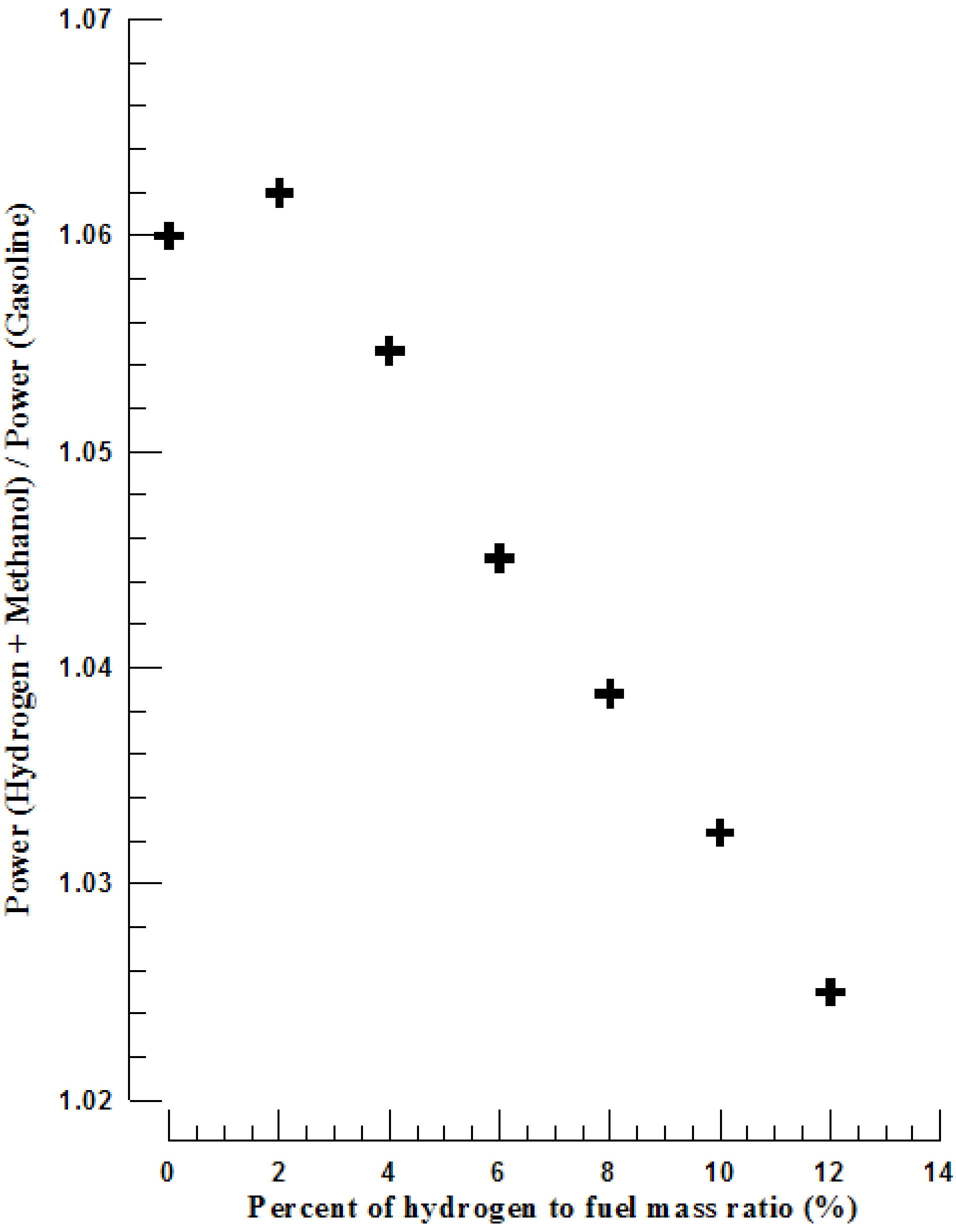

Figure 5: Effect of Hydrogen Addition on the Engine Power

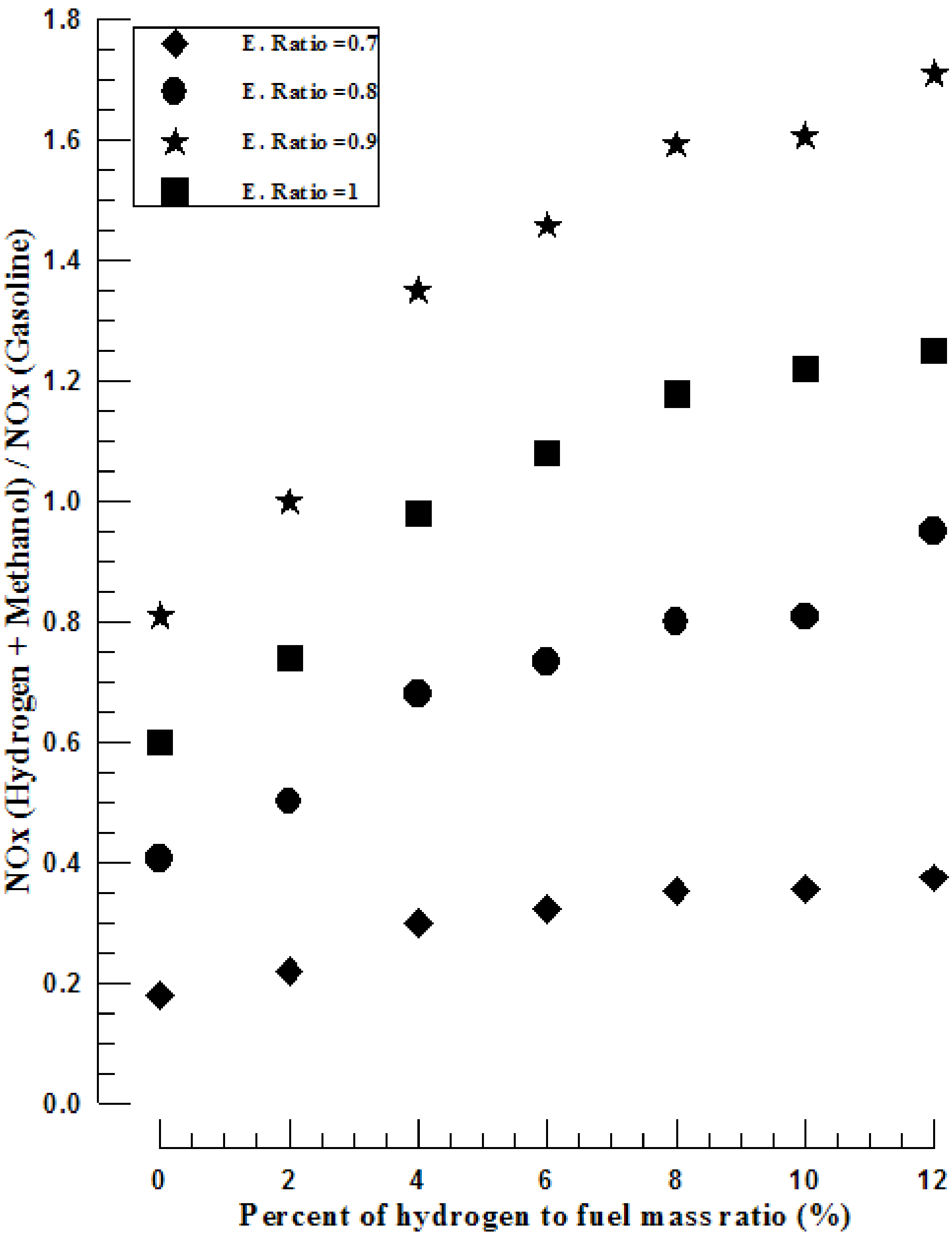

Figure 6: Effect of Hydrogen Addition and Equivalence Ratio on the NOx Emission

6. Conclusion

A single-cylinder, four stroke, spark ignition engine was operated on blending of hydrogen-methanol fuels (0-12 mass %). The specific fuel consumption was poorer with methanol fuel. The important improvement of hydrogen addition is to reduce the s.f.c of methanol engines. The advantage of the hydrogen-supplemented fuel presents in requiring a smaller quantity of hydrogen, which considerable reduces the problems connected with hydrogen storage in the automobile. Methanol fuel has high heat of vaporization, therefore, it is reduce the peak temperature inside the cylinder and hence reduce the NOx emissions. Nitrogen oxide emissions increased as the percentage of hydrogen addition increases. In all percentage of hydrogen in methanol the engine power was greater than with pure gasoline fuel. High compression ratios were possible because of methanol's high-octane quality and hydrogen's high self-ignition temperature. To avoid the difficulty of cold starting with methanol fuels, a dual fuel-supply system was used. The engine was started on hydrogen and then switched on to methanol fuels when warmed up.

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