Effect of Hydroxy Gas Addition on Performance and Emissions of Diesel Engine

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Abstract - ***Emission from engine exhaust is serious problem from environment point of view. For that search, alternative fuels are encouraged. Hydroxy gas (HHO) is expected to be one of the most important alternate fuel in the near future to meet the stringent emission norms. The hydroxy (HHO) gas enrichment is resulted in better combustion and reduced emission outputs in compression ignition engines. To assist the poor ignition characteristics of diesel, the HHO gas can be used to improve combustion. When the hydroxy gas is enriched with air in diesel engine, the thermal efficiency for compression ratio 18 increases by 9.25% comparing to baseline diesel combustion and the specific fuel consumption is reduced by 15% at full load condition. The HC emission is reduced at an average of 33% due to better combustion at higher compression ratio with hydroxy gas. The CO emission is reduced marginally, an average of 23% reduction of CO emission is observed. NO is increased with hydroxy gas enrichment at full load condition. The exhaust gas temperature is also increased. Smoke opacity is 8% as compared 10% for baseline diesel operation is observed.***

Key Words: *Hydroxy gas, SFC, Emissions, diesel engine.*

1. INTRODUCTION

The use of petroleum crude reserves is increasing in developing countries at high rates. Energy security is an important consideration for development of future transport fuels. Among the all gaseous fuels hydrogen or hydroxy (HHO) gas is considered to be one of the clean alternative fuel. The difficulty of controlling prices and the uncertain reserves are strong incentives for pursuing energy security. Global warming and local pollution hot spots associated with fossil fuel usage are further significant environmental and societal problems [1]. There is strong need for research, development and demonstrations of use of hydroxy gas in internal combustion engines. The hydroxy gas has an advantage of zero harmful emissions and potentially high efficiency because of absence of carbon. The hydroxy gas can be used in combination with other fuels in a dual fuel mode. Adding hydroxy gas in compression ignition engines can improve the thermal efficiency and specific fuel consumption with reduction of CO and HC emission [2]. There are various induction methods used for hydrogen induction such as fuel carburetion method, intake manifold or inlet port injection and direct in-cylinder injection. The paper presents investigation of improvement in performance and reduction in emission by using hydroxy (HHO) gas addition in single cylinder diesel engine.

Hydrogen is considered as clean burning carbon less fuel. Hydrogen is not an energy source; it is an energy carrier which can be used in IC engines. Hydroxy (HHO) gas is mixture of hydrogen and oxygen particles at 2:1 ratio. Hydroxy gas produces only water after combustion. It is a non-toxic, non-odorant gas and also can be burn completely. When hydrogen is burned, hydrogen combustion does not produce toxic products such as hydrocarbons, carbon monoxide except for the formation of NO_x. Onboard generation of the hydroxy gas can be a better option for transport vehicles. Hydrogen has a high auto ignition temperature and wide flammability range making it highly suitable for high-compression lean-burn engines. In addition, a high flame speed prevents engine knock. Hydrogen has the ability to burn at extremely lean equivalence ratios. Hydrogen will burn at mixtures seven times leaner than gasoline and five times leaner than methane. Efficiencies are also improved because hydrogen has a very small gap quenching distance allowing fuel to burn more completely. The only drawback to hydrogen is that even though its lower heat value is greater than other hydrocarbon fuels it is less dense therefore a volume of hydrogen contains less energy [1, 2, 3]. The stored liquid hydrogen serves as higher stored energy density of hydrogen available for combustion [4]. The brake thermal efficiency of 29.4% can be observed at full load for the optimized injection of hydrogen [5]. Hydroxy (HHO) gas addition in diesel engine, using hydroxy electronic control unit resulted in 13.5% reduction in CO emissions, 5% HC emissions and SFC by an average of 14 % [6]. As low as 5-10% of the hydrogen fuel in diesel engine can reduce specific fuel consumption [7]. At varying flow rate of hydrogen, the brake thermal efficiency of the hydrogen diesel duel fuel operation is quite higher than the diesel fuel operation, over the entire brake power range. There was 80% decrease in CO emission, when hydrogen was used as dual fuel [8]. The hydroxy gas enrichment helped an overall 11.06% improvement in brake thermal efficiency. CO and HC emissions decreased by 15.38 % and 18.18% respectively. Also NO_x emission increased by 11.19% [9]. Use of HHO gas in biodiesel blended diesel engine resulted in reduction of the unburned hydrocarbon emission and led to improved thermal efficiency [10]. Also the hydroxy gas blending with diesel resulted in reduction of specific fuel consumption is reduced compared to base diesel operation [11].

2. COMBUSTION CHARACTERISTICS OF HYDROGEN

Combustion of hydrogen is fundamentally different from the combustion of hydrocarbon fuel. Hydrogen has wider flammability limits of 4-75 % by volume in air compared to diesel of 0.7-5% by volume. The minimum energy required for ignition of hydrogen–air mixture is 0.02 *mJ* only. This enables hydrogen engine to run well on lean mixtures and ensures prompt ignition but create the problems of premature ignition and flashback due to hot spots present in the cylinder. Backfire can be eliminated by avoiding hot spots in the combustion chamber, and intake manifold that acts as an ignition source for hydrogen and by exhaust gas recirculation or water injection. The density of hydrogen is 0.0837 kg/m^3, which is lighter than air that it can disperse into the atmosphere easily. Hydrogen has the highest energy to weight ratio of all fuels. The flame speed of injection hydrogen is 270 *cm/s* that may cause a very high rate of cylinder pressure rise. The diffusivity of hydrogen is 0.63 cm^2/s. As the hydrogen self-ignition temperature is 858 K compared to diesel of 530 K hence it allows a larger compression ratio to be used for hydrogen in IC engine [3]. The dual fuel operation is the most practical mode of diesel engine while operating with hydrogen. In multi cylinder diesel engine, 45% of energy can be substituted by using hydrogen enriched combustion. Adding hydrogen into diesel engine can reduces CO and HC, but will increase NO_x due to high temperature generated within the combustion chamber during combustion. This high temperature causes some of the nitrogen in the air to combine with the oxygen in the air, which forms oxides of nitrogen [4]. Table 1 gives properties of hydrogen, diesel, petrol and CNG.

Table 1: Properties of Hydrogen, Diesel, Petrol and CNG [3, 4, 5, 6]

Sr. No.	Properties	Diesel	Petrol	CNG	H_2
1.	Auto Ignition Temperature (*K*)	530	533-733	723	858
2.	Minimum ignition energy (*mJ*)	---	0.24	0.28	0.02
3.	Flammability Limits (volume % in air)	0.7-5	1.4-7.6	0.4-1.6	4-75
4.	Stoichiometric air fuel ratio on mass basis	14.5	14.6	14.49	34.3
5.	Limits of flammability (equivalence ratio)	---	0.7-3.8	0.4-1.6	0.1-7.1
6.	Density at 16 ^0C and 1.01 *bar* (kg/m^3)	833-881	721-785	0.72	0.0838
7.	Net heating value (*MJ/kg*)	42.5	43.9	45.8	119.93
8.	Flame velocity (*cm/s*)	30	37-43	38	265-325
9.	Quenching gap in NTP air (*cm*)	---	0.2	0.21	0.064
10.	Diffusivity in air (cm^2/s)	---	0.08	0.16	0.63
11.	Research octane number	30	92-98	120	130
12.	Motor octane number	---	80-90	---	---
13.	Cetane number	40-55	13-17	---	---

3. EXPERIMENTAL PROCEDURE

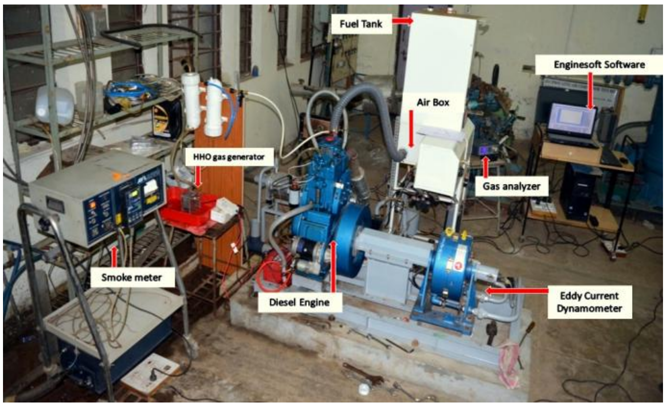

Figure -1: Experimental Setup

Figure 1 shows the experimental setup for the diesel engine supplemented with hydroxy gas through dry cell hydroxy (HHO) gas generator. The experimentation was carried out on VCR diesel engine at constant flow rate of hydroxy gas for compression ratio 18. The engine specifications are as shown in Table 2. The engine is coupled with eddy current dynamometer for loading and data is generated on computer. For emission measurement the AVL DiGas 444 5-channel emission gas analyzer and AVL 437 Diesel smoke meter is used. First engine is set to compression ratio 18 and engine is started. The base readings are taken for compression ratio 18. The readings are taken for different loading conditions ranging from 4 *kg*, 8 *kg* and 12 *kg* at constant speed of 1500 *rpm*. Then hydroxy (HHO) gas at 1 *lpm* flow rate is passed into intake manifold. Again the readings were taken for different loading conditions and at constant speed of 1500 *rpm*. The performance data is recorded in computer enginesoft software package and emissions are record from gas analyzer and smoke meter. In this experimentation, continues manifold induction of hydroxy gas (HHO) at 1 *lpm* is incorporated.

Table 2: Test Engine Specification

Engine Specifications	Diesel Engine
Model	TV1
Make	Kirloskar
Power (*kW*)	3.5
Maximum speed (*rpm*)	1500
Cylinder bore (*mm*)	87.5
Stroke (*mm*)	110
Connecting rod length (*mm*)	234
Compression Ratio (VCR)	12-18
Stroke type	4 stroke
Number of cylinder	1
Speed type	Constant
Cooling type	Water
Fuel	Diesel
Swept volume (*cc*)	661.5

4. RESULTS AND DISCUSSION

The performance and emission characteristics of diesel with hydroxy (HHO) gas enrichment compared with baseline diesel operation.

4.1 Performance Parameters

4.1.1 Brake thermal efficiency

Figure 2 shows the brake thermal efficiency for baseline diesel and with 1 *lpm* enrichment of hydroxy gas. The thermal efficiency of diesel engine when enriched with hydroxy gas is higher than baseline diesel. Due to increase in calorific value of overall mixture in the combustion chamber increases the thermal efficiency. The high value of thermal efficiency can be attributed to better mixing of hydroxy gas with air which results in better combustion. The brake thermal efficiency, at full load is maximum at compression ratio 18 when enriched with hydroxy gas. The thermal efficiency increased by 9.25 % from 32.44 % to 35.75 % comparing to baseline diesel and with hydroxy gas enrichment

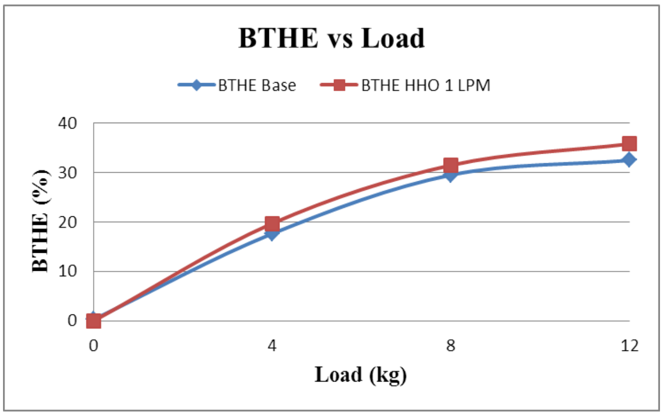

Figure -2: Variation of brake thermal efficiency with load

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4.1.2 Specific Fuel Consumption

Figure 3 shows the variation in the specific fuel consumption with load. It is observed that, fuel consumption is maximum at load 4 *kg* and then it decrease towards full load of 12 *kg*. When enriched with hydroxy gas, there is reduction in specific fuel consumption. The reduction in SFC is due to uniform mixing of hydroxy gas with air (high diffusivity of hydrogen) as well as oxygen. Hydroxy (HHO) gas which assists diesel fuel during combustion process and yields better combustion. HHO gains a high flame speed and wide flammability, the addition of hydroxy gas would help the fuel to be burned faster and more complete at constant speed conditions.

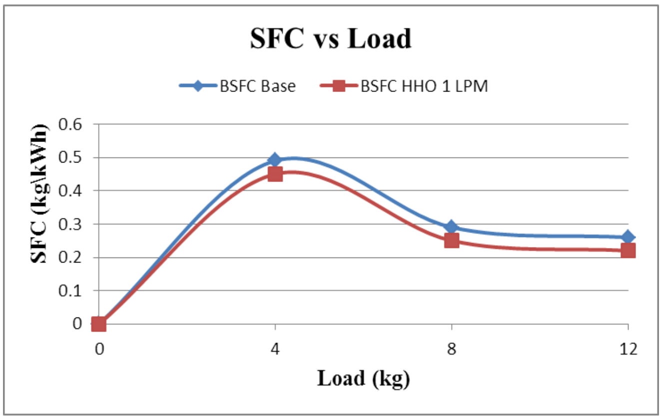

Figure -3: Variation of specific fuel consumption with load

The specific fuel consumption is reduced by 15% at full load condition.

4.1.3 Exhaust Gas Temperature

The variation of exhaust gas temperature for various loads is shown in Figure 4. The trend shows that the EGT increases with increase in load. At full load condition, the EGT rises from 322.23 ^{0}C to 334.55 ^{0}C when enriched with hydroxy gas.

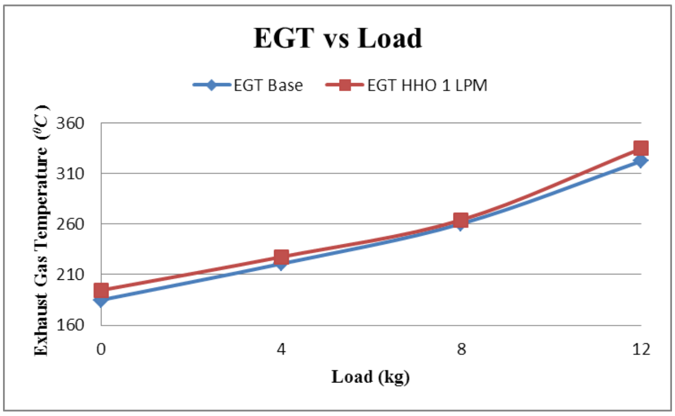

Figure -4: Variation with exhaust gas temperature with load

The maximum exhaust gas temperature 334.55 ^0C is reached at full load condition. The Figure 3 shows that a better combustion was takes place after enrichment of hydroxy gas in to the engine. Because of high residence time associated due to high auto ignition temperature of hydroxy gas, more charge gets accumulated inside the cylinder contributes to increase the exhaust gas temperature. Due to the increase in peak combustion temperature, the exhaust gas temperature of the hydroxy gas enriched engine is higher than diesel.

4.2 Emission Parameters

4.2.1 Hydrocarbon

The HC emission of hydroxy gas enriched with diesel is lower compared to baseline diesel. Since hydrogen is carbonless, burning of hydroxy gas along with diesel leads to reduced hydrocarbon level and because of high cylinder temperature the carbon particles present in lubricating oil and main fuel, gets oxidizes and converted into CO_2.

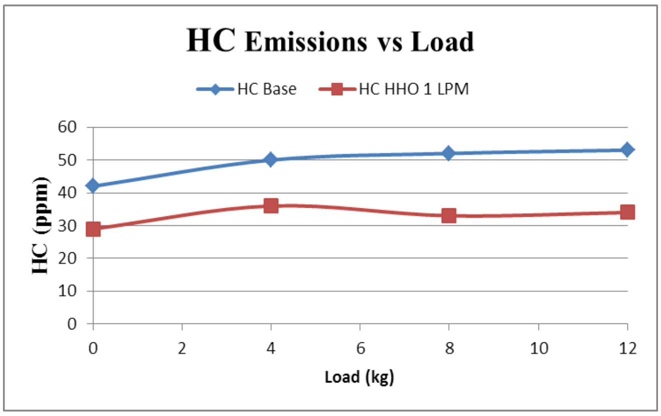

Figure -5: Variation of HC emission with load

Figure 5 shows the HC emission reduces marginally due to hydroxy gas enrichment. The short quenching distance and wide flammability range of hydrogen yield engine to expel less HC emissions. The HC emission is reduced at an average of 33% due to better combustion at higher compression ratio with hydroxy gas. At full load condition, the HC emission reduced from 53 *ppm* to 34 *ppm* with maximum reduction of 37% compared to baseline diesel HC emission.

4.2.2 Carbon Monoxide

The variation of the carbon monoxide emission with hydroxy gas enrichment is shown in Figure 6. It is found that the carbon monoxide decreases with hydroxy gas addition.

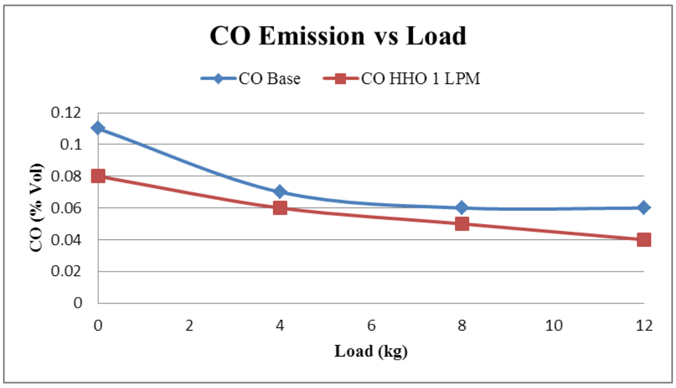

Figure -6: Variation of CO emission with load

The reason for lower CO emission is the absence of carbon in the hydrogen structure. There is an average of 23% reduction of CO emission. At full load condition, the CO emission reduced from 0.06 % vol to 0.04% vol. with maximum reduction of 33%.

4.2.3 Oxides of Nitrogen

The variation of oxides of nitrogen with respect to the load with and without hydroxy gas enrichment is shown in Figure 7. The formation of oxides of nitrogen is due to the peak combustion temperature, the oxygen concentration in the combustion chamber and the residence time of high temperature gas in the cylinder.

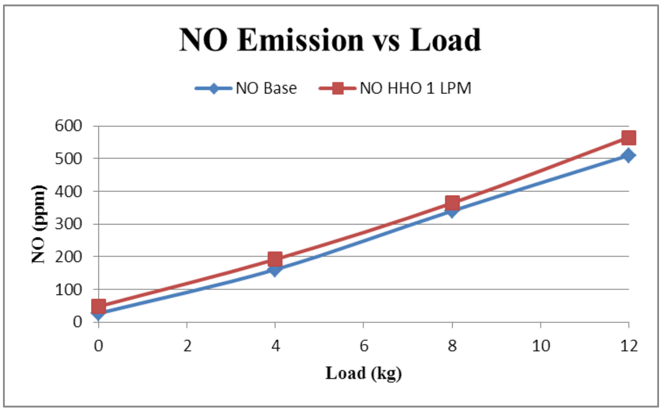

Figure -7: Variation of NO emission with load

The enrichment of hydroxy gas, which has high calorific value as compared to diesel, causes temperature rise in the combustion chamber hence causing increase in NO emission. The maximum value of NO is observed when enriched with hydroxy gas, 565 *ppm*, at full load condition.

4.2.4 Smoke

The Figure 8 compares the amount of smoke emission by the test engine during its combustion with and without hydroxy gas enrichment. When hydroxy gas is inducted into the combustion process, the smoke reduces substantially.

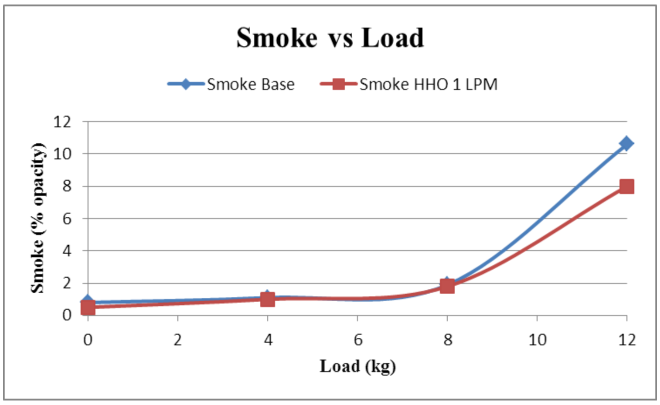

Figure -8: Variation of smoke with load

The smoke is emitted from the engine due to the incomplete combustion of the fuel-air mixture. If heavier hydrocarbon fuel molecule structure is fractured into lighter and smaller hydrocarbon structure in less time, the homogeneous mixture can be formed, when hydroxy gas is inducted into the combustion process of the diesel engine, it reduces smoke. When hydroxy gas is inducted at full load of the engine, the smoke opacity is 8% as compared 10% for baseline diesel operation.

5. CONCLUSIONS

From the results obtained after experimentations on single cylinder four stroke diesel engine, it is seen that, the hydroxy gas enrichment results in significant improvement in performance and reduction in emission parameters except the exhaust gas temperature and NO emission which increases with increase in load. The thermal efficiency of diesel engine is increases and specific fuel consumption is reduces when enriched with hydroxy gas. The exhaust gas temperature seems to be increased causing increase in NO_x. Carbon monoxide (CO) and hydrocarbon (HC) are reduced marginally due to better combustion with hydroxy gas and absence of carbon. NO_x can be minimized by using EGR technique.

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