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Hydrogen Operated SI Engines, its Consequences on Performance, Environment and Safe Use: a Review

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Abstract: From experience since 1970 various researchers and engineers attempting to produce a best suitable and reliable way to replace existing fossil fuels such as gasoline, diesel etc. Hydrogen gas has been considered as a best alternative to gasoline in case of SI engine and diesel in case of CI engine. Automobile exhaust pollution has considerable contribution in today's overall pollution levels. The best suitable alternative fuels such as hydrogen reduces this critical pollution levels. Hydrogen combustion produces very clean exhaust due to its desirable characteristics. When hydrogen tested on various SI engines as solely or partially at various parametric levels then in all experiments it reduces pollution levels drastically compared to that of SI engine which running purely on petrol. Hydrogen burning lowers the HC, CO and NO_X levels. As of now hydrogen combustion is dangerous due to back fire problems, but newly developed technologies and science in fire arresters ensures us the backfire free operation of hydrogen operating engine and same time make it possible to control hydrogen supply precisely. In this paper by using work done so far the discussion is made on performance and emissions behaviour of hydrogen fuelled SI engine and its safe use.

Keywords: Hydrogen; Gasoline; SI Engine; Emissions; Performance; Safety

I. INTRODUCTION

All we know the fossil fuels such as petroleum, natural gas and coal *etc* are being depleting rapidly. These fuels fulfil the energy demand. They are producing high levels of emissions which causing global pollution and environmental problems such as the greenhouse effect, acid rains, ozone layer depletion also by combusting them causes to hamper the natural environment and eventually entire life on our planet. Researchers, engineers and scientists always trying to develop new fuels and burning technologies which will able to lower the today's pollutions levels. Now a day's hopes have again been raised about production and development in ''hydrogen economy'' sector because most of them agreed that hydrogen is best alternative fuel to replace the existing fossil fuels as hydrogen is having the clean burning characteristics. Hydrogen gas running systems are capable to reduce greenhouse effect, acid rains, ozone layer depletion and other environmental problems by reducing CO_2, HC and NO_X emissions. The use of hydrogen as an energy source is a long term option to reduce CO_2 emissions. A worldwide conversion from fossil fuels to hydrogen would eliminate many of the problems and their consequences. These advantages show that there is urgent need to introduce hydrogen gas running systems. Hydrogen can be produced by using non-polluting sources and which is the ideal way such as water electrolysis. The economies and lifestyle of their population of highly developed countries depend on light trucks and cars. These vehicles contribute most of the carbon monoxide (CO), carbon dioxide (CO_2), volatile organic compounds (hydrocarbons, HC), and nitrogen oxides (NOx) emitted in exhaust [1], [8].

The hydrogen gas is acting as a light gaseous fuel. It is having high heating value on mass basis, wide flammability that gives wide mixture range in air which permits extremely lean or rich mixtures to support combustion.

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It requires lower amount of energy to start ignition process which results in extremely high speed flames. Its energy released by combustion per unit mass of stoichiometric mixture remains high. The combustion properties of hydrogen have much influence on its performance as an engine fuel [4]. The SI engine fuelled directly by injecting hydrogen in cylinder is having 30% more power comparative to conventional running SI engine due to increase in cycle heat release [1], [4].

Hydrogen can be produced from renewable energy sources such as solar, wind, water separation using electrolysis. The inherent properties of fossil fuels or non conventional fuels make them popular during the last century but unfortunately these fossil fuels are not renewable. In addition the pollutants emitted by fossil energy systems such as CO, CO_2, NO_X, radioactivity, heavy metals, ashes *etc* are greater and more damaging than those that might be produced by a renewable based hydrogen energy system. For an engine running only with hydrogen the exhaust gases doesn't contains carbon oxides, hydrocarbons, particles and lead compounds excluding the unburned hydrocarbons or the carbon oxides provided by oil burning inside the combustion chamber. Small amount of nitrogen oxides are still exists in exhaust gases because of a higher burning temperature occurring inside the cylinder in case of hydrogen burning [3].

II. TYPES OF HYDROGEN SUBSTITUTION

There are mainly two different ways available to introduce hydrogen in combustion chamber for burning process.

A. Partial hydrogen substitution.

There are many resources available to produce the hydrogen that is why it is considered as a privileged alternative fuel. The power output of the hydrogen supplied engine is mainly depends on the types of fuelling adopted. Generally 20% power rise in output can be observed to that of purely gasoline running engines. The partial substitution is used in single cylinder engine operating at 8.5 compression ratio. The hydrogen is directly injected inside the cylinder through a valve purposely located as shown in Fig. 1. From experiment it is observed that by direct injection of hydrogen the engine power output increases by 30%, Indicated Specific Fuel Consumption becomes lower especially at partial loads due improved combustion process which is expected and desirable. This partially substituted hydrogen operated engine does not produce a lot of polluting substances such as CO, CO_2, HC, particles and lead compounds. There is only NOx as polluting substance found in the exhaust gases [1].

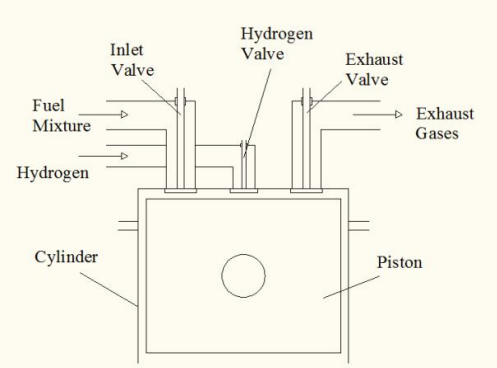

Fig. 1 Direct injection of hydrogen inside the cylinder through a valve in the combustion chamber.

If hydrogen is used as supplementary fuel in a four cylinder, four stroke SI engine then it results in improved engine performance. The experiments carried by various author's shows that the specific fuel consumption decreases while the engine thermal efficiency increases also at the same time little decrease in brake power is observed. If the engine running on supplementary hydrogen then the heat loss to cooling water and unaccounted losses reduced by 36% and 30%

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respectively. If the hydrogen mass flow rate goes beyond to that of gasoline by 5%, the amount of air supply reduces causes to deteriorate the operation of engine [5].

B. Total hydrogen substitution.

The small capacity engines always run on the slightly rich mixture hence they consume more fuel and there by having the high pollution levels. To overcome above stated problems a single cylinder, four strokes, air cooled SI engine is selected for experiment. By the substitution of hydrogen in cylinder 24% decrease in power output noticed due to leaner combustion also decrease in engine operating temperature is observed. At 2200rpm it is found that knocking reduces drastically as carburettor is eliminated and most suitable excess air ratio will become 1.5. Also by elimination of carburettor and supply of lean mixtures the back fire problem avoided which is very dangerous in case of hydrogen usages. The supply of lean mixture also reduces NO_X level by 66%. The specific fuel consumption is also reduced by 57%. As we know the lubricating oil vaporizes at operating temperatures the small traces of HC pollutants are observed. Finally it is concluded that to run any small existing SI engine on hydrogen there is no requirements of large modifications [4].

Variation of thermal efficiency, power, exhaust gas temperature and exhaust emissions like as NOx, CO, CO_2, HC and O_2 for both hydrogen and gasoline were investigated by comparing the performance and emissions of a four cylinder SI engine running on both gasoline and hydrogen at partial loads. As hydrogen is found in a gaseous state rapid burning of hydrogen is possible and it is advantageous. It gives an increased fuel economy and decreased emissions. For purely hydrogen operated engine values found approximately zero for CO, CO_2 and HC emissions. However, when engine running at the speed of 2600 rpm backfire problem is experienced. The internal mixing method has advantage of reduce the problem of backfire and detonation. The high pressure injector helps to inject the hydrogen in to the engine cylinder directly at the later stages of compression stroke which results in backfire free operation, high thermal efficiency and high power output. The hydrogen was introduced inside the engine cylinder in two ways by both a carburettor and an in-line multi point injection system. The second type that is injection system is more advantageous as it gives comparatively increased power output and moment at all engine speeds while the carburettor system is less advantageous. The compression ratio and equivalence ratio had a significant effect on both performance and emission characteristics of the engine. The electronic control system had advantages for improving the performance of hydrogen fuelled engine. If we compare engine operation between hydrogen and natural gas then results shows that brake specific fuel consumption was reduced and the brake thermal efficiency was improved. The hydrogen operated SI engines was found profitable in terms of both thermal efficiency and nitrogen oxides emissions. For hydrogen fuelled engine, at high combustion temperatures the NO and NO_2 emissions occur by combination of nitrogen and oxygen. In case of hydrogen fuelled internal combustion engines the rapid combustion causes the high NO level. As mixture becomes leaner the NOx emission was found to be about 66% less than that of engine running purely on gasoline. For gasoline operated engine maximum NO_X occurs at 2200 rpm due to occurrence of high temperatures while for hydrogen operated engine NOx occurs at 1800 rpm. Though theoretically CO and CO_2 are not observed in the exhaust of hydrogen operated engine but as oil film burn in this case which is present on the inside of cylinder wall hence small amount of CO and CO_2 observed in actual practice. In case of hydrogen operated engine the HC emissions are also close to zero but small amount of HC emission comes from the unburned evaporated lubrication oil [4]. Direct injection of hydrogen has advantageous as it gives normal combustion and achieves 30% increase in engine power. The higher combustion temperature causes to increase the NOx level in exhaust. This NOx level contained in exhaust can be minimized by use of catalytic converter, ignition timing tuning and cooled exhaust gas recirculation method. The better combustion process at partial loads results in better efficiency in case of hydrogen fuelled engines [3]. The NOx emission level is a strong function of excess air ratio, λ. The NO_X levels at full load is much higher if the engine is operating with $\lambda = 1$ to 1.5 comparative to the gasoline engine because of the rise in burning temperature. If the engine is running at lean hydrogen air mixtures with excess air ratio $\lambda > 1.5$ then combustion temperature decreases and thereby NOx emission level decreases drastically. At $\lambda > 2$ maximum temperature with cylinder is approximately 2100 K and NOx emissions level is virtually zero [1].

Backfire is the main problem in case of total hydrogen substitution. Operating the engine at lean mixture can avoid this problem drastically. It is concluded from several experiments that with an excess air to fuel ratio, $\lambda=2$ the backfire free operation can be achieved [7].

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III. SAFETY

The improper handling of all the motor fuels such as diesel, gasoline and natural gas includes risk of fire and explosion. Hydrogen is also falls in same category. The properly designed, maintained and operated vehicles and fuel stations can be proves the safe use of hydrogen or safer than diesel and other fuels. The inherent properties of hydrogen always make us to question of safety in storage and its handling as it has considerably different chemical and physical properties. [9]. Safety is a relative issue. Use of gasoline is more and same times it is safe but large scale use of gasoline always involves risk of a fire in a crash. This is same in case of hydrogen. But hydrogen is very promising eco-friendly fuel. In comparison with all available fossil motor fuels harmful emissions are almost negligible and there is no problem about sustainability of hydrogen as it is a vastly abundant element. Day by day heavy research is going on to overcome the major drawbacks such as huge cost of extraction. The low energy density is also a considerable problem. A low range travels involves the continuous production of hydrogen on-board a vehicle and is also promising but these days not at a low cost. The replacement of gasoline with hydrogen as the mass fuel requires convenient and low cost running, low filling times and long travel on single fuelled tank. Until any new technology to achieve stated facts till end of reservoirs of gasoline will continue to dominate the fuel market. The day when hydrogen becomes capable of offering the same conveniences as that of gasoline, definitely gasoline and all remaining fossil fuels will be replaced by hydrogen [10]. This suggests the necessity and wide scope of research needed in area of hydrogen storage and its handling.

IV. CONCLUSION

Today, it becomes necessary to replace the fossil fuels to a renewable, cleanest fuel such as hydrogen of engine combustion processes. Use of hydrogen is the efficient and economical way to decrease the pollutant emissions level drastically. This will also beneficial to reduce the dependency on hydrocarbons fuels. The properties posses by hydrogen has plays vital role to be an excellent fuel for internal combustion engines and they also signifies a reliability to replacement of conventional fuels, same time it also provides the benefit of less modification and no change in operating principles of the existing engines design.

From above study we come to know the direct injection of hydrogen is profitable in all terms but it also add new components there by cost and modification to existing operating system. The partial substitution is advantageous compared to total substitutions as no or less modification needed but at high excess air ratios the operation of system deteriorates. A total substitution is more advantageous than the partial in case of power output as it gives grater power output while consuming less quantity of fuel. But for small capacity engines it is found that power output of engine lowers due to leaner combustion. Also in all types of hydrogen usage safety has prime importance.

V. FUTURE SCOPE

It is possible that hydrogen will dominate the fuel market in future and in next coming days can be act as best alternative to the conventional fossil fuels as it is cleanest and renewable fuel. To convert the existing SI engine on hydrogen without any large modifications it is very important and necessary to find out the best suitable composition of Hydrogen-Air-Gasoline mixture for small, medium and high capacity engines. The maximum power output at best economy, low specific fuel consumption and also clean and complete burning and low emission levels should be obtained when engine runs on above mentioned composition. Also there is huge scope in development of sustainable design and manufacturing of storage and handling devices of hydrogen which are having no risks of fires and explosions.

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