STUDIES ON TIMED MANIFOLD INJECTION IN HYDROGEN OPERATED SPARK IGNITION ENGINE : PERFORMANCE, COMBUSTION AND EXHAUST EMISSION CHARACTERISTICS

by

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CERTIFICATE

I, the undersigned, certify that the thesis entitled "Studies on Timed Manifold Injection (TMI) in Hydrogen Operated Spark Ignition Engine - Performance, Combustion and Exhaust Emission Characteristics" submitted by Mr. Lalit Mohan Das for the award of the degree of 'Doctor of Philosophy' in the Faculty of Engineering of the Indian Institute of Technology, New Delhi is a record of candidate's own bonafide research work carried out under my guidance and supervision. The matter embodied in this thesis has not been submitted in part or full, elsewhere for the award of any degree.

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ABSTRACT

Spark ignition (S.I.) engines are widely used in the transportation sector, agricultural sector, and for various miscelleneous applications. These engines are invariably the primemovers for light vehicles. They are used in tractors and for small size portable gen-sets. They have varied and many applications. Their numbers are rapidly growing and there is no replacement for them in foreseeable future.

These engines use petroleum fuels which are non-renewable in nature. There are limited reserves of these fuels and they are not going to last long. The consumption of petroleum fuels has been growing rapidly with the growing use of engines. The world seems to need more and more of these engines and the engines need fuel. This has caused great scarcities and the prices of petroleum fuels have increased rapidly in the world market.

The growing use of vehicular engines burning petroleum fuels has increased vehicular exhaust emissions. Pollution from automobiles has now acquired a menacing proportion. Automobile exhaust accounts for most of the carbon-monoxide and lead pollution of the environment. Unburned hydrocarbons and oxides of nitrogen coming out from the tail pipes of vehicles contribute towards photochemical smog formation.

The modern world is thus forced with the twin problems of growing scarcity of petroleum fuels needed for operating the ever-growing number of automobiles, as also the rapid degradation of the environment due to vehicular exhaust pollution. It is increasingly being realised world over that the only solution to these problems lies in searching out "clean-burning" renewable, alternate fuels for automobiles.

Hydrogen is one such fuel. Hydrogen offers the distinctive advantage of being the only fuel the basic resource of which is recyclable in a short time cycle. It starts with water molecule being split using energy from practically any non-fossil source such as solar, nuclear, wind and organic waste and upon combustion produces water vapour as the principal exhaust which ultimately returns to the earth's water supply. Thus, looking at the future, hydrogen, has an unlimited supply potential.

Water formed when hydrogen burns is harmless and hydrogen itself is non-toxic. Since the fuel does not contain either carbon or sulphur atoms, the exhaust emissions from a hydrogen-fuelled engine does not contain carbon monoxide, carbon dioxide, hydrocarbons, sulphur dioxides and particulate matter. Additionally it contains no lead, no smoke and is virtually odourless. Hence, from an environmental standpoint hydrogen can be considered an exceptionally "clean" fuel. The only pollutant of concern in a hydrogen-fuelled engine is nitric oxide.

Hydrogen, because of its wider flammability limits and smaller flame quench distance, is likely to have more complete combustion inside the engine cylinder as compared to hydrocarbon fuels. Hydrogen can be ignited in a conventional spark ignition (S.I.) engine with a low energy spark. Because of wide flammability range, hydrogen powered engines can adopt "quality regulation" which not only reduces throttling losses, but enables the engine to operate on an ultralean mixture in over wide ranges of load and speed.

Radiation hazard from a hydrogen-air fire is less compared to that from a corresponding hydrocarbon fire because of the low emissivity of hydrogen flame. Moreover, the radiations from a hydrogen fire are at a wavelength which is readily absorbed by the atmosphere. Being very light, leaking hydrogen rises rapidly through air, thus confining the risk of explosion only to the space immediately above the leak. On the other hand, spilled gasoline quickly spreads over the ground, thus endangering a larger area surrounding the spill.

However, use of hydrogen as an S.I. engine fuel poses a number of problems such as backfiring during suction, preignition during compression and knocking due to rapid rate of pressure rise during combustion. These and other allied problems have seriously hampered the use of hydrogen as a spark ignition engine fuel. In the present investigation efforts have been made to generate extensive experimental data on performance, emission and combustion characteristics of hydrogen operated engine and explore the possibility of identifying some potential solutions to these problems.

Fuel-air mixture formation technique seems to have a very great impact on engine performance. Backfiring during suction of the hydrogen-air mixture happens to be one of the greatest problems associated with hydrogen engine. To overcome this problem different fuel induction techniques were tried to find the best possible induction method suitable for wide range of hydrogen operation without backfire. With both carburettion and continuous manifold injection techniques the hydrogen-fuelled engine gave "severe" backfire under some operating conditions or other. Experiments with these two induction techniques showed that neither carburettion nor continuous manifold injection is completely free from the malady of backfire.

The other methods that were tried included timed manifold injection (TMI) and low pressure direct cylinder injection (LPDI). With LPDI it was found difficult to cover the entire range of load, speed and equivalence ratio. Even though the injector worked satisfactorily and the nagging problem of leakage was virtually solved it was difficult to have sufficient hydrogen flow rate to provide a rich mixture at relatively low pressures.

A comparison between LPDI and TMI indicated that LPDI is an unattractive approach. Hydrogen seems to be very difficult to mix with air during the near-stagnant cylinder conditions that exist after the closure of the intake valve. As a result, complete fuel-air mixing for a charge with near-stoichiometric composition is almost impossible.

Because of the tough requirement on the part of the injector to survive in contact with combustion chamber pressure and temperature and because of the limitations of getting the entire range of engine performance at relatively low pressures (upto 8 Kgf/cm^2) and due to the problem of inadequate mixing conditions, LPDI was not found to be a satisfactory method of mixture formation.

Timed manifold injection (TMI) was finally adopted as the fuel induction technique. This involved timed injection of fuel delivered under a pressure of 1.4 to 5.5 Kgf/cm^2 at appropriate positions in the intake manifold, but upstream the intake valve. The timed injection was scheduled such that the fuel was being injected after allowing a sufficient quantity of fresh air to enter the combustion chamber, and to reduce the temperature levels of potential hot spots. The most difficult practical problem encountered was the development of a suitable injector without any leakage. Several injector designs were developed and tested to satisfy the combined requirement of ensuring appropriate injection duration with flow controllability. Cam-actuated and hydraulically operated injectors were specifically designed, fabricated and developed for tests with timed manifold injection (TMI) and low pressure direct cylinder injection. Since the leakage of hydrogen at an unscheduled point in the cycle could lead to serious combustion as well as safety-related problems, the development of a leak-proof injector over an extended period of operation seemed to be one of the most stringent requirements in the implementation of the system hardware. Different materials after various heat treatment methods were tested in the severe thermal environment of the engine combustion chamber of a gasoline engine to eliminate long range reliability problems connected with leakage, wear, corrosion and material compatibility. It is only after a series of severe endurance tests that the injector was put to hydrogen use.

Two different designs of hydrogen injectors were developed for this purpose. The finally accepted version was evolved through a series of modifications keeping in view the injection pressure, injection duration and hydrogen flow controllability. With the injector developed, quality governing of the fuel delivery could be easily achieved as it was not strictly dictated by intake air flow.

In the experiments four different injection durations of 14°, 45°, 60°, 70° crank angle (CA) were tried. The 14° CA duration was obtained with the hydraulically operated injector. The physcial design of the injector seemed to be very sensitive and did not offer much flexibility in changing the injection duration. To have the required flow rate over such a short injection duration would have been to increase the supply pressure of hydrogen gas. The cam-actuated injection system proved much superior in this respect. The injection duration could be very conveniently altered with the system to obtain the required flow capabilities. However, for TMI, injection duration did not seem to be a critical factor for engine performance unless the duration is drastically changed. Regulating the fuel feed pressure rather than altering the injection duration appeared to be an easier mode of operation. Therefore all the experiments were carried out with 45° crank angle injection duration.

A single cylinder Varimax research engine was selected for the tests. This engine offers sufficient scope of generating a vast amount of quantitative information. It permits variation of spark timing, compression ratio, injection timing over a wide range and under dynamic conditions. Optimal dynamic control of various engine parameters can be accomplished while the engine is running, thus giving a clearer picture of engine overall performance. The engine was instrumented to provide information on peak cylinder pressure, rate of pressure rise and combustion duration. Oxides of nitrogen (NO_x) were also experimentally determined as functions of equivalence ratio.

Detailed experiments were carried out over entire range of engine speed and load. Series of tests were also conducted at consecutively increasing equivalence ratios from lean combustion limit to the rich mixture, a little above the stoichiometric. Compression ratios were changed from 6:1 to 11:1.

Based on the test results various graphs were also plotted to correlate mean effective pressures and thermal efficiency with equivalence ratios and compression ratios at different engine speeds. Other important engine parameters such as fuel consumption, power output and mechanical efficiency were calculated to obtain hydrogen engine characteristics at various operating ranges.

The engine was able to run at a very low equivalence ratio (0.218). But it was observed that for an equivalence ratio below 0.28, the ignition could not be sustained.

Peak power output calculations showed it to be quite high if the unique advantageous features of hydrogen as a fuel are appropriately explored and capitalized whenever possible.

The exhaust gas temperature using hydrogen was found to be lower than that using gasoline as fuel.

Even though unthrottled operation was found in general to exhibit higher brake thermal efficiency, it was practically observed that some throttling was necessary at very light loads to limit extremely lean operation.

On the strength of the present work, it can be concluded that hydrogen can be conveniently utilised as a fuel in the spark ignition engine. There is no fundamental engine-related problem that could hamper the adaptation of the engine to hydrogen use. An appropriately designed timed manifold injection (TMI) system can eliminate undesirable combustion phenomena associated with carburettion of hydrogen.