FUEL INDUCTION TECHNIQUES FOR A HYDROGEN OPERATED ENGINE

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Abstract—It is practically impossible to replace the internal combustion engines which have already become an indispensable and integral part of our present day life style, particularly in the transportation and agricultural sectors. Unfortunately, the survival of these engines has, of late, been threatened by the dual problems of the fuel crisis and environmental pollution. Therefore, to sustain the present growth rate of civilization, a non-depletable, clean fuel must be expeditiously sought. Hydrogen exactly caters to these specified needs. Hydrogen, even though "renewable" and "clean-burning" it does give rise to some undesirable combustion problems in an engine operation, such as backfire, pre-ignition, knocking and rapid rate of pressure rise. It has been experimentally evaluated that the fuel induction technique (FIT) does play a very dominant role in obtaining smooth engine operation. This paper discusses such various possible modes. Research work carried out by different investigators has been highlighted.

1. INTRODUCTION

A fuel has an infinite supply potential. It can be generated from water using any non-fossil energy source and upon combustion it produces water which goes back to the earth's water supply system from where it came. From an environmental standpoint, it is exceptionally clean.

The above-mentioned characteristics define a very desirable fuel and hydrogen does possess these characteristics. So situations arising out of the present-day energy crisis do not affect the hydrogen-fuel-system. As far as engine operation is concerned, a total hydrogen-fuelled engine will not emit unburnt hydrocarbons, CO, particulate matter, sulphur dioxide, smoke etc. From several practical considerations hydrogen is safer compared to conventional petroleum fuels. Being very light, leaking hydrogen rises up very rapidly through the air, thus creating an explosion possibility only to the space immediately above the leak. On the other hand, spilled gasoline creates safety-related problems which do persist for a long time. Because of low emissivity characteristics, radiation hazards from a hydrogen flame are of lesser consequence as compared to a gasoline flame.

It is evident that petroleum fuels are liquid at room temperature whereas hydrogen remains a gas even at a much lower temperature (i.e. — 253°C). The flammability limits, ranges of equivalence ratios over which the engine system is operable, auto-ignition temperature and minimum ignition energy are some of the properties which determine the suitability of the fuel for engine application. However, since some combustion characteristics of hydrogen fuel set it completely apart from other conventional fuels, unless these properties are appropriately exploited to an advantage for improved engine characteristics, they might give rise to various unwanted combustion problems.

2. UNDESIRABLE COMBUSTION PROBLEMS

Figure 1 shows the ranges of equivalence ratios suitable for hydrogen engine operation. A close look at the properties of the fuel brings in some very important points with respect to engine operation. Interestingly, most properties of hydrogen fuel if appropriately exploited to a point of advantage, could prove extremely desirable. On the other hand, the same property, if wrongly used, could be fatal.

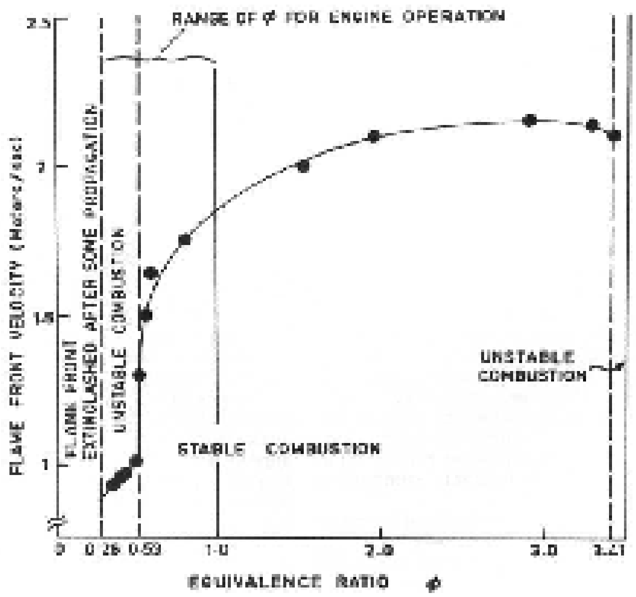

Fig. 1 Ranges of equivalence ratio for engine operation

The ignition energy required to ignite an air-fuel mixture depends very much on the air-fuel or equivalence ratio—hydrogen has an extremely low ignition energy compared to gasoline. This is a very crucial property. On one hand, the low minimum ignition energy enables the conventional ignition system to be effective with a very low energy spark whereas at the same time it makes the system susceptible to surface ignition. Surface ignition is a highly undesirable combustion phenomenon because it precipitates flashback, pre-ignition and rapid rates of pressure rise. Based on the lower flammability limit, hydrogen seems to be superior to gasoline, but a small leakage from a hydrogen operated system brings in the problem of safety. As far as the quenching distance is concerned, hydrogen combustion which can be initiated with a low energy spark, becomes difficult to quench. Because of the smaller quenching distance of hydrogen, a flame in a hydrogen-air mixture escapes more readily past an even nearly closed intake valve than a hydrocarbon-air mixture.

The minimum ignition energy required for ignition (0.02 mJ) of a hydrogen-air mixture has often been responsible for the fresh charge being ignited and thereby causing a flame that propagates through the induction system giving rise to backfire. The simplest method to avoid backfire is to ensure the absence of combustible mixture in the intake manifold. A reduction of temperature level could also prove very effective. On the other hand, conditions leading to pre-ignition could be disposed of by preparing a late hydrogen-air mixture. These can be achieved by various methods such as (i) use of leaner mixtures, (ii) exhaust gas recirculation, (iii) intake air cooling (by liquid hydrogen or by water) and (iv) reduction of valve overlap.

3. FUEL INDUCTION TECHNIQUES (FIT)

The fuel induction techniques have been found to be playing a very dominant and sensitive role in determining the performance characteristics of an I.C. Engine. The 'FIT' for an S.I. engine can be classified into four categories such as Carburetion, Inlet Manifold Injection, Inlet Port Injection and Direct Cylinder Injection. These conventional methods of 'FIT' could also be applied to engine operation with a non-conventional alternative fuel, such as hydrogen. Of these methods; carburetion by the use of a gas carburettor has been the simplest and the oldest technique. In a gasoline-fuelled engine, the volume occupied by the fuel is about 1.7% of the mixture whereas a carburetted hydrogen engine, using gaseous hydrogen, results in a power output loss of 15%. Thus, apart from eliminating unwanted combustion symptoms, fuel induction techniques have also been quite effective in compensating for the power loss. Injection of hydrogen into the inlet manifold offers an alternative to the conventional load control method by throttling. This method uses the typical properties of hydrogen fuel (such as wide flammability limits) to a point of advantage. It also possesses the ability to initiate fuel delivery at a timing position sometime after the beginning of intake stroke. The system could be so designed that the intake manifold does not contain any combustible mixture thereby avoiding extreme situation leading to undesirable combustion phenomena. In a carburetted engine system, the valve overlap between the exhaust and the intake stroke can bring the fuel-air charge into contact with the residual hot gases. However, if by any chance pre-ignition does take place during intake stroke, it will have much lesser consequence as compared to that occurring in a carburetted engine. Some investigators have also carried out research on intake port injection. In such a system both air and fuel enter the combustion chamber during the intake stroke, but are not pre-mixed in the intake manifold.

Direct cylinder injection of hydrogen into the combustion chamber does have all the benefits of the late injection as characterized by manifold injection. In addition, the system permits for fuel delivery after the closure of the intake valve and thus, intrinsically precludes the possibility of backfire. However, as described later, the injection system will have to cater to some stringent requirements in respect of the severe thermal environment which the injector is bound to encounter. Besides, all the mechanical parts which form part of the injection system must be able to withstand such a high pressure, say to the tune of about 100 atm. When considering a practical automobile, maintaining a high pressure such as about 100 bars, in a vehicle for onboard storage methods raises serious problems. However a detailed discussion on vehicular storage methods is beyond the scope of the paper.

4. ACHIEVEMENTS AND GAPS

Researchers throughout the world have been working persistently for decades and hence most of the benefits and problems of hydrogen engines have already been identified.

A definite conclusion which can be drawn from these research results is that the undesirable combustion phenomena have greatly impeded the practical achievement of a common hydrogen-fuelled autovehicle: and the mode of fuel induction from one method to other has very seriously influenced the situation.

In the earliest phase of hydrogen engine research Ricardo [1], had adopted the carburetted technique, primarily with a view to achieve hydrogen-fuelled engine operation. Ricardo is reported to have encountered the problems of "popping back into the carburettor"