Review of Challenges In Designing Fuel Induction System For Hydrogen Fuelled Engine

Gutte K. P.[1], Fulari S. P.[2], Jadhav D. V.[3], Gonate D. N.[4],Shinde V. V.[5]
[1, 2, 3, 4, 5]Department of Mechanical Engineering
[1, 2, 3, 4, 5]Sinhgad Institute of Technology, Kusgaon (Bk), Lonavala

Abstract*-Considering the limited fossil fuel reserves, the hydrogen has been considered as one of the substitution fuel for spark ignition engine. Hydrogenfulfils the required needs of SI engine and it is one of the renewable and clean burning fuel. It has been experimentally evaluated that the fuel induction technique does play a vital role in obtaining smooth engine operation. We have calculated the required air-fuel ratio for hydrogen to be burned in combustion chamber. Based upon these calculations we have studied various fuel induction techniques like carburation, timed manifold injection, continuous manifold injection and direct cylinder injection. We compared all these techniques with parameters like cost, design complexity, availability, material and adaptability. After studying merits and demerits of these techniques for hydrogen based engine, we finally concluded that, the carburettor with appropriate modifications can enhance the performance of hydrogen based engine. This review has influenced and guided design of fuel induction system for hydrogen fuelled engine.*

Keywords:-Hydrogen, Fuel induction technique, SI engine, Air-fuel ratio, Carburettor, etc.

I. INTRODUCTION

It is well known that fossil fuel reserves are becoming exhausted at an alarming rate. Moreover, the combustion of such fuels results in the emission of noxious pollutants which threaten the survival of life in this planet [1]. The role of existing internal combustion engines needs to be reviewed now in the context of these two major crises. In view of the versatility of internal combustion engines, they will continue to dominate the transportation sector [1].

There is a considerable limitation for the battery and fuel-cell powered vehicles with regard to range and acceleration. Apart from the limited life period, the other problem with the unrestricted combustion of fossil fuels is the level of CO_2 emission into the Earth's atmosphere [2]. There are various alternative fuels that are being seriously investigated in several parts of the world. The currently used hydrocarbon fuels release about the same amount of CO_2 per amount of heat produced and even hydrocarbon fuel with a greater hydrogen content do not lead to substantial improvement. Hydrogen shows the distinctive features of a practically acceptable carbon-free fuel [3].Hydrogen reduces the smoke, particulate and soot emissions to the considerable amount by the maximum replacement of 20% in C.I engine without sacrificing the engine power output [3]. The problems like pre-ignition and backfire could be eliminated compared to S.I engine that make the usage of hydrogen to be safer in CI mode [4].

In the history of engine development, hydrogen has been tried several times as an alternative fuel chiefly from the point of view of shortage of fossil fuels. Hydrogen does not experience problems associated with liquid fuels, such as vapor lock, cold wall quenching, inadequate vaporization, poor mixing, and so forth. The other significant feature of hydrogen in the present day context is the “clean-burning” characteristics of the fuel[5]. When hydrogen is burned in air, the main product is water. Hydrogen combustion does not produce toxic products such as hydrocarbons, carbon monoxide, oxides of sulphur, organic acids and carbon dioxide. Acid rain and the CO_2 greenhouse effect are eliminated. Some oxides of nitrogen are generated and our experiments show that it is possible to get the concentration of NOx drastically reduced by monitoring the engine operation. In today's world, where the effect of global warming turns out to be a crucial problem, the basic advantage of hydrogen combustion is that the greenhouse gas carbon dioxide (CO_2) is not formed at all when hydrogen is burned. This clean-burning property promises an accelerated entry of hydrogen into the existing transportation sectors, as well as several energy consuming sectors, of the developing countries[12].

Like CNG, hydrogen engine fuelling also needs an entirely different approach from that of liquid fuelling.The main objective is to ensure proper air-fuel mixture to the engine reducing the main hindrances like backfire and pre-ignition to some extent[6]. Various types of fuel induction techniques are carburetor continuous manifold injection (cmi), timed manifold injection (tmi), low pressure direct injection (lpdi) & high pressure direct injection (hpdi).

According to various conditions and parameters these various methods of fuel induction technique are being used for hydrogen fuelled engine [6].

The main challenges in the designing of the fuel induction technique for the hydrogen fuelled engine are the various properties of hydrogen. Hydrogen is highly inflammable, it is lighter than the air hence escape from little gap also, its density which cause to spread it over large distance within short period of time. Such basic problems occurring in the designing of fuel induction technique make it challenging and complex. Hydrogen is very efficient fuel as compared to other fuels and also it is the environment efficient fuel. But due to the safety problems the usage of hydrogen are limited. Use of hydrogen for transportation in automobile industry is restricted due to the lack of efficient and safe fuel induction technique[7].

Here in this paper, we reviewed various types of fuel induction techniques used for hydrogen fuel induction. We studied the working of the fuel induction techniques and compared all those techniques with various parameters. Parameters like cost, material, availability, adaptability, system requirement etc. were studied. Based on the study of these techniques on such parameters we observed some merits and demerits of all techniques. By studying these merits and demerits one can easily select the best fuel induction technique.

II.STUDY OF VARIOUS FUEL INDUCTION TECHNIQUES

Detailed study of above mentioned fuel induction techniques are given here.

A. Carburetor

Carburetor is the device which is used to create the homogenous mixture of fuel and air in certain specific amount. The main function of the carburetor is to supply the required quantity of mixture in proper proportion[6]. As the engine started the suction is created inside the cylinder and air flows from atmosphere to cylinder as the air passes through the venturi the pressure of air fall below the atmosphere, the pressure at the nozzle tip is also below atmosphere because on fuel surface in the fuel tank is also atmospheric[8]. This pressure difference causes the flow of fuel through fuel jet into the air stream as the fuel and air pass head of venturi the fuel gets vaporize and uniform mixture is supplied to engine. The quantity of mixture supplied to the engine depends on opening of throttle valve[9].

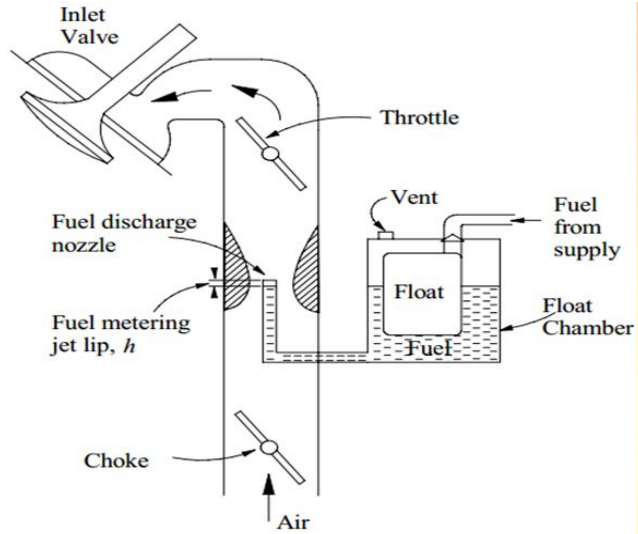

Fig. a Simple Carburetor

Advantages

i. Simple and cheap
ii. If curative steps are taken the problem of backfire can be reduced to some extent

Disadvantages

i. Uncontrolled combustion leads high pressure rise.
ii. Backfire and pre-ignition.

B. Continues Manifold Injection

In this system fuel flows at all time from the fuel injectors but at the variable flow rate. This is in contrast to most fuel injection systems which provide fuel during short pulses of varying duration with the constant rate of flow during each pulse[6]. Continuous injection systems can be multipoint or single point but not direct. The control unit simply uses a butterfly valve for the air which is linked by a mechanical linkage to a rotary valve for the fuel.

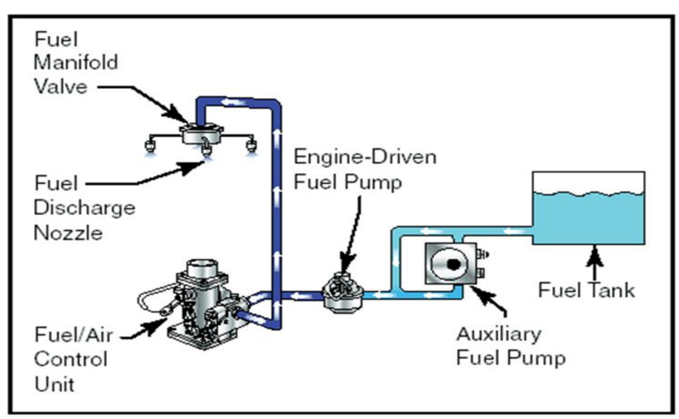

Fig. bContinuous Manifold Injection

Advantages

i. Improved fuel air mixture / ratio
ii. Uniform delivery to all cylinders
iii. Easier starting

Disadvantages

i. Major problem of backfire with hydrogen engine
ii. Expensive than carburetor

C. Timed Manifold Injection (TMI)

It is observed that TMI system offer an alternative tool load control method by throttling. It possess ability to initiate fuel delivery at a timing position sometimes after then beginning of intake stroke. The system was designed so that the intake manifold does not contain any combustible mixtures there by avoiding extreme situations leading to undesirable combustion phenomenon. TMI system is designed to ensure air been inducted prior to fuel delivery this provide a precooling effect and thus renders the pre ignition sources ineffective. Furthermore, it helps to quench and dilute any residual combustion products that could be present in the compression space near TDC[6].

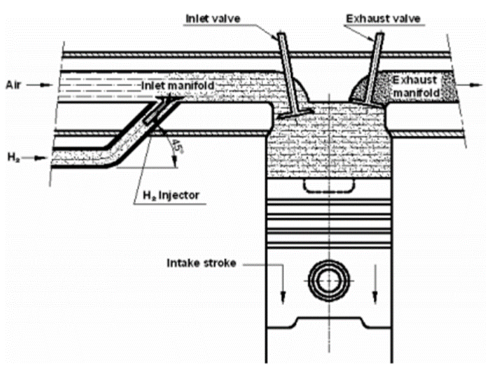

Fig. cTimed Manifold Injection

Advantages

i. Appropriately designed TMI can removed undesirable combustion phenomenon such as backfire and pre ignition.

Disadvantages

i. Very high cost of injector and system leads to high operating cost.

D. Low Pressure Direct Injection System (LPDI) And High Pressure Direct Injection System (HPDI)

In LPDI hydrogen at low pressure is directly injected into the combustion chamber while in HPDI hydrogen in liquid form at high pressure is directly injected into combustion chamber. HPDI system requires a cylinder for storage of liquid hydrogen and a pump for supplying hydrogen to the engine which makes the system bulky[11].

Advantages

i. It eliminates problem of backfire and pre-ignition.

Disadvantages

i. It has problem of incomplete combustion due to less time allowed of air fuel mixing.
ii. The injector needed to be capable of surviving in the severe thermal environmental condition as hotspot are created in combustion chamber, which ultimately result in increasing cost of maintenance and operation.

III.AIR-FUEL CALCULATION

For any kind of SI engine to operate in good condition, supply of proper A/F ratio is must. Therefore fuel induction system has to supply the appropriate amount of the air fuel mixture to the engine. The system must be adaptable to the sudden changes in the requirement of the air fuel ratio[10].

The theoretical or stoichiometric combustion of hydrogen and oxygen is given as:

$$2H_2 + O_2 = 2H_2O$$

Moles of H_2 for complete combustion = 2 moles
Moles of O_2 for complete combustion = 1 mole

Because air is used as the oxidizer instead oxygen, the nitrogen in the air needs to be included in the calculation:
Moles of N_2 in air
= Moles of O_2 x (79% N_2 in air / 21% O_2 in air)
= 1 mole of O_2 x (79% N_2 in air / 21% O_2 in air)
= 3.762 moles N_2

Number of moles of air = Moles ofO_2 + moles ofN_2 = 1 + 3.762
= 4.762 moles of air

Weight of O_2 = 1 mole of O_2 x 32 g/mole = 32 g
Weight of N_2 = 3.762 moles of N_2 x 28 g/mole = 105.33 g
Weight of air = weight of O_2+ weight of N (1)
= 32g + 105.33 g
= 137.33 g
Weight of H_2 = 2 moles of H_2 x 2 g/mole
= 4 g

Stoichiometric air/fuel (A/F) ratio for hydrogen and air is:

A/F based on mass:
= mass of air/mass of fuel
= 137.33 g / 4 g
= 34.33:1
A/F based on volume:
= volume (moles) of air/volume (moles) of fuel
= 4.762 / 2
= 2.4:1

The percent of the combustion chamber occupied by hydrogen for a stoichiometric mixture:

% H_2 = volume (moles) of H_2/total volume (2)
= volume H_2 / (volume air +volume of H_2)
= 2 / (4.762 + 2)
= 29.6%

As these calculations show, the stoichiometric or chemically correct A/F ratio for the complete combustion of hydrogen in air is about 34:1 by mass. This means that for complete combustion, 34 pound of air are required for every pound of hydrogen.

IV. COMPARISON OF VARIOUS FUEL INDUCTION TECHNIQUES

We have compared all above fuel induction techniques on different parameters.

In carburetor the problem of backfire is pronounced due to uncontrolled combustion also in continuous manifold injection there are symptoms of backfire. In timed manifold injection backfire problem reduces up to certain level and in HDPI & LPDI backfire can be eliminated completely.

Adaptability of the carburetor with system is more than any other fuel induction technique. Controlled manifold injection technique also adaptable with large no. of systems whereas the TMI, LPDI & HPDI techniques are less adaptable with the system. The fuel induction technique must be adaptable with the system to supply appropriate amount of air-fuel ratio.

Comparing with system requirement of various fuel induction technique, carburetor and CMI has less system requirement. LPDI needs moderate system requirement to adopt system but HPDI & TMI needs more system requirements to adopt the system. High pressure direct injection technique requires pressure controlling and pressure storing devices which needs more area and more system parameters to adopt the system.

Availability of the various fuel induction technique in market helps the system to keep updated with latest innovations. Carburetor and CMI systems are easily available in the market whereas HPDI system is difficult to get in market as HPDI system has highly precise components. Systems like LPDI and TMI can be obtained easily in market.

Comparing on the basis of the material of various fuel induction technique, carburetor is made up of cast iron whereas CMI is available in cast iron as well as in plastic. LPDI system is made from steel and some of its components from cast iron. But HPDI system is totally made up of chromium and aluminium. According to preciseness working of various fuel induction techniques there material get changed. Working parameters also affect the selection of the material.

V. CONCLUSION

In this paper, the characteristics of different types of fuel induction methods were studied and their compatibility with hydrogen gas was taken into consideration. Thus by referring to our respective reference papers and other sources we have concluded that the use of Carburation System with suitable modifications can be best suited for hydrogen gas based engines, especially generator setup.

Carburetor is the simplest and easiest fuel induction technique for our system. Though it is oldest technique of fuel mixing, with suitable modification in carburetor it can be used for hydrogen gas based fuel engines.

LPDI, HPDI & TMI are better techniques but their complexity and low adaptability makes system too costly as compared to carburetor. Other fuel induction techniques are bulky and increases the weight and size of the system. By studying all parameters, we conclude that Carburetor best suits our system. In future, modifications and innovations in the HPDI & LPDI system will help the hydrogen fuelled engine.

All fuel induction techniques are capable of supplying appropriate air fuel ratio to the engine. But comparing on various parameters we observed many merits and demerits of the fuel induction techniques.

There is an immense scope in the field of energy when hydrogen is considered as a fuel. This respective field is still in its primitive stages and there are many challenges up ahead. This paper can be referred in the future and it will be very helpful for the upcoming research and will result in simplicity and further development of their project.

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