© 2015 IJEDR | Volume 3, Issue 3 | ISSN: 2321-9939

# Safety Aspects of a Hydrogen-Fuelled Engine System Development

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***Abstract* - Safety aspects will become essential for the introduction and acceptance of gaseous and liquid hydrogen as an energy carrier and fuel in energy supply system. However, its temperamental combustion behavior often raises problems of safety. This paper describes the development of an overall effective gaseous hydrogen fuel supply system for an engine test cell. In order to tackle the symptoms of undesirable combustion various safety measures have been discussed.**

***Index Terms* - Combustion, NFPA, Stoichiometric, Inertization, Embrittlement, Permeability, Inviscid**

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## I. INTRODUCTION

Hydrogen is probably a unique, versatile fuel which possess the potential of providing an ultimate solution to the twin problems of the energy crisis and environmental pollution. Unfortunately this fuel cannot be routinely handled exactly in the same manner as the conventional petroleum-based fuel, because of the wide difference in combustion characteristics of both fuels.

Hydrogen is a renewable, recyclable fuel which can be generated from an infinite source potential using practically any non-fossil energy. Upon combustion, it produces almost no harmful pollutants. Tables 1 and 2 list some important properties of hydrogen which must be carefully reviewed in planning out the development of a safe hydrogen-fuelled engine system. Initially, at present a hydrogen engine has to be basically a converted system, from one which has been originally designed to operate on petroleum fuels. Any "converted system", in general is bound to exhibit some reliability and safety problems. Evaluation of the safety hazards of hydrogen fuel operating in a petroleum-fuel based engine system is obviously a highly complex task. Perhaps the magnitude of these safety related problems could be drastically reduced when used in a hydrogen-specific engine system.

There exists an inherent difference between the use of hydrogen and hydrocarbon fuel in engines irrespective of in whatever form the former is used, i.e. whether gas(medium. pressure or high pressure), cryogenic liquid or metallic hydrides. Therefore, care must be exercised throughout the entire sequence of creating a convenient situation for adopting a facility so that this new fuel exhibits a standard of safety currently accepted for existing conventional fuels which have achieved such standards after long years of wide spread use.

## II. DESIGN CONSIDERATIONS

As emphasized earlier, hydrogen has a few properties which set it apart from conventional fuels. The properties which require special treatment to lessen the chances of risk are broad combustible range, low minimum ignition energy and rapid rate of diffusion. It will not be out of context to emphasize at this point that hydrogen has been classified by the NFPA (National Fire Protection Association) in its most hazardous group of flammable liquids, gases and volatile solids. It is thus essential that specific care be taken in selecting the material as well as location for hydrogen fuel utilization.

Hydrogen has a specific gravity of 0.0695 at 20˚C and 101.3 kPa. It is the smallest and the lightest element in nature. Thus, it can diffuse rapidly through air. Hence, if hydrogen is used in a confined area, there is a possibility of diffused hydrogen being amassed at the top. In an engine system, cast parts should be avoided as far as possible. Cast parts, being porous, could help diffuse hydrogen under certain circumstances and create unanticipated problems. The low molecular weight of hydrogen results in a high diffusivity such that hydrogen diffuses 3-8 times faster than air.

Hydrogen is colourless, odourless and tasteless. Most of the gaseous fuels, in general, contain odorants. So, odorized warning agent will work well as an additive to gaseous hydrogen. At stoichiometric composition, the minimum spark energy of hydrogen is an order of magnitude lower than that of hydrocarbons. It is because of this property, hydrogen-air mixture can be ignited by a number of ignition sources some of which may be relatively weak also. Hydrogen fuel possesses a high normal burning velocity which is a very important safety-related property of a combustible fuel. This, however is different from the flame speed, which is the sum of burning velocity and displacement velocity of the of the unburnt gas mixtures. The stoichiometric value of hydrogen burning velocity is almost five times that of propane.

| Property | Hydrogen | Methane | Gasoline |
|---|---|---|---|
| Molecular weight | 2.016 | 16.043 | 107.0 |
| Density at NTP(g/m³) | 83.764 | 651.19 | 4400 |
| Specific heat(J/g/K) | 14.89 | 2.22 | 1.62 |
| Specific heat ratio | 1.383 | 1.308 | 1.05 |
| Viscosity | 0.0000875 | 0.000110 | 0.00005 |

| | | | |
|---|---|---|---|
| Gas constant(R) | 40.7030 | 5.11477 | 0.77 |
| Diffusion coefficient | 0.61 | 0.16 | 0.005 |
| Heat of combustion low (KJ/g) | 119.93 | 50.02 | 44.5 |
| Heat of combustion high (KJ/g) | 141.86 | 55.53 | 48 |

Thermodynamic properties (generally accepted values from the literature)

## III. CURATIVE AND PREVENTIVE MAINTENANCE

It is advisable to use special, effective hydrogen- specific sensors to monitor this combustible gas in a hydrogen environment. In the event of an accidental leakage the combustible gas monitoring system should automatically come into operation thereby shutting off the fuel supply. The location of the detecting device is a critical consideration. Sometimes the response and sensitivity of the detector may be influenced by the presence of moisture or by a mixture of gases such as nitrogen, carbon dioxide and helium.

Besides using nitrogen, carbon dioxide, etc., extinguishing powders such as ammonium phosphate or potassium chloride can also bring about inertness. These have been found to be quite successful as a means for temporary inertization of hydrogen-air mixtures, thereby preventing explosions from progressing through the systems. These are, therefore functionally effective explosion suppressants.

It has been reported that a liquid hydrogen splash does not damage the tissue immediately. This is so because the blood supply to the tissue acts as a heat source which causes the formation of a protective gas film between the cryogen of the warm tissue. The extent of damage seems to be larger in the case of touching surfaces which have been cooled by liquid hydrogen or cold hydrogen vapours. The period of exposure, in all such cases essentially determines the magnitude of loss caused due to frostbite.

In view of the small size of hydrogen atoms and the molecules they can be readily dissolved into and diffuse through many materials, thus resulting in considerable degradation of the mechanical properties of most metals. Such a phenomenon is referred to as embrittlement. Hydrogen embrittlement often causes premature structure failure by brittle fracture. The failures of aerojet pressure vessels and Los Alamos pipeline have already shown that the extent of damage due to embrittlement could be quite severe at welds. Thus safety aspects in material selection form an important factor in hydrogen service. All structures essentially are susceptible to varying extents of hydrogen embrittlement. It has been found out that ferric steels and nickel-based super alloys are highly susceptible, whereas austenitic stainless steels are only moderately affected and low aluminum alloys and copper alloys are relatively unaffected.

The selection of the chemical for hydrogen use is a very important safety consideration because hydrogen reacts with a number of chemicals. For example, it explodes with chlorine in light.

## IV. ENGINE SPECIFIC SYSTEM

Certain inherent reliability problems of the system such as leakage, abrasion, wear, corrosion and material incompatibility must be thoroughly investigated and mechanical properties such as strength, hardness and machinability must be studied before adopting any material for hydrogen use. The choice of proper material is important. Permeability of steel to hydrogen is low at room temperature whereas the diffusion coefficient of hydrogen in steels is relatively high.

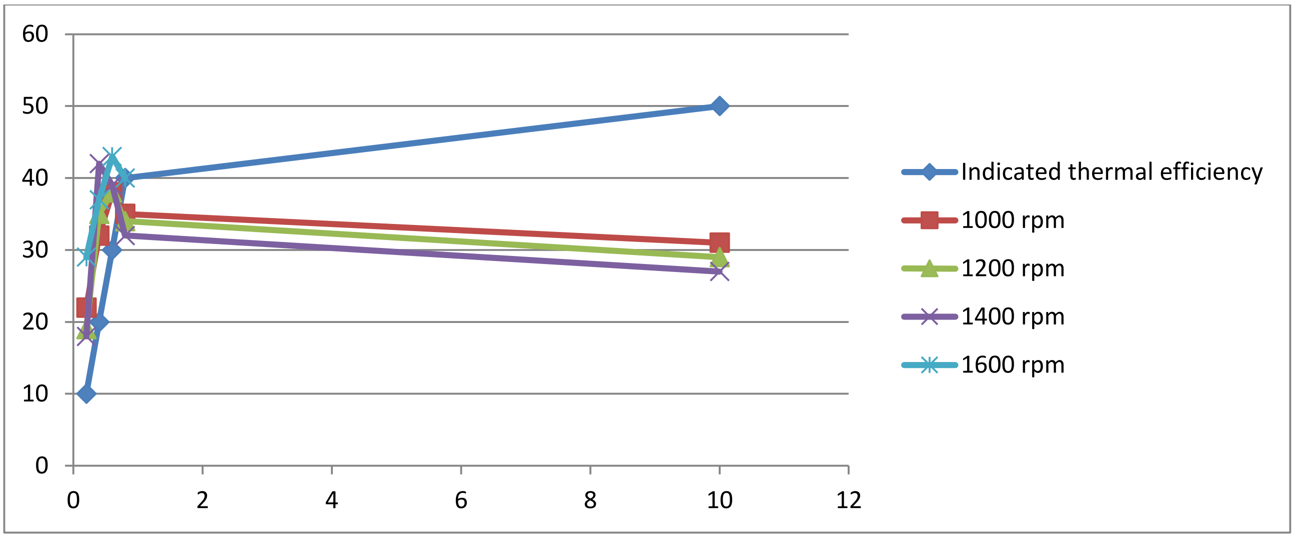
Engine operation should preferably be carried out with well dispersed water sprays in the exhaust. This helps suppress the detonation pressure and thus reduces the number and temperature of ignition sources in the exhaust system. Sometimes CO2 may be used along with the water sprays to reduce the effects of potential hazards. The fuel supply system should preferably work with precision and no improper adjustment or alignment problems should be permitted between different moving and connecting parts.

In a technical report, Zalosh and Short have brought forth some generic causes of hydrogen accidents as given in Table

| accidents as given in Table Category | % of Incidents |
|---|---|
| Undetected leaks | 22 |
| Hydrogen-oxygen off-gas explosion | 17 |
| Piping and pressure vessel rupture | 14 |
| Inadequate inert gas purging | 8 |
| Vent an exhaust system incidents | 7 |
| Hydrogen chlorine incidents | 7 |
| Other incidents | 25 |

The incidents due to undetected leaks demonstrate hydrogen’s propensity to leak past normally air-tight seals. Depending upon the pressure difference and the leak area, the volumetric leak rate is governed either by gas density or viscosity. A comparative evaluation between air and hydrogen indicate that hydrogen has larger viscous and inviscid leaks than air. So it will be erroneous to assume that an air-tight equipment is also “gas-tight”.

In today’s age one of the biggest problems that we face are the twin challenges of the fuel crisis and environmental degradation. Extensive research is being carried out in the whole world over the past several years. Both carburetion and timed manifold injection have been widely investigated as fuelling modes of an engine.




Equivalence ratio Vs Indicated thermal efficiency

The merits of timed manifold injection system have been brought out in terms of engine's performance. The above graph shows the indicated thermal efficiency as a function ratio at constant compression ratio for various speeds. Fuel induction techniques do play a sensitive role as far as safety aspects are concerned. The timed manifold injection system has been found to be superior to carburetion in that in the former the fuel injection can be delayed somewhat after the intake of air has begun with a view to facilitate reduction of temperature levels of the potential hot spots responsible for backfire and other undesirable combustion phenomena. However, development of a suitable injector demands certain rigorous conditions. In view of the wide flammability range of hydrogen and its invisible odourless flame, the injector, under no circumstances should leak hydrogen either into the engine cylinder or in the intake manifold at any unscheduled point in the cycle.

There occurs sometimes the possibility of engine misfire. Under such circumstances, any unburned hydrogen should be conducted to the outside through a closed exhaust system. Similarly, in the event of the engine stopping abruptly due to some reason hydrogen supply system should be cut-off immediately. These design precautions will ensure the possibility of no hydrogen being amassed in the event of a sudden accidental failure of engine operation.

## V. CONCLUSION

There is no room for doubt that a wee-educated person should be able to use hydrogen fuel safely. However, the hydrogen automobile need not be hastily introduced in a large scale without adequately demonstrating its safe operation. An initial bad image from premature introduction in public, can ultimately cause serious damage. Hydrogen-specific vehicles should be as routinely accepted as gasoline-powered vehicles probably after an initial run-in period in which demonstration automobiles would exhibit ample reliability and safety.

## REFERENCES

[1] National Fire Protection Association (NFFPA), Standard 325M, Fire hazard properties of flammable liquids, gases and volatile solids.
[2] D.P. Gregory, Scientific American, p.381
[3] T.L. Bowen, Hazards associated with hydrogen fuel, Proc.11th Intersoc. Energy Conversion Engng Conf.,p.997
[4] J.G. Hust, Survey for materials for hydrogen services
[5] J.S Laws, V. Frick and J. McConnel, Hydrogen gas pressure vessel problems in the M-1 facilities.
[6] D.A. Mathis, Hydrogen Technology for Energy
[7] R.G. Zalosh and T.P. Short, Comparative analysis of hydrogen fire and explosion incidents.
[8] P.R.Khajuria, Hydrogen fueled spark ignition engine-its performance and exhaust emission characteristics.
[9] H.B. Mathur, Combustion related studies on a timed manifold injection hydrogen engine
[10] http://auto.howstuffworks.com/fuel-efficiency/alternative-fuels/safety-concerns-of-fuel-cells.htm
[11] http://www.arhab.org/pdfs/h2_safety_fsheet.pdf
[12] http://www.thenakedscientists.com/forum/index.php?topic=34795.0