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HYDROGEN AS FUEL IN INTERNAL COMBUSTION ENGINE

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A number of manufacturers are now leasing demonstration vehicles to consumers using hydrogen-fueled internal combustion engines (H_2ICEs) as well as fuel cell vehicles. Developing countries in particular are pushing for H_2ICEs (powering two- and three-wheelers as well as passenger cars and buses) to decrease local pollution at an affordable cost. This article offers a comprehensive overview of H_2ICEs. Topics that are discussed include fundamentals of the combustion of hydrogen, details on the different mixture formation strategies and their emissions characteristics, measures to convert existing vehicles, dedicated hydrogen engine features, a state of the art on increasing power output and efficiency while controlling emissions and modeling.

1. Introduction

It may be possible to use hydrogen to fuel internal combustion engines, either directly or blended with natural gas (up to 20%). Used pure in a fuel cell with an electric motor, it could be viewed as an alternative to the direct storage of electricity in batteries. Today, industry accounts for 99% of all hydrogen consumed. The conversion of biomass to produce hydrogen seems like an attractive alternative, but needs a great ideal of Research.

Finally, despite its cost (currently very high) and its mediocre energy efficiency, the electrolysis of water is the preferred pathway for producing hydrogen from non-fossil sources. Today, there are about forty hydrogen service stations in the world, fairly equally distributed between Europe, North America and Japan. In conclusion, the transport sector will continue to be heavily dependent on petroleum products. The most commonly used alternative motor fuels at global level are biofuels, LPG and NG motor fuel. In a more distant future, it may be possible to consider hydrogen a replacement fuel if certain technical and economic challenges are overcome.

2. Literature Survey

Hydrogen seems to be a viable solution for future transportation, and the hydrogen internal combustion engine could act as a bridging technology towards a widespread hydrogen infrastructure, In order for hydrogen vehicles to become commercially feasible, challenging tasks in hydrogen production, distribution and storage have to be addressed [1]. There are several methods for producing hydrogen from solar energy. Currently, the most widely used solar hydrogen production method is to obtain hydrogen by electrolyzing the water at low temperature. It is planned for a future work to conduct a detailed cost and exergoeconomic analysis for various types of solar-hydrogen systems for comparison purposes [2]. It was found that an increase in humidity from 0% to 90% leads to only a slight increase in the minimum ignition energy. This indicates that humidity has no significant influence on the MIE [3]. It was found that there is a reduction of about 20% in the peak power output of the engine when operating with hydrogen. The brake thermal efficiency with hydrogen is about 2% greater than that of gasoline. A lean limit equivalence ratio of about 0.3 could be attained with hydrogen as compared to 0.83 with gasoline. CO, CO_2 and HC emissions were negligible with hydrogen operation [4]. By adopting manifold injection technique the hydrogen–diesel dual fuel engine operates smoothly with a significant improvement in performance and reduction in emissions. [5]. Compression ratio and equivalence ratio have a significant effect on both performance and emission characteristics of the engine and have to be carefully designed to achieve the best engine performance characteristics. Higher compression ratios can be applied satisfactorily to increase the power output and efficiency, mainly because of the relatively fast burning characteristics of the hydrogen–air mixtures [6]. The relative accuracy of the equivalence ratio was found to be below 1.47%. Adiabatic burning velocities of methane + hydrogen + air mixtures were found in satisfactory agreement with the literature results and with the Konnov model predictions. In lean flames enrichment by hydrogen has little effect on [NO], while in rich flames the concentration of nitric oxide decreases significantly [7]. Ammonia present in the wastewater, which is not treated before being discharged to the river, is increasing nitrate levels in ground and drinking water. Nitrate contamination in ground and drinking water is harmful to humans. Air from a blower is sent into a stripping unit which contains ammonia-rich liquid wastes from the already existing solids-decantation unit. This air is sent through a micro bubbler creating large surface area contacts with the wastewater. Ammonia is carried with the air into the batch absorber unit. This ammonia/air gas mixture is bubbled through 0.5 M Potassium Hydroxide (KOH), which captures/absorbs the ammonia [8].

3. Hydrogen as Fuel in I. C. Engines

3.1. Methods of Production of Hydrogen

Important methods of hydrogen production are Solar-Thermal Hydrogen Production, Hydrogen Production via Solar Electricity, Hydrogen Production via Photo-electrolysis, Photo-biological Hydrogen Production and Hydrogen Production from Human Waste

3.2. Selection of Cost Effective Method

Hydrogen production cost for renewable sources compared to fossil fuels is shown in fig. 1. Researchers at the University of Florida, studying the utilization of domestic fuels for hydrogen production, have found that ammonia-based solar powered electrolysis will produce the cheapest hydrogen by the year 2024.

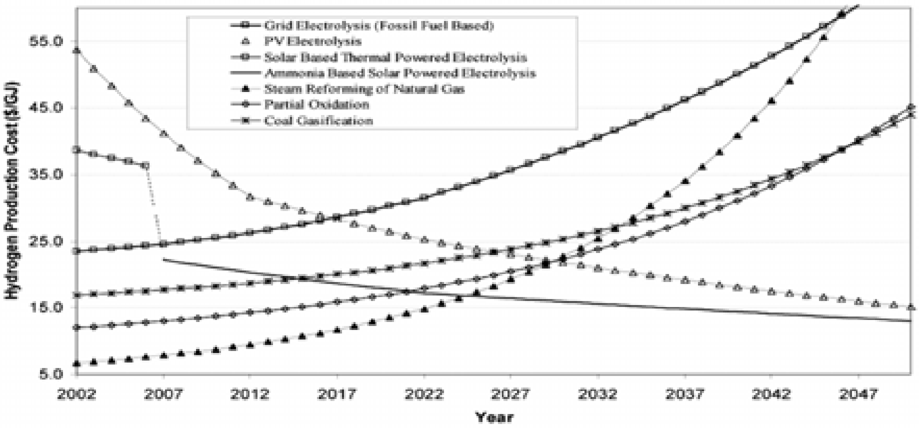

Fig. 1: Hydrogen production costs for renewable sources compared to fossil fuels

3.3. Procedure and Experimental Setup for Hydrogen Production from Human Waste

3.3.1. Ammonia Capturing Process

As shown in fig. 2, Air from a blower is sent into a stripping unit which contains ammonia-rich liquid wastes from the already existing solids-decantation unit. This air is sent through a micro bubbler creating large surface area contacts with the wastewater. Ammonia is carried with the air into the batch absorber unit. This ammonia/air gas mixture is bubbled through 0.5 M potassium hydroxide (KOH), which captures/absorbs the ammonia. The air is recycled back to the blower.

3.3.2 Transporting Ammonia

Liquid ammonia can be transported by pipeline, railway, or truck at a distribution center depending upon distance of place where it is to be supplied.

3.3.3 Ammonia Electrolysis

Ammonia pumped into a 5,000 gallon above ground vertical single wall stainless steel storage tank. It is then electrolyzed in an alkaline Ammonia Catalytic Electrolyzer (ACE) .The nitrogen can be vented to the atmosphere or collected and sold. A 24-hr supply of hydrogen is generated, compressed and stored. The major components of the process are discussed in detail in the fig.3.

3.4. Combustive Properties of Hydrogen

The Hydrogen is having combustive properties such as wide range of flammability, low ignition energy, small quenching distance, high auto ignition temperature, high flame speed, high diffusivity and low density.

3.5. Engine Design or Conversion

Use of Hydrogen in I C Engine needs following conversions in the design:

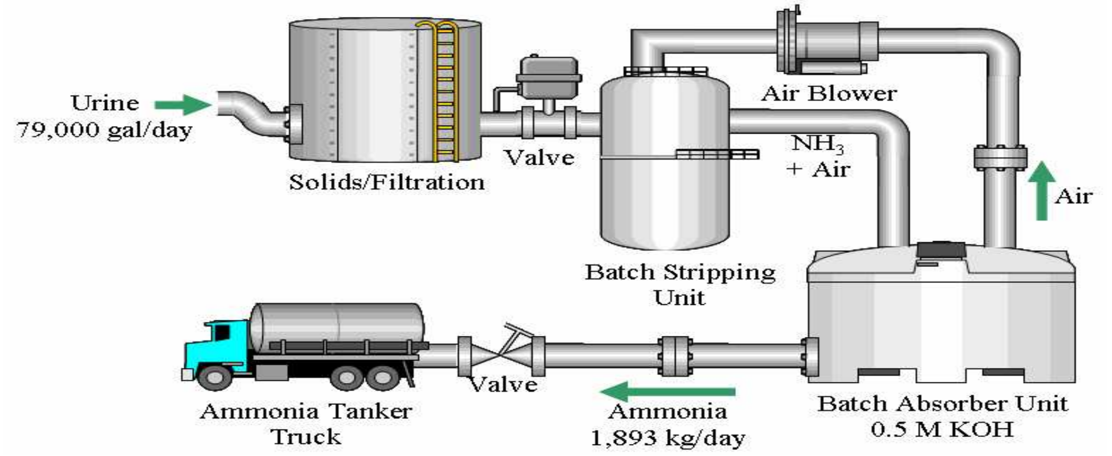

Fig. 2: Schematic representation of a process that captures 97% of ammonia in human urine at the wastewater treatment plant.

i. ***Spark Plugs*****:** Cold-rated spark plugs can be used, since there are hardly any spark plug deposits to burn off. Spark plugs with platinum electrodes are to be avoided.
ii. ***Ignition System*****:** To avoid uncontrolled ignition due to residual ignition energy, the ignition system should be properly grounded. Also, induction ignition in an adjacent ignition cable should be avoided, for instance, by using a coil-on-plug system.

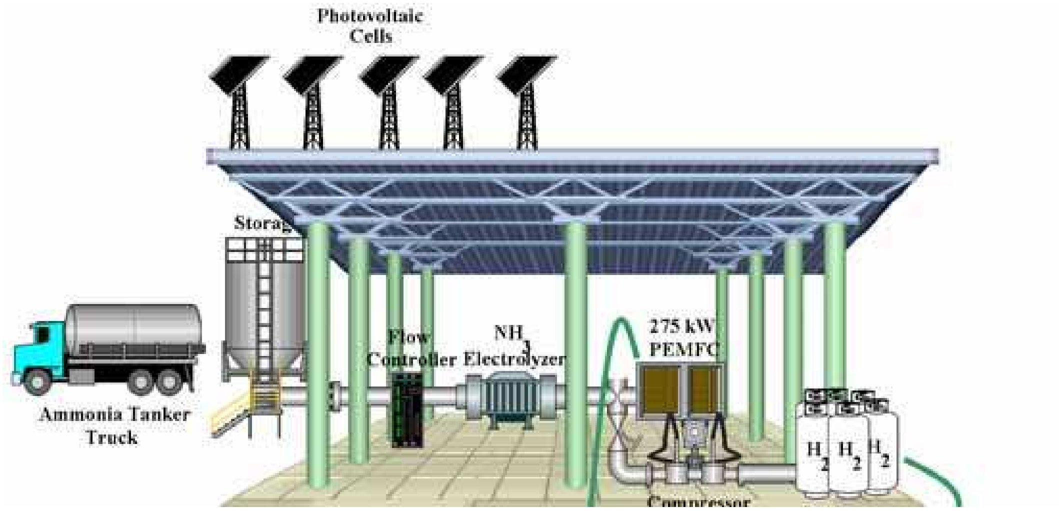

Fig. 3: Ammonia-to-hydrogen process visualization.

iii. ***Hot Spots:*** Measures to avoid hot spots include the use of cooled exhaust valves; multi-valve engine heads to further lower the exhaust valve temperature; a proper oil control; additional engine coolant passages around valves and other areas with high thermal loads (if possible); the delay of fuel introduction to create a period of air cooling (using timed manifold or DI); and adequate scavenging (e.g., using variable valve timing) to decrease residual gas temperatures.

iv. ***Valve Seats and Injectors*****:** The very low lubricity of hydrogen has to be accounted for; suitable valve seat materials have to be chosen and the design of the injectors should take this into account.

v. ***Lubrication:*** Engine lubrication oil compatible with increased water concentration in the crankcase has to be chosen.

vi. ***Crankcase Ventilation*****:** Positive crankcase ventilation is generally recommended due to unthrottled operation (high manifold air pressures) and to decrease hydrogen concentrations (from blow by) in the crankcase.

vii. ***Compression Ratio*****:** The choice of the optimal compression ratio is similar to that for any fuel; it should be chosen as high as possible to increase engine efficiency, with the limit given by increased heat losses or the occurrence of abnormal combustion (in the case of hydrogen, primarily surface ignition). Compression ratios used in H_2ICEs range from 7.5:1 to 14.5:1.

3.6. Power Output

The theoretical maximum power output from a hydrogen engine depends on the air/fuel ratio and fuel injection method used. The air/fuel ratio for hydrogen is 34:1. At this air/fuel ratio, hydrogen will displace 29% of the combustion chamber leaving only 71% for the air. For direct injection systems, which mix the fuel with the air after the intake valve has closed (and thus the combustion chamber has 100% air), the maximum output of the engine can be approximately 15% higher than that for gasoline engines. At a stoichiometric air/fuel ratio, the combustion temperature is very high and as a result it will form a large amount of nitrogen oxides (NO_x), which is a criteria pollutant. Since one of the reasons for using hydrogen is low exhaust emissions, hydrogen engines are not normally designed to run at a stoichiometric air/fuel ratio. Typically hydrogen engines are designed to use about twice as much air as theoretically required for complete combustion. At this air/fuel ratio, the formation of NO_x is reduced to near zero. Unfortunately, this also reduces the power out- put to about half that of a similarly sized gasoline engine. To make up for the power loss, hydrogen engines are usually larger than gasoline engines, and are equipped with turbochargers or superchargers.

3.7. Hydrogen Safety

The unique properties of hydrogen require an adapted approach when laying out a safety concept for both hydrogen engine test cells as well as hydrogen-powered vehicles. The gaseous state of the fuel at ambient conditions in combination with the low density, wide flammability and invisibility of the gas as well as its flames require amended measures to guarantee a safety level equivalent to conventional fuels. When properly taking the unique properties into account by facility designers, engineers and operators, hydrogen can be as safe as, or safer than, gasoline or diesel fuel. Differences in local codes and standards for hydrogen application and use make it impossible to provide an all-inclusive summary of all hydrogen safety aspects. Therefore, this chapter is rather meant as a summary of best-practice recommendations based on the authors' expertise and the limited number of publications in this area.

4. Future Scope

Future scopes in this topic are:

i. In order for hydrogen vehicles to become commercially feasible, challenging tasks in hydrogen production, distribution and storage have to be addressed.
ii. Although the H_2ICE has made significant progress recently, there remain many topics requiring further investigation, ranging from fundamentals to demonstrations.
iii. It is planned for a future work to conduct a detailed cost and exergoeconomic analysis for various types of solar-hydrogen systems
iv. It is required to work in order to reduce fuel cell cost.
v. It is required to work in order to reduce fuel cell durability.

5. Conclusions

Utilizing hydrogen for I C engines will be a great alternative for traditional fuels. It presents an array of challenges not present with gasoline. These challenges may the country from switching to hydrogen only economy. Hopefully soon we will find methods to meet these challenges and recognize hydrogen as an efficient energy source. Hydrogen seems to be a viable solution for future transportation, and the hydrogen internal combustion engine could act as a bridging technology towards a widespread hydrogen infrastructure. Hydrogen combustion engine vehicles can initially be designed for bi-fuel applications. Although hydrogen is the most abundant element in the universe, it is not readily available in its molecular form and has to be produced using other energy sources. Hydrogen is therefore considered an energy carrier rather than an energy source.

In order for hydrogen vehicles to become commercially feasible, challenging tasks in hydrogen production, distribution and storage have to be addressed. Utilizing hydrogen for I C engines will be a great alternative for traditional fuels. An elegant solution to the storage problem of H2 is one of the most important issues. Renewable hydrogen must be pursued as a long-term strategy. Hydrogen ICE and hybrid technologies may play a commercial role in the near term. Hydrogen FCVs are believed to be the long-term solution.

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