Influence of energetics and ecologics parameters in internal combustion engines using hydrogen as an alternative fuel

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1. Advatages of alternative fuels used on internal combustion engines

The Increasing problems of urban air quality and global warming have brought about a need to consider alternative fuels and Cosworth Technology has valuable experience in this area. The regulated emissions from vehicles, which affect urban air quality, are hydrocarbons (HCs), oxides of nitrogen (NOX), carbon monoxide (CO) and, in the case of diesels, particulate matter (PM). Carbon dioxide (CO2) emissions, though not regulated, do contribute to global warming. Measuring CO2 emission levels is the best way to quantify the effect of vehicle fuel consumption on the environment, when considering fuels of such widely varying energy density and chemical composition.Alternative fuels offer significant reductions in all these emissions. In addition, when running on alternative fuels, engines are quieter than an equivalent diesel engine.

Alternative fuels for internal combustion engines:

- liquid petroleum gas (LPG)
- compressed natural gas (CNG)
- liquefied natural gas (LNG)
- rapeseed methyl ester (RME)
- methanol - usually blended with 15% gasoline (M85)
- ethanol - usually blended with 15% gasoline (E85)
- hydrogen
- di-methyl ether (DME)

1.1. Liquid Petroleum Gas (LPG)

- Liquid Petroleum Gas is a mixture of (30-100%) propane and the balance butane.
- It is stored in pressure vessels at 7 bar depending on ambient temperature.
- The fuel offers significant HC and CO emissions benefits and up to 13% reduction in CO2, compared with gasoline.
- The fuel has 80% of the energy density of gasoline and so requires a slightly larger fuel tank to achieve the same range.

A gasoline engine can run on LPG with only minor mechanical changes - usually restricted to the valve seat insert material.

1.2. Compressed Natural Gas (CNG)

- Compressed natural gas, which is mainly methane, is stored in pressure vessels at either 200 or 250bar.
- When stored at 250bar, it still only has 32% of the energy density of gasoline. The fuel tanks are therefore quite bulky and heavy, due to the pressure they have to withstand.

- Engine modifications required for operation on natural gas are the same as for LPG.
- Natural gas engines produce extremely low HC emissions if measured against a non-methane standard (as used in North America).
- If methane optimised catalysts are fitted to a vehicle, very low total HC emissions can be achieved.
- Vehicles running on natural gas produce 26% less CO2 than when running on gasoline.
- Any reduction compared with a diesel engine depends on the vehicle use pattern.

1.3. Hydrogen

- Hydrogen is the only fuel that can be used in an internal combustion engine which produces no tailpipe HC, CO or CO2 emissions.
- Hydrogen should be produced using electrolysis of water from renewable energy sources in order to produce a favourable "well-to-wheel" analysis, when compared with other fuels.
- The use of hydrogen in engines could provide an important stepping-stone to the widespread application of fuel cells in vehicles, by stimulating the need for a refuelling infrastructure.
- Significant changes to the combustion system of a spark ignition engine are required in order to run it on hydrogen.
- Hydrogen is normally either stored on the vehicle as a gas under very high pressure like CNG or in a cryogenic storage vessel at –250°C.

1.4. Methanol

- Methanol is usually combined with 15% gasoline by volume (M85) to improve cold starting when used as a vehicle fuel.
- Great care must be taken in the design of a methanol fuel system as the fuel is incompatible with many materials.
- Methanol is produced principally from coal or natural gas, but can be bio-derived.
- Methanol is toxic so custom-designed vehicle refuelling equipment is used to minimise operator exposure to methanol.

Currently, manufacturing methanol is very energy intensive, so the life cycle energy use and emissions are less favourable than the tailpipe emissions suggest.

1.5. Ethanol

- Ethanol is usually combined with 15% gasoline by volume (E85) to improve cold starting, when used as a vehicle fuel.
- It is bio-derived through the fermentation of organic raw material.
- Tailpipe emissions are reduced when running on E85, but currently manufacturing the ethanol is very intensive, so the life-cycle energy use and emissions are less favourable than tailpipe emissions suggest.

2. Benefits of a Hydrogen Economy

Widespread use of hydrogen as an energy source in this country could help address concerns about energy security, global climate change, and air quality. Fuel cells are an important enabling technology for the Hydrogen Future and have the potential to revolutionize the way we power our nation, offering cleaner, more-efficient alternatives to the combustion of gasoline and other fossil fuels. These benefits are explained in more detail below.

2.1. Reduce Greenhouse Gas Emissions

Greenhouse gases are thought to be responsible for changes in global climate. They trap excess heat from the sun's infrared radiation that would otherwise escape into space, much like a greenhouse is used to trap heat. When we drive our cars, and light, heat, and cool our homes, we generate greenhouse gases. But if we used hydrogen in very high efficiency fuel cells for our transportation and to generate power, we could significantly reduce the GHG emissions - especially if the hydrogen is produced using renewable resources, nuclear power, or clean fossil technologies.

2.2. Reduce Air Pollution

The combustion of fossil fuels by electric power plants, vehicles, and other sources is responsible for most of the smog and harmful particulates in the air. Fuel cells powered by pure hydrogen emit no harmful pollutants. Fuel cells that use a reformer to convert fuels such as natural gas, methanol, or gasoline to hydrogen do emit small amounts of air pollutants such as carbon monoxide (CO), although it is much less than the amount produced by the combustion of fossil fuels.

2.3. Improve Energy Efficiency

Fuel cells are significantly more energy efficient than combustion-based power generation technologies. A conventional combustion-based power plant typically generates electricity at efficiencies of 33 to 35 percent, while fuel cell plants can generate electricity at efficiencies of up to 60 percent. When fuel cells are used to generate electricity and heat (co-generation), they can reach efficiencies of up to 85 percent. Internal-combustion engines in today's automobiles convert less than 30 percent of the energy in gasoline into power that moves the vehicle. Vehicles using electric motors powered by hydrogen fuel cells are much more energy efficient, utilizing 40-60 percent of the fuel's energy. Even Fuel Cell Vehicles that reform hydrogen from gasoline can use about 40 percent of the energy in the fuel.

3. Hydrogen used as bi-fuel for internal combustion engines

First of all, a vehicle need not be restricted to a single fuel. If a vehicle is to be used in an area where an alternative fuel is not readily available, the ability to run on gasoline or diesel as well as some alternative fuel is a safety net against getting stranded without enough fuel to drive to the nearest alternative-fuel refuelling station. Vehicles that run on an alternative fuel without the ability to run on gasoline, are referred to as *dedicated* alternative-fuel vehicles; in that sense, most cars and trucks are "dedicated" gasoline or diesel vehicles.

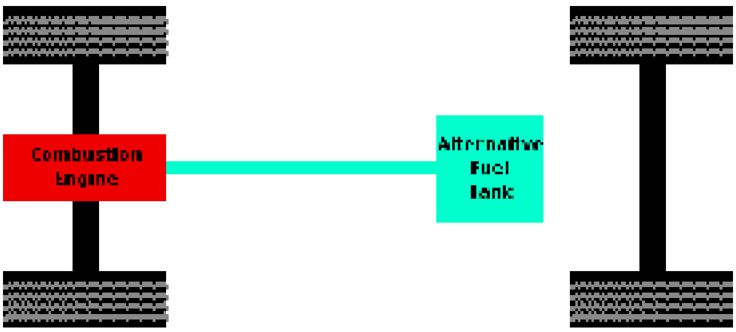

Fig. 3.1. Alternative fuel tank

The engine of a dedicated vehicle can be optimised to run on its one fuel; for example, the BMW Group is a dedicated hydrogen vehicle, and because hydrogen has an octane rating of 130, its engine has an extremely high compression ratio (12.5:1!), which helps it produce more power than the standard gasoline versions of the car. If it had to be able to run on gasoline as well, it couldn't use this high compression ratio--even 100 octane aviation gasoline would blow the engine up with "knocking" or detonation.

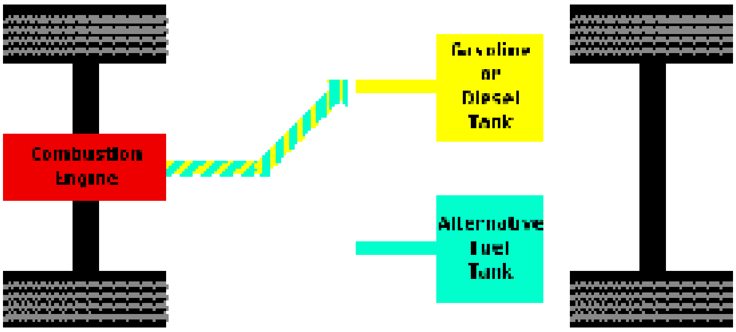

Fig. 3.2. Tanks for bi-fuel systems

There are two common ways to allow a vehicle to run on an alternative fuel as well as gasoline, depending on whether gasoline and the alternative fuel can be mixed in one fuel tank. If the two fuels cannot be mixed, like hydrogen and gasoline, then one needs two complete separate fuel systems--that is, two sets of fuel tanks and injectors or carburettors, with the ability to switch back and forth between them. For example, a hydrogen carburettor (or "mixer") can be installed as a "hat" over the throttle body of a fuel-injected gasoline engine, and fuel flow to the gasoline injectors is turned off when hydrogen is going to the carburettor. Such an arrangement is called a *bi-fuel* system. It gives the ability to run on alternative fuel where it is available, with gasoline as a backup; however, it requires the vehicle to bear the weight and cost of two complete fuel systems.

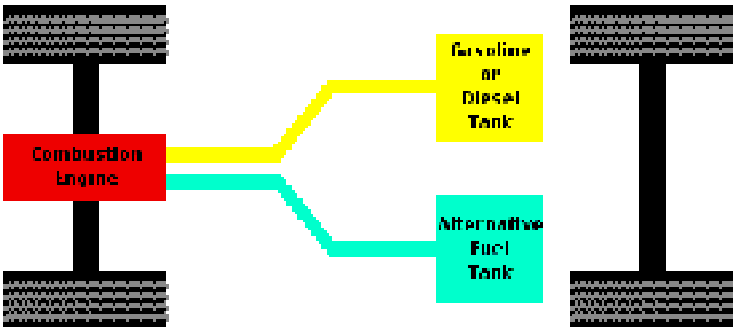

Fig. 3.3. Bi-fuel tanks

In addition, a *dual-fuel* system is sometimes used for heavy-duty vehicle engines (buses and large trucks). I have heard this term used interchangeably with "bi-fuel", but my understanding is that it properly refers to a system that uses *both* a conventional *and* an alternative fuel in a fixed ratio all the time, as opposed to one at a time (bi-fuel) or in variable amounts (flex-fuel). The example with which we are most familiar is a conversion of a diesel engine to burn mostly hydrogen, with just enough diesel fuel injected to initiate combustion. This has the advantage of not requiring as much change to the engine as a dedicated hydrogen conversion (which requires spark plugs for ignition, for example), but it does not confer the flexibility of a dual-fuel or flex-fuel conversion because it cannot run on conventional (diesel) fuel alone.

4. The potential of the hydrogen internal combustion engine

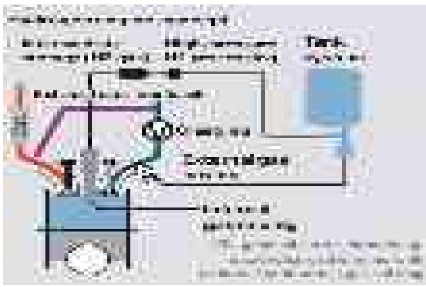

Fig. 4.1. Hydrogen engine concept

In the last years, engineers have been demonstrating the potential of the hydrogen internal combustion engine on the test rig. While the present series-production hydrogen engine is capable of operating with external gas mixing and a fuel-to-air ratio (lambda) of 1, investigations and experiments on the engine test rig are taking this performance a good step further. Tests on monovalent research engines have successfully demonstrated the charging, external gas mixing and direct injection of hydrogen into the cylinder. On the basis of this research, the BMW Group has submitted a patent application for a hydrogen direct fuel-injection method which combines the best performance characteristics of petrol and diesel engine combustion processes. Its performance is superior to that of present day petrol engines. The next stage is to further optimize various parameters specific to the hydrogen combustion process, by modifying the engine, optimizing the auxiliary
power supply and incorporating all of these elements in an integrated energy management system. Through these measures, the BMW Group aims to achieve a total efficiency of 50 percent which, in terms of maximum output, is easily competitive with other power plant concepts.

Fig. 4.2. Potential of internal combustion engine

Fig. 4.3. Combustion chamber simulation

In its liquid, supercooled form, hydrogen takes up 4.5 times less space than compressed hydrogen gas at 250 bar and 0°C. Liquid storage of hydrogen allows the vehicle to travel for an acceptable distance on one tank, despite the fact that, liter for liter, diesel or petrol contains almost four times as much energy. The BMW
hydrogen cars are equipped with a heavily insulated tank to store liquid hydrogen at a temperature of minus 253 degrees Celsius. But even the best insulation cannot prevent hydrogen from gradually evaporating and escaping from the tank if the vehicle is not used for an extended period of time.

Efforts are therefore being made to prolong the period for which the vehicle can remain immobile before this phenomenon, known as “boil-off”, starts to take effect. One possibility, which is being investigated by one of the project partners, is to use a counterflow system to liquefy incoming air when hydrogen is extracted from the tank. This liquid air is then used to cool the insulating layer when the engine is running, thus reducing the temperature difference between the stored fuel and the inner wall of the tank and slowing the rise in temperature of the hydrogen inside the tank. This effect can be maintained when the vehicle is stationary until such time as all the air stored in the insulation layer has evaporated. Using this process, it is expected that a “resting time” of around 12 days could be achieved. The filling process, too, has been designed for maximum simplicity and ease of use. It takes just three minutes to fill the tank, either using a fully automated filling robot or a simple manual procedure. The resistance of the double-walled tank to the extremes of heat, cold and pressure generated by various filling operations and accident scenarios has been demonstrated in numerous tests and simulations. This data has led safety experts to the conclusion that the use of hydrogen as an automotive fuel presents no more danger than the more familiarpetroleum products.

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