ANNALS of the ORADEA UNIVERSITY.
Fascicle of Management and Technological Engineering, Volume VII (XVII), 2008

EXHAUST EMISSIONS FROM NATURAL GAS VEHICLES

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Keywords: natural gas, emissions, engines.

Abstract

Natural gas is one of the most promising fuel alternatives for the future. Independent of vehicle category, natural gas will help to bring down harmful emissions. There are already excellent natural gas vehicles on the market. However, some technical improvements are still needed, especially in the heavy-duty sector.

This report is a status report on engine technology, exhaust emissions, energy efficiency and environmental impacts in general from a technical point of view. The report does not cover commercial aspects, and it does not deal with refueling or fuel storage related issues.

1. INTRODUCTION

Natural gas is well suited as an Otto engine fuel, as methane has high knock resistance. Gaseous fuels easily form a homogeneous mixture with air. This, and the simplicity of the fuel molecule, is advantageous for soot-free complete combustion. In general, for both light- and heavy-duty applications, the decisive factor for regulated emissions is the engine and exhaust gas aftertreatment technology used on the vehicle.

Fuel chemistry, on the other hand, is clearly linked to exhaust gas toxicity, and in this respect the simple chemical structure of methane gives a clear advantage over conventional fuels. Research organisations like TNO and VTT have studied unregulated emissions from different fuel alternatives.
In general, three main features or components determine the emission performance of a gas engine, i.e. combustion system, fuel system and catalyst technology. A division of spark-ignition automotive gas engines into three categories according to the air-fuel ratio can be made:
· stoichiometric engines
· lean-burn engines
· engines optimised for low consumption but not low emissions

2. OVERVIEW

Since the 1980s environmental issues have had a great impact on most human activities in the developed countries. Exhaust emission requirements are becoming more and more stringent. For gasoline-fuelled light-duty vehicles, many countries in the world have since the 1980s implemented regulations that in practice are met only by using three-way catalyst technology. In favorable conditions a three-way catalyst in conjunction with a closed-loop fuel system is capable of reducing the regulated exhaust emissions (carbon monoxide CO, unburned hydrocarbons HC, and nitrogen oxides NOx) by more than 90 % compared to pre-catalyst vehicles. Honda has presented a prototype gasoline vehicle, which is capable of achieving 1/10 of the US ULEV emission levels. The vehicle will go into closed-loop operation only 15 seconds after start, and this means that this vehicle is extremely clean although it runs on gasoline. Figure 1.1 shows the development of the European emission regulations for light-duty vehicles.

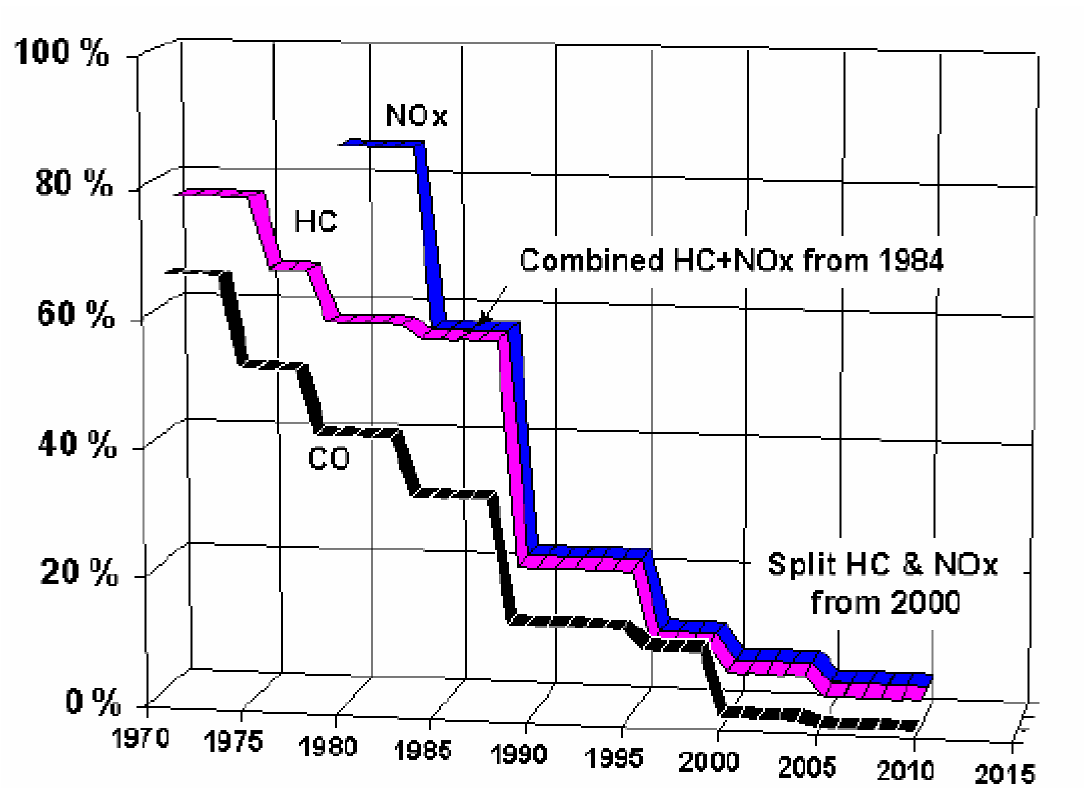

Figure 1.1. The development of European light-duty vehicle emission regulations

In the pre-catalyst age, switching from gasoline to a gaseous fuel often meant reduced exhaust emissions. Today, however, the engine management and the catalyst efficiency are totally decisive from the emissions point of view, whereas the fuel itself plays a minor role. This is especially true for the regulated emissions. If an advanced catalyst equipped gasoline vehicle is retrofitted to gaseous fuel without a comparable level of ophistication, it is probable that the emissions will increase rather than decrease.

On many markets, requirements for on-board diagnostic (OBD) systems are emerging. This will in practice mean that in the future the alternative fuel systems have to work seamlessly together with the vehicle's own engine management system. If alternative fuel technology relies on exemptions, it will probably be on the wrong route. To secure the future, the alternative fuel technology has, after a certain lead time, to be as good and advanced as the conventional fuel technology. The conventional diesel engine is very energy efficient and reliable. For these reasons, the direct injection diesel engine is currently almost the only power unit used in heavy-duty vehicles. The conventional diesel engine is, however, facing difficulties in meeting increasingly stringent emission regulations. There is no technology available for the diesel engine that could cut emissions of all major components to the same extent as the threeway catalyst does for gasoline engines. The most important pollutants of the diesel engine are particulates, nitrogen oxides and hydrocarbons.

As the gasoline vehicle population is getting cleaner, the relative share and importance of heavy-duty diesel vehicle emissions are increasing. This is especially true in urban conditions. Diesel emissions can be reduced by engine, fuel system and fuel modifications and by using exhaust aftertreatment. In Europe, the limit values for the regulated emissions were cut by more than 50 % from 1985 to 1995. In the Nordic countries, high quality, practically sulphur-free reformulated diesel fuel is already widely used. The European Union has agreed to introduce practically sulphur free diesel for the whole Community by the year 2005. Reformulated diesel can, to some extent, reduce the regulated emissions of both old and new engines. More importantly, however, reformulated diesel fuel reduces the toxicity of diesel exhaust substantially. The ractically sulphur-free fuel also makes it possible to apply exhaust aftertreatment, the most common option being an oxidising catalyst.For some special applications, i.e. city buses, refuse and delivery trucks, alternatives other than the conventional diesel engine are under consideration. Over the last 20 years the main driving force behind the promotion of alternative motor fuels has shifted from oil substitution to improving urban air quality.

By substituting the conventional diesel by an advanced engine capable of burning alternative fuels such as alcohols or gaseous fuels, exhaust emissions and exhaust toxicity can be lowered substantially. In this sector the gaseous fuels are clear market leaders compared to other alternatives. Gaseous fuels like methane, propane and butane are inherently clean-burning fuels, which in avourable conditions give a soot-free combustion and less harmful exhaust components than conventional liquid hydrocarbon fuels. However, to achieve low overall exhaust emissions, advanced engine technologies and control systems have to be applied.

Engines which work well in steady-state (i.e. ECE R49) emission testing do not necessarily perform so well in real life service.

Most heavy-duty gas engines are diesel engines converted to spark-ignition Otto cycle engines. Low engine efficiency and for some gas engines also low power output is a problem. In normal service, gas engines can consume 25-35 % more energy than their diesel counterparts. In order to overcome the efficiency deficit, engine manufacturers are working towards lean-burn combustion, higher specific power output and some special turbocharging and fuel injection systems. New engine technologies and electronics like variable valve timing, skip-fire etc. can help to enhance the performance of gas engines. In many applications, natural gas can contribute to the reduction of toxic automotive emissions. However, there is also the aspect of general energy use and greenhouse gas emissions. International agreements like the Kyoto agreement have been signed to stop the growth of greenhouse gas emissions. The general perception is that the gas resources are more extensive than the known oil resources. From the viewpoint of sustainable development the societies should seek for energy solutions which combine energy diversification, low greenhouse gas emissions and also low toxicity.

In these respects natural gas is an attractive alternative also in the transportation sector. In gasoline fuelled cars substantial carbon dioxide reductions can be achieved by switching to natural gas, and as the technology for heavy-duty engines improves, we might see a reduction potential in this sector, too. The vehicle population and general energy use is growing fast in developing countries. As natural gas is a clean burning fuel, this fuel is a good option in vehicles which do not have sophisticated exhaust gas aftertreatment systems.
Figure 1.2 shows two energy demand scenarios, "sustained growth" and "dematerialization". In both cases, natural gas is projected to cover a substantial part of the energy demand in the time frame 2000-2060.

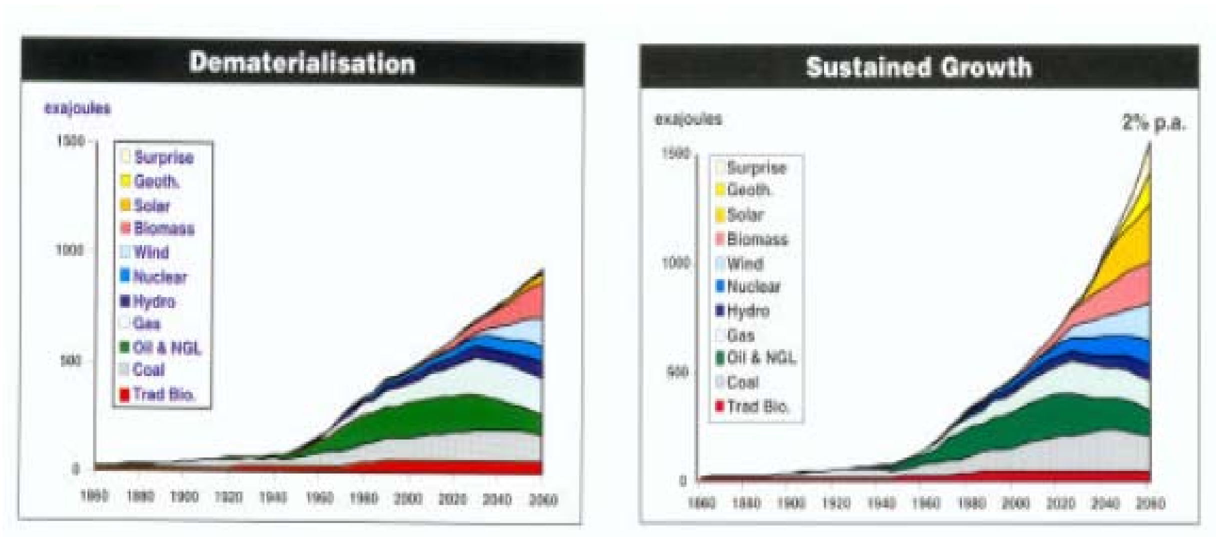

Figure 1.2. Energy scenarios by Shell International

This report aims at documenting the emission benefits, with emphasis on harmful and poisonous emissions, of natural gas as an automotive fuel. There are numerous benefits which originate from the simple chemical structure of methane, the main constituent of natural gas. The most important feature is that emissions from natural gas fuelled vehicles are less noxious than the exhaust emissions from gasoline and diesel vehicles. The unburned hydrocarbons in the exhaust of a natural gas fuelled vehicle consist mainly of methane, and therefore one can expect that natural gas exhaust would be less harmful to human health compared to gasoline or diesel exhaust.

Natural gas can be used as an automotive fuel as such. Normally the gas is stored under pressure as CNG (Compressed Natural Gas). Liquefied natural gas (LNG) and biogas are viable options to CNG. The use of LNG solves the problem of bulky fuel storage and restricted vehicle operating range. Biogas collected from waste treatment facilities can be purified and used as CNG. This means that natural gas vehicles can also be run on a fuel, which originates from renewable sources. Natural gas can also serve as a feedstock for a number of different fuels, i.e. methanol, DME (di-methyl ether) and synthetic diesel fuel (Fischer-Tropsch diesel). Synthetic diesel fuel would, from an end-point of view, be the easiest way to use natural gas in transportation, as no modifications to the existing diesel vehicle fleet or to the existing refuelling infrastructure would be required. DME, a gaseous fuel with similar physical properties to LPG (Liquefied Petroleum Gas), has good ignition properties, and can thus be used in diesel cycle engines. DME has clear emission advantages over conventional diesel fuels. DME, however, requires major modifications to the engine, fuel storage and distribution systems.

Hereafter, only the conventional use of natural gas as a transportation fuel, i.e. the direct use of natural gas as the fuel, will be covered. Focus will be on CNG applications, as from an engine point of view in current fuel systems both CNG and LNG are delivered to the engine in gaseous form. Some of the comments on on-board fuel storage are relevant to CNG only.

The technology of gas fuelled vehicles has still to be enhanced. The auto manufacturers have put in a lot of effort to develop and refine gasoline and diesel fuelled vehicles. Compared to this, the amount of work on natural gas fuelled vehicles is so far rather limited. As a result, at least in the past, most of the natural gas vehicles were not so very sophisticated. Most of the light-duty vehicles are actually bi-fuel solutions, which are not optimised for natural gas. However, some recent bi-fuel models with integrated computer systems are now optimised on natural gas as well as on gasoline, with excellent emissions on both fuels. This is an emerging trend for all OEMs offering bi-fuel vehicles.

The heavy-duty gas engines are mainly converted diesel engines, not engines designed especially for gas. Thus, at this stage, there is still room for technical improvements to enhance the emission performance, efficiency and also to some extent the reliability of natural gas fuelled engines and vehicles.

Ultimately, when the level of technical sophistication of gas engines is at the same level as for the conventional technologies, natural gas engines should have clear advantages from an environmental point of view over conventional fuels.

3. CONCLUSIONS

There are very promising technologies available for natural gas vehicle applications. Most of the technical issues have been solved or will be solved in the near future. The task to get NGVs really going is really not a technical issue, but rather more a marketing issue. Work to building up adequate refuelling networks is also needed.

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