**The European Association of Internal
Combustion Engine Manufacturers**

EUROMOT

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Admissible Hydrogen Concentrations in Pipeline Gas for Internal Combustion Engines

1. Introduction

In June 2012, GERG – the European Gas Research Group – has launched a project to establish and analyse the level of knowledge existing about admissible hydrogen concentrations for all components of the natural gas system including stationary gas engines DNV KEMA has been contracted to provide an analysis for gas engines and especially to identify where sensitive areas exist when hydrogen concentrations in pipeline gas are raised to levels up to 10%.

Not much literature exists on the effect of hydrogen in lean-burn gas engines. Existing literature on the subject of hydrogen in gas engines is often focussed on rich-burn automotive high speed engines (stoichiometric engines). Please note, that these engines are not comparable to high-efficiency lean-burn industrial engine types and thus the results are not applicable to modern industrial engines. Small high speed rich burn engines are less knock sensitive to the gas composition hydrogen (H2) content due to the faster cylinder combustion process (shorter time available for knock to develop) than bigger medium speed gas engines.

In the following, EUROMOT identifies possible challenges and issues regarding lean-burn gas engines as well as making recommendations on under what circumstances the hydrogen concentrations could possibly be increased to up to 10 vol%.

2. Hydrogen Effect on Methane Number

The combustion behaviour of natural gases is of particular importance for internal combustion engines (e.g. used in stationary engine plants, packaged CHP systems or natural gas vehicles). A key property is the methane number[1]. It describes the knock behaviour of fuel gases in internal combustion engines and strongly depends on the specific gas composition. Also different engine types might behave differently on the gas composition changes, e.g. for a small high speed stochiometric engine additional nitrogen (N2) into the natural gas works effectively for knock prevention but in bigger lean burn engine applications there is already a high amount of nitrogen (N2) in the combustion air that addition of N2 to the fuel gas will have much lower effect on the knocking prevention behaviour.

One very significant impact of raising the hydrogen content in pipeline gas is that it lowers the methane number. High methane numbers mean high knock resistance; high knock resistance, in turn, means good combustion, high efficiencies and thus low CO2 emissions.

If methane numbers are too low, knock may cause severe engine damage or lead to losses in efficiency and performance (such as lower output, higher fuel consumption and emissions, etc.). If engine operation has to be adjusted to avoid knocking combustion it also leads to a lower load step response and power capacity.

For modern gas engines the admissible hydrogen concentration in pipeline gas is therefore contingent on the gas quality in the pipeline:

- When pipeline gas has a high methane number (such as Russian natural gas), modern gas engines might be capable (further investigation needed see also section 3 about study need) of running on natural gas with a hydrogen content of up to 10 %. If the engine is optimised for a certain fuel composition/quality at site, any deterioration of the methane number will negatively impact the engine output and efficiency.
- When pipeline gas has a low methane (such as Lybian natural gas) number injecting large amounts of hydrogen up to 10 % will start to create severe problems as described above. This negative impact increases the lower the Methane Number (MN) in the pipeline gas gets. The impact of hydrogen on the methane number (MN) is well-known, however, it should be noted that the impact of a 10% level of hydrogen in gas on the commonly used AVL method for calculating the methane number has not been tested by AVL (ditto for high N2 contents of the natural gas, see above remark for differences between different engine types). This requires further investigation. Please note that hydrogen behaves differently than hydrocarbons because its oxidation is a very simple reaction whereas for example methane needs more than 80 steps for complete oxidation.

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[1] Further information on the Methane number can be found under www.euromot.eu: http://www.euromot.eu/download/3a88a6f6-af39-4c4d-bb51-0e0be660d02d/GAS%20QUALITY%20methane%20number%20calculation%202012-04-04.pdf

Furthermore, the hydrogen content injected in to the pipeline gas changes the combustion velocity in internal combustion engines. This will influence the phasing of the combustion and the peak pressure and peak temperature. This can also lead to knocking, increase in emissions, etc. This impact is especially problematic when the gas engines receives fluctuating amounts of hydrogen in the gas!

3. Existing Gas Engines

In a survey of members companies, EUROMOT found that manufacturers have set maximum levels of hydrogen in engine specifications for the fleet of existing engines. These range typically between 2-5 vol% hydrogen in the gaseous fuel. However, if the MN of the base gas is already low, any addition of hydrogen will lead to deteriorating performance. Hydrogen burns also much faster than methane and thus the engine behaviour might become very unpredictably at higher hydrogen contents of the natural gas. Existing engines in the market have not been tested for high levels of hydrogen, therefore engine manufacturers cannot guarantee for their ability to run on high hydrogen content. However, EUROMOT expects that part of existing engines will have to be adapted to run on high hydrogen levels and therefore further studies into this subject are needed. Currently, following issues are known to exist:

- Older engines may lack control systems
- The maximum peak pressures may be an issue.
- Hydrogen embrittlement is caused by atomic hydrogen which diffuses from the surface into the structure and recombines in the material to molecular hydrogen, and thus exposes the metallic structure to an internal pressure, with following impact:
    - Hydrogen is not suitable for the use with engine components made out of grey cast iron, as the hydrogen can degrade and cause leakages in this material. This is a potential safety risk. This might be a problem for existing engines, thus further investigations are needed.
    - Impacts are expected on high-pressure storage, especially in connection with high-strength carbon steels
- The closer a gas engine is to the next scheduled maintenance the more likely gas engines are to experience problems

4. Gas train components

In this paper, EUROMOT focusses on admissible levels of hydrogen for internal combustion engines. EUROMOT recommends analysing the admissible levels of hydrogen in the gas train components, e.g. gaskets and valves. Hydrogen is a very small molecule and escapes much easier from confinements than hydrocarbons, it might also degrade sealings in the gas system (this is dependent on the material, e.g. polymer seals need to be examined, for this question the pressure level here can be crucial in the assessment).

5. Explosion risks

Rules exist for a maximum 25% lower explosion limit (LEL) in the exhaust system of gas engines. This is crucial for exhaust systems that are long and have a large volume, especially when an oxidation catalyst is present for exhaust gas emission reduction. **Hydrogen has very wide explosion limits**. Compared to “normal” natural gas operation, a lot more purging of the exhaust system is necessary. The ignition temperature and ignition energy of hydrogen is a lot lower than with methane; especially, with an oxidation catalyst in use it can easily ignite in the exhaust. Therefore, a much stronger focus has to be put on actions reducing explosion risks if the natural gas hydrogen content is increased. A completely new design of the engine and connected systems might be the result of such a study e. g. flame arrestors will be necessary to avoid backfiring.

Furthermore, extinguishing distances are considerably reduced by the hydrogen and lead to a higher security classification; in this connection the gap width must be reduced when using flame filters.

6. Boundary conditions

The focus of the GERG study is on the technical admissible hydrogen level. However, the development of gas quality specifications and also the idea of injecting hydrogen into pipeline gas have to take into consideration not just the purely technical aspects of whether it is technical feasible or not but also other boundary conditions.

Internal combustion engine manufacturers have a number of rules and regulations to adhere to, which are impacted by the gas quality supplied:

- Increasingly stricter emission regulations: Stationary engines are regulated on national level (e.g. TA Luft) and also multinational level (Gothenburg Protocol) Lowering the gas quality as discussed on the basis of the EASEE-gas proposal (“EASEE-gas Common Business Practice”) increases NOx emissions. Stricter emission limits lead also to a bigger need to apply secondary abatement techniques for emission compliance. Secondary abatement such as SCR are bulky with big volumes, extra volumes in the exhaust train increases explosion risks!
- In particular, fluctuation of gas qualities and fluctuating hydrogen content are problematic for tuning gas engines. Broad gas specifications allowing unlimited fluctuation as proposed by EASEE-gas preclude the tunability of control parameters necessary to ensure the safe operation of gas engines with hydrogen.
- Electricity Network Codes: The new Network Code on Requirements for Generators , as developed by ENTSO-E , will make stricter load response requirements in order to make the European electricity grid ready for increases in renewable energy. Fluctuating and low methane numbers will make it very challenging to meet these dynamic output demands.

The hydrogen discussion is not the only change to the gas quality. Currently, CEN TC 234 WG11 is discussing broader gas specifications which may result in a lower methane number and increase sulfur content, etc. Any gas quality specification needs to consider the impact on emissions and the electricity grid.

7. Pre-warning system

A pre-warning system could be helpful, as gas engines could be adapted to the new gas quality and negative impacts like knocking can be reduced. Nevertheless the performance of the gas engine will deteriorate. To our knowledge setting up an early warning system like this will be very challenging/impractical and expensive as a very large number of gas chromatographs throughout the system would have to be installed. Furthermore, commonly used gas chromatographs for determining hydrocarbons are not suitable for the determination of hydrogen; flame ionization detectors as well as thermal conductivity detectors have to be employed together with special carrier gases. Simple systems such as sensors will not work. An “early pre-warning information” of a high hydrogen content is not enough, engine performance is also dependent on MN and LHV besides H2 of the gas. Further development work is also needed to incorporate the gas quality information into the engine control system.

8. Restricting the speed and size of gas quality (and hydrogen) fluctuation

Gas engines are sensitive to the fluctuation of gas quality. Restricting the speed and size of gas quality and hydrogen fluctuation will therefore be necessary. Further investigation are necessary to determine how to restrict the fluctuation of hydrogen levels in the gas. Furthermore, it may be necessary to restrict changes of the heating value.

9. Measurement of energy supplied via the gaseous fuel

Measurement of energy supplied via the gaseous fuel with a gas meter will experience huge errors when adding higher amounts of hydrogen (more than 3% hydrogen content). This is critical, as fuel cost is the biggest O&M cost for a stationary plant and profit margins on energy production are low. This issue needs to be solved before introducing higher amounts of hydrogen in to the pipeline gas.

10. Conclusion and recommendation

As we have discussed above, the injection of large quantities of hydrogen into the pipeline gas will reduce the methane number with negative impacts regarding knocking, emissions and engine output.

Injecting hydrogen up to 10% might only be admissible for modern gas engines if the resulting methane number of the pipeline gas remains high (see also second bullet remark in above section 2 concerning MN). From a performance point of view a MN of 80 and higher is optimal. However, in some markets we already see today methane numbers of typically down to 70; this can be addressed by specific engine versions at the cost of lower efficiency and engine output.

The impact on the fleet of existing engines is unclear as they have not been tested for proposed levels of hydrogen. Further research is needed to establish the impact on the fleet of existing gas engines.

Before allowing the introduction of H2 in the pipeline system, a thorough investigation has to be carried out on:

1. Required measures for a safe gas supply;
2. Effect on the MN determination with the AVL method;
3. Safety aspects in the exhaust system in case of misfiring and misstarts

Literature:

Professor Ghazi Karim from the University of Calgary has written several papers (SAE, ASME) about the effects of hydrogen in dual fuel engines and has always warned about the consequences.

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