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TECHNICAL ASSOCIATION
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# Impact of hydrogen in natural gas on end-use applications

## Why inject hydrogen in natural gas?

Besides biogas and biomass, electrical energy from wind or sun is becoming an important source of renewable energy.

However, from time to time, a surplus of renewable power will be produced and the electricity grid is not able to store this energy, so the renewable generation would have to be curtailed.

Solutions such as power-to-gas technologies help to integrate intermittent renewable electricity into the energy system. Power-to-gas technology can store the excess power production of renewables by converting it to hydrogen and/or synthetic methane and injecting it into the natural gas grid.

The natural gas industry is strongly committed to support the integration of renewable gases (biomethane, hydrogen, syngas…) in their grids.

On a national or even EU level, power-to-gas offers a way to address one of the main challenges of the energy transition, the storage and transmission of large amounts of surplus energy from renewables, which is a political consensus in Europe.

The present paper is only dealing with mixtures hydrogen / natural gas.

Another way is to convert hydrogen by combining it with $CO_2$ into synthetic methane which could be injected in natural gas.

## Consequences of hydrogen / natural gas mixtures

It is generally agreed that mixtures of natural gas with up to 10 %vol hydrogen can be injected and conveyed without significant integrity problems in traditional natural gas grids (i.e. NaturalHy project [1]) apart of few applications (gas turbines, gas as feedstock…). Of course, a case by case integrity analysis should be carried out before this is accomplished.

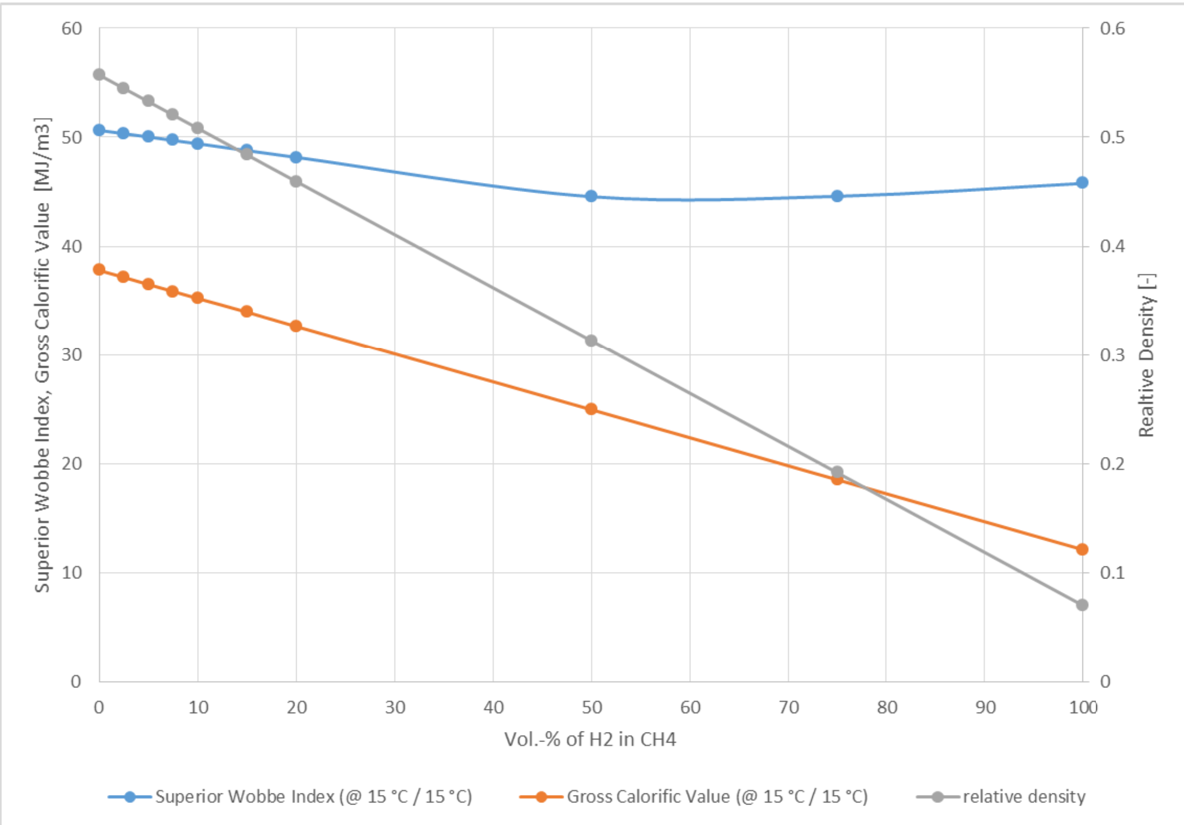
Many natural gas applications can use mixtures of hydrogen and natural gas without significant problems. As an example, modern domestic appliances are certified according to Gas Appliance Regulation (GAR) [2], using a test gas with 23 % hydrogen (G222, defined in EN 437 [3]) and several pilot projects in Europe, focusing on residential/commercial utilization, have demonstrated that safe operation of these types of appliances is feasible with up to 20% of hydrogen in natural gas [4], [5], [6], [7].

Some stakeholders, however, have concerns regarding the utilization of hydrogen/natural gas mixtures [8], [9], [10] This paper addresses these concerns, pointing out available solutions and highlighting opportunities which may arise due to the blending of hydrogen and natural gas [18].

- **Impact of hydrogen/natural gas blending on main gas quality characteristics.**

  The addition of hydrogen to natural gas directly influences several gas properties related to utilization: density, Net Calorific Value (NCV), Gross Calorific Value (GCV), Wobbe Index, combustion air requirement, Methane Number, …

  The impact is different, depending on the parameter. As seen in the graph below, the impact of hydrogen concentrations is very strong for density and GCV, and small for Wobbe Index.




*Impact of $H_2$ concentration in $CH_4/H_2$ mixtures on some gas quality properties.*

Depending on the type of gas utilisation, the parameters of interest are not the same. For residential utilisation, it always is the Wobbe Index, whereas for industrial processes it usually is either Wobbe Index, NCV or composition in non-combustion applications. For engines, the parameters are the net calorific value (NCV) and the Methane Number, while for gas turbines, the modified Wobbe Index taking into account the temperature of the gas is of interest, amongst other properties.

Fluctuations in these properties are not exclusive to hydrogen admixture. They can occur due to changes in local natural gas qualities and compositions. Depending on the application that the gas is used for, some end users may be affected more than others.

- **Impact of hydrogen/natural gas blending on the different end use sectors.**

*Residential & commercial:*

In the residential sector, gas appliances are not too sensitive, as the requirements for these appliances are not as challenging as in other sectors, e. g. thermal processing industries or power generation. Research projects in Europe [4], [5], [6] [11] show that many residential appliances can safely be operated with hydrogen/natural gas mixtures.

*Industrial processes:*

In industry, natural gas is used either as a feedstock for chemical processes (e. g. production of hydrogen or ammonia) or as a fuel to provide process heat in a multitude of manufacturing processes. The operational requirements of industrial processes are often very challenging in terms of efficiency, product quality and compliance with emissions regulations, e.g. for nitrogen oxides (NOx). The admixture of hydrogen into natural gas can be considered as a change in local gas quality from the end-user's point of view.

Technologies are available on the market to mitigate the impact of gas quality fluctuations on industrial applications (e.g. Wobbelis/Indelis devices) [12], [13]. With regards to hydrogen in natural gas, recent research projects show that the effects of significant amounts of hydrogen in natural gas on industrial combustion processes can be minimized in terms of efficiency, heat transfer and NOx emissions if appropriate measurement and control technologies are used [14]. As the industrial sector is characterized by a large degree of specialization and optimization, some of these solutions have to be tailored to specific applications.

*Gas engines:*

Hydrogen admixture in natural gas – in principle- leads to a higher knocking propensity of the fuel. However, engine knocking is not caused exclusively by fuel properties, but also by the engine design and tuning. For low fraction of hydrogen within the natural gas (<5%), it seems that hydrogen behaves as a catalyst which enhances the flame stability and the combustion efficiency. As a consequence, the engine runs smoothly with a lower level of cyclic dispersion [15]. This efficiency gain can be observed on lean and stoichiometric conditions.

On the other hand, hydrogen admixture offers new approaches. The better stability of the flame and combustion in lean operating condition with hydrogen opens the way to ultra-lean combustion process which has the advantage to save great amount of fuel and raise the thermal efficiency. However, the greater the excess air ratio is, the higher the level of hydrogen has to be in order to keep a good stability of the engine, but higher levels of hydrogen increase the amount of NOx within exhaust gas. It means that post catalyst converters will have to be adapted to the amount of hydrogen inside the fuel gas.

<u>Gas turbines</u>:

Gas turbines could be the most sensitive application to variable amounts of hydrogen in natural gas, due to the lean premixed combustion processes common in modern power plant gas turbines.

In principle, gas turbines can be designed to work with almost any kind of fuel, but are very sensitive to fluctuations in fuel properties (e. g. Net Wobbe Index, Net Calorific Value, burning velocity etc.). Manufacturers are currently developing new combustor systems which offer greater flexibility in terms of fuel quality, without sacrificing efficiency or NOx emission performance [16], [17].

- **Impact of hydrogen on NOx emissions.**

In principle, higher concentrations of hydrogen in a natural gas can lead to higher NOx emissions due to higher local temperatures in the reaction zone.

However, NOx formation is very much dependent on the specific process and application. For example, two industrial process burners operating with the same boundary conditions can behave very differently in terms of NOx emissions. Studies show that even significant concentrations of hydrogen in natural gas can be handled without dramatic increases in NOx emissions if appropriate measurement and control technologies are used to control the process [14].

## Conclusion

On a national or even EU level, power-to-gas offers a way to address one of the main challenges of the energy transition, the storage and transmission of large amounts of surplus energy from renewables in the natural gas grid.

Many gas applications are able to handle mixtures of natural gas and hydrogen without significant problems.

- Research demonstrated that many residential and commercial gas appliances can handle up to 30 % of hydrogen in natural gas without safety concerns.
- In industrial thermal applications it could be shown (on semi-industrial scale) that up to 50 % of hydrogen in natural gas could be handle without

negative impact on efficiency, product quality and pollutant emissions if proper measurements and control technologies are applied.

Gas turbines and gas engines are probably the most sensitive end-use applications with regard to hydrogen admixture into natural gas. Manufacturers and researchers are currently investigating new technologies to address this issue. It is worth noting that many of the consequences of hydrogen admixture to natural gas are qualitatively rather similar to gas quality fluctuations in general.

Blending of hydrogen into natural gas can present some challenges to various end-use applications in terms of efficiency, process control or pollutant emissions. Some end-users will be affected less than others. Nevertheless, technological solutions are available for many of these problems, albeit at a cost. Also, it needs to be pointed out that appliances and applications in the field today (which were never designed with hydrogen concentrations in natural gas in mind) may prove to be much more challenging in this context. However, for many applications, it is technologically feasible to have them accept even significant concentrations of hydrogen in the fuel without negative impact in terms of safety, efficiency, product quality or pollutant emissions.

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