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The Impact of Hydrogen Admixture into Natural Gas on Residential and Commercial Gas Appliances

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Abstract: Hydrogen as a carbon-free fuel is commonly expected to play a major role in future energy supply, e.g., as an admixture gas in natural gas grids. Which impacts on residential and commercial gas appliances can be expected due to the significantly different physical and chemical properties of hydrogen-enriched natural gas? This paper analyses and discusses blends of hydrogen and natural gas from the perspective of combustion science. The admixture of hydrogen into natural gas changes the properties of the fuel gas. Depending on the combustion system, burner design and other boundary conditions, these changes may cause higher combustion temperatures and laminar combustion velocities, while changing flame positions and shapes are also to be expected. For appliances that are designed for natural gas, these effects may cause risk of flashback, reduced operational safety, material deterioration, higher nitrogen oxides emissions (NOx), and efficiency losses. Theoretical considerations and first measurements indicate that the effects of hydrogen admixture on combustion temperatures and the laminar combustion velocities are often largely mitigated by a shift towards higher air excess ratios in the absence of combustion control systems, but also that common combustion control technologies may be unable to react properly to the presence of hydrogen in the fuel.

Keywords: hydrogen; combustion; admixture; blend; H2NG; power-to-gas; emissions; decarbonisation; pollutants; appliance technology

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1. Introduction

Climate change and the resulting need to reduce the emission of greenhouse gases (GHG) while still providing energy for a growing world population is one of the major challenges of the 21st century, affecting all sectors of society and economy. While the widespread use of electricity from renewable sources is one option to reduce energy-related greenhouse gas emissions, the use of hydrogen as a carbon-free fuel is also considered a promising decarbonisation option, particularly in hard-to-abate applications, e.g., aviation, heavy duty road and ship transport or some industrial high temperature processes.

In Europe, natural gas is the second most important primary energy source (after oil) today [1]. The European gas industry considers hydrogen (H_2) to be essential for the decarbonisation of their business model. They support the creation of dedicated hydrogen infrastructures supplying hydrogen to end-users [2], but also prepare for the injection of hydrogen into existing natural gas pipelines in order to reduce CO_2 emissions quickly and ramp up demand for hydrogen. In Germany, for example, the German association for gas and water (DVGW) plans to increase permissible hydrogen concentrations in natural gas from just below 10 vol% to 20 vol% in the near future [3]. The situation is similar in other European nations [4,5] and in the EU itself [6].

In the European Union, natural gas consumption is distributed relatively evenly across the residential and commercial, industrial, and power generation sectors, while vehicles only play a negligible role [7]. The residential and commercial sector is the biggest, both in terms of gas consumption and the number of installed appliances. It is estimated that the stock of installed appliances accounts for more than 200 million residential and commercial appliances within the European Union [8]. This includes heating systems, appliances for warm water production, cooking and catering devices and micro-CHP appliances (CHP: combined heat and power), but also other applications such as decorative fires.

Within the framework of the Horizon 2020 project "THyGA–Testing Hydrogen for Gas Applications" [9], nine EU-based research organizations and companies investigate how the admixture of hydrogen in natural gas can affect appliances in the residential and commercial sector, looking at natural gas blends (H2NG) with up to 60 vol% H_2. Measurements are being carried out for up to 100 appliances of different types and technologies. The measurement campaigns are accompanied by a market analysis [8], theoretical investigations into the impact of hydrogen on combustion processes in these appliances [10], a literature review [11], and analyses to assess if and how materials in pipes and fittings may be affected by H_2 [12]. Additional investigations study how the potential negative effects of H_2 admixture might be mitigated, and how certification and standardization processes may have to be adapted for high hydrogen admixture levels.

In this paper, hydrogen admixture to natural gas is analysed from the perspective of combustion theory. The effects on relevant fuel characteristics such as Wobbe Index, calorific values, air requirements, and laminar combustion velocities are discussed, and the potential impact on typical end-use equipment in the field are deduced and discussed.

2. Materials and Methods

Calculations were done using the COSILAB software suite [13]. As a reaction model, an adiabatic chemical equilibrium was chosen to determine adiabatic combustion temperatures while a freely propagating one-dimensional premixed flame model was used to determine the laminar combustion velocities using the reaction mechanism GRI 3.0 [14], which includes 53 species and 325 reaction equations.

All values are given in the ISO reference system of 15 °C/15 °C, with a reference pressure of 1.01325 bar (1 atm), which is used in the European gas quality standard EN 16726 [15].

3. Results and Discussion

3.1. Natural Gas and Hydrogen/Natural Gas Blends (H2NG)

In the residential and commercial sector, natural gas is exclusively used as a fuel to provide low-temperature heat, which is then used for space heating, food preparation or to produce warm water, to name the most common applications. With the exception of fuel cell CHP appliances, gas is burned directly with burners to produce a hot flue gas. Therefore, the changing fuel properties due to the admixture of hydrogen into natural gas must be considered when assessing how residential and commercial gas appliances may respond to higher levels of H_2 in natural gas.

Natural gas (which mostly consists of methane, CH_4) and hydrogen differ significantly in their physical properties. Hence, in many ways, the question of which level of hydrogen in natural gas is acceptable to both legacy and new appliances is a question of gas quality.

Gas quality and its impact on gas-fired appliances and equipment in different sectors have been investigated by both the gas industry and equipment manufacturers and operators of equipment for quite some time (e.g., [16–19]). There are regulations in place in many countries which specify a number of criteria which a gas must comply with so that it may be injected into public gas grids. Common gas quality criteria are the relative density d, the (volumetric) gross calorific value (GCV) and the Wobbe Index (WI), a criterion for fuel gas interchangeability.

If two gases have the same Wobbe Index and are burned with the same burner nozzle and with the same nozzle pressure, they will release the same amount of heat [20]. This means that an appliance can fulfil its purpose, i.e., satisfy a given heat demand with both gases without the need to physically modify the hardware.

While this is a very reduced way to tackle a complex topic, it is convenient to quantify fuel interchangeability in this manner, at least for chemically similar fuels.

Figure 1 shows how relative density, which is the ratio of the standard density of the fuel and the standard density of air, gross calorific value and Wobbe Index change when hydrogen is blended with methane, representing natural gas in this consideration. While both d and GCV decline linearly with higher levels of H_2, the reduction of the Wobbe Index is far less pronounced, and also non-linear. For example, pure methane and pure hydrogen differ by about 70% in terms of the GCV, but only by about 10% in terms of the Wobbe Index.

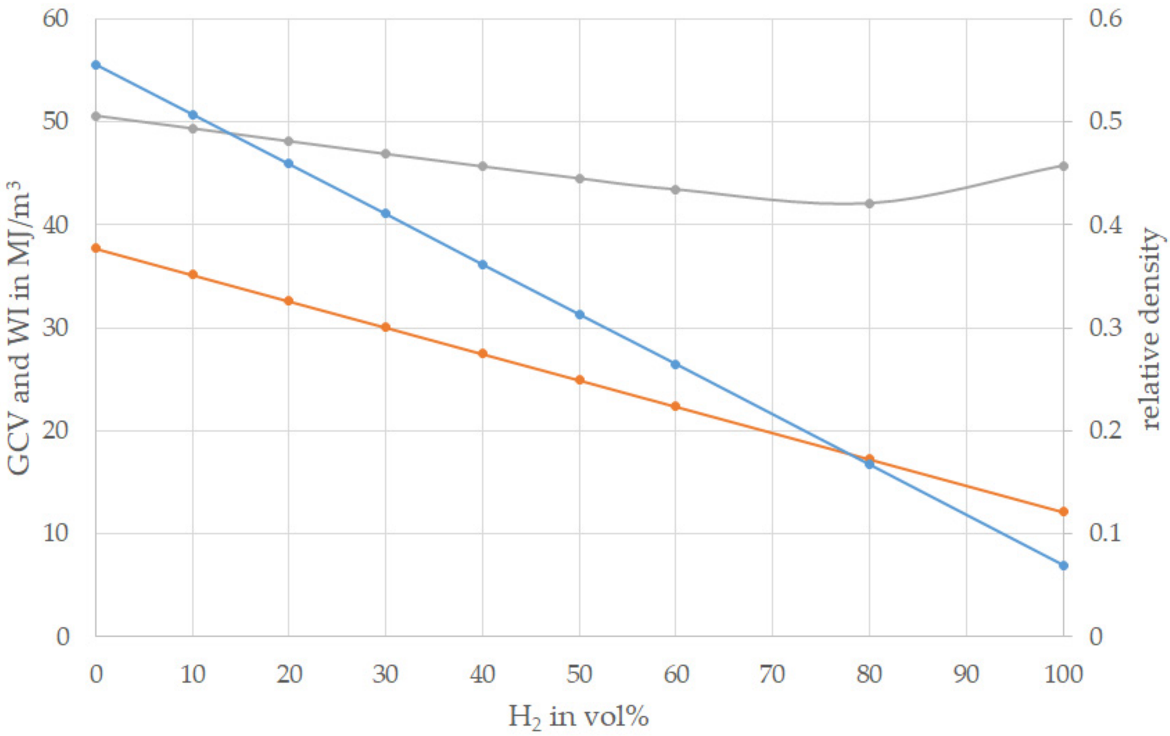

Figure 1. Relative densities, gross calorific values and Wobbe Indices for CH_4/H_2 blends. All values given in the ISO reference system 15 °C/15 °C.

So far, only a binary mixture of methane and hydrogen was considered. Natural gas, however, consists not only of methane, but also contains higher hydrocarbons (e.g., ethane and propane) or inert species such as carbon dioxide or nitrogen. Gas compositions vary depending on where the gas was extracted, how it was processed, and whether it was mixed with other natural gases in the gas infrastructure. At any given location within a gas network, local gas composition can change over time.

It is therefore important for all market partners to specify the gas that is being transported and used. As it is impractical to prescribe gas compositions for grid operations, it is common practice to specify the gas quality using a small number of relevant criteria. In the European gas quality standard EN 16726 [15], for example, a range for the relative density is given as well as a minimum Methane Number, while the EASEE-gas Common Business Practice from 2005 [21], a voluntary agreement within the European gas industry to facilitate cross border gas trading in the EU, also specifies a range of permissible Wobbe Indices for H-Gases.

Figure 2 shows three typical natural gases (Russian H-gas and North Sea H-gas, the two most important H-gas qualities in the EU as well as CH_4 as a reference) in a gas quality diagram along with the limits imposed on relative density and Wobbe Index by EN 16726 and the EASEE-gas Common Business Practice, respectively. It is obvious that the most restrictive limit to hydrogen admixture, at least from a regulatory perspective, is the density criterion, and that the Wobbe Index range is far less critical in this context. Hydrogen admixture above 30 vol% was not considered in this diagram, as most public discussions about H_2 admixture into natural gas grids focus on concentrations up to 20–30 vol%. The diagram also underlines that permissible hydrogen limits must consider the quality and composition of the natural gas that the hydrogen is being admixed to.

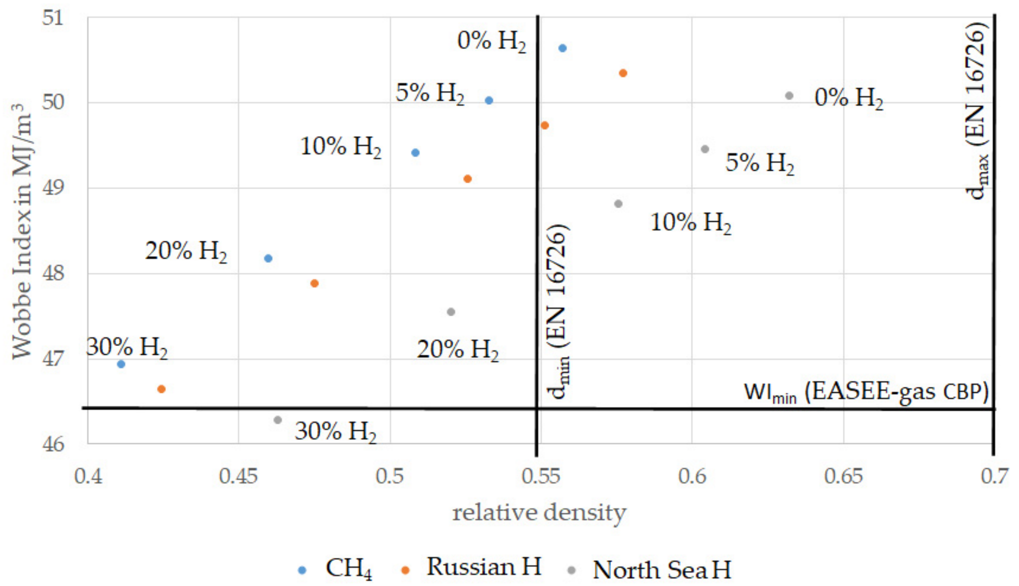

Figure 2. Hydrogen admixture to natural gases in a gas quality diagram. All values given in the ISO reference system 15 °C/15 °C.

Other combustion-related aspects should be considered as well, however. One of the main concerns in the context of H_2 admixture into natural gas and its impact on end-use equipment relates to expected higher combustion temperatures. With higher levels of hydrogen, the adiabatic combustion temperature of the fuel blend increases (cf. Figure 3), as long as other operational parameters like the air excess ratio λ remain constant. Temperatures are important since they affect many different aspects of a combustion process. They may cause local overheating of components, but they can also lead to increased emissions of nitrogen oxides (NO_X).

Another issue to consider is an increase in the laminar combustion velocity S_L. Combustion velocities are crucial for flame stabilization in premixed burners. Most residential and commercial appliances use premixed (heating appliances) or partially premixed burners (gas hobs and ovens), in contrast to industrial burner systems where non-premixed systems are more common [22]. As combustion processes in residential appliances are usually laminar [23], the laminar combustion velocity is the relevant property for this application. In a premixed laminar burner, the flame will stabilize where there is an equilibrium between local laminar combustion velocities and the local flow speed.

Figure 4 shows S_L plotted over the equivalence ratio φ (=1/λ), calculated for atmospheric pressure p = 1.01325 bar. A freely propagating one-dimensional flame model was used in combination with the GRI 3.0 reaction mechanism [14] to calculate laminar combustion velocities, and the values agree well with data from both simulations and measurements found in the literature (see [24], for example).

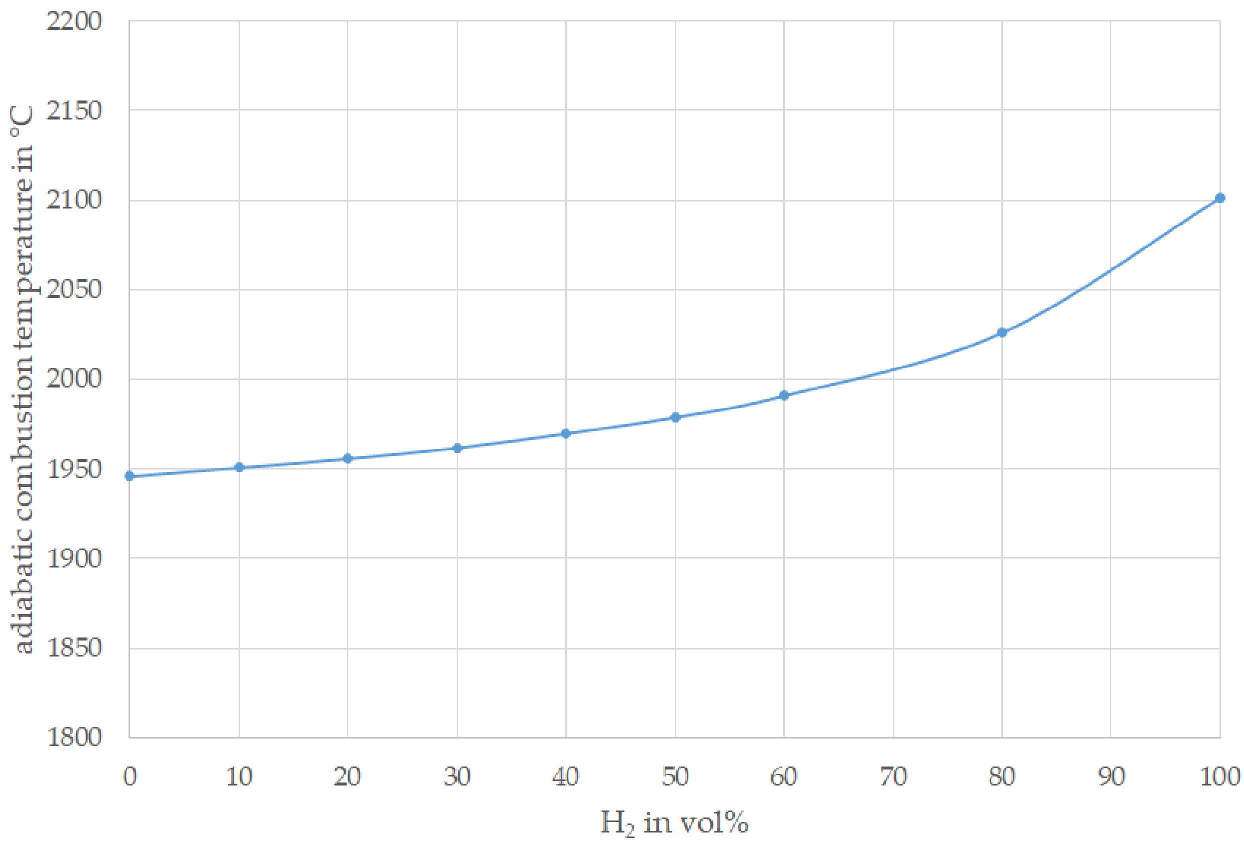

Figure 3. Adiabatic combustion temperature of CH_4/H_2 blends at stoichiometric conditions (p = 1.01325 bar).

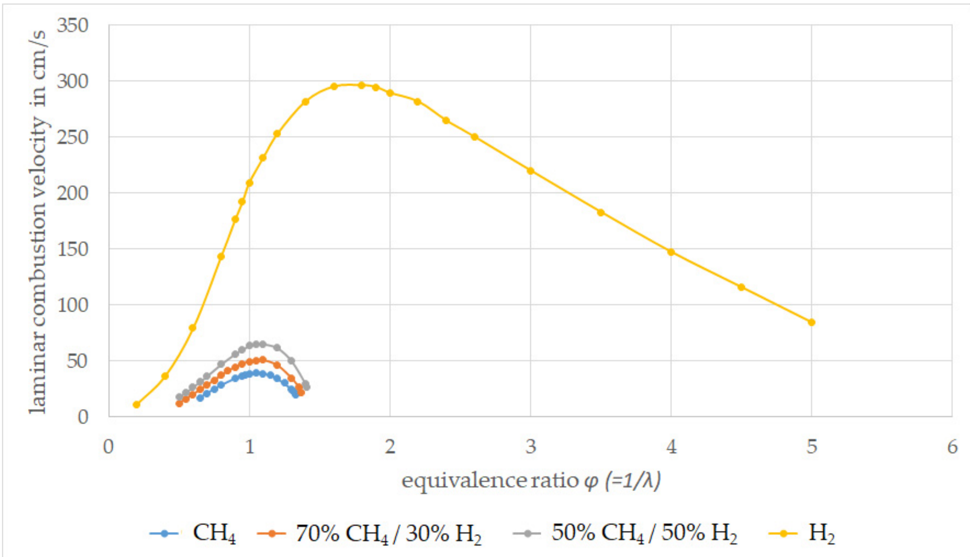

Figure 4. Laminar combustion velocity of CH_4, CH_4/H_2 blends and H_2 as a function of the equivalence ratio (=1/λ).

It can be seen that S_L increases significantly once H_2 is admixed to CH_4. As a consequence, there are concerns that higher levels of H_2 in natural gas may cause flashbacks in appliances that are not designed for it, especially at partial load when flow speeds are lower anyway. In a flashback, the flame moves upstream into the burner itself because the local combustion velocity is higher than the local flow speed, leading to a safety shutdown or, in the worst case, to damage in the burner. Given the strong impact of H_2 admixture on the laminar combustion velocities of a natural gas/hydrogen blend and the safety-related implications, this is obviously an aspect to consider.

As previously stated, the Wobbe Index is often used as the primary criterion to assess the impact of varying fuel gas compositions on combustion equipment, particularly for residential and commercial appliances, or to specify permissible gas qualities.

Table 1 highlights why looking only at the Wobbe Index is insufficient when discussing the impact of hydrogen admixture on end-use equipment. In this table, fuel properties for pure methane (CH_4, representing natural gas (H-gas)), pure hydrogen, and two blends of CH_4 with an inert (nitrogen (N_2) and carbon dioxide (CO_2), respectively) are compared. The methane blends were chosen in such a way that they have almost identical Wobbe Indices as pure hydrogen. It can be seen that, despite near identical Wobbe Indices, all other given fuel properties are very different when comparing H_2 with the blends. Thus, while the Wobbe Index is a useful fuel gas interchangeability criterion as long as certain assumptions are met (which generally is the case for residential and commercial applications, less so in industrial equipment [25,26]), it becomes far less meaningful when discussing chemically very different fuel gases or more complex combustion applications.

Table 1. Fuel properties of CH_4, two CH_4/inert blends and 100% H_2 [1].

	Unit	**100% CH_4**	**94% CH_4/ 6% CO_2**	**92% CH_4/ 8% N_2**	**100% H_2**
WI	MJ/m^3	50.64	45.28	45.27	45.78
GCV	MJ/m^3	37.80	35.53	34.78	12.10
d	-	0.5571	0.6157	0.5901	0.0698
T_{ad} (λ = 1)	°C	1982	1971	1974	2096
S_L (λ = 1)	cm/s	38.57	36.79	37.52	209

[1] All concentrations are given in vol%, ISO reference system 15 °C/15 °C.

It is important to realise that the changes in fuel properties due to the admixture of hydrogen in natural gas are only one aspect when assessing the impact of hydrogen on both legacy and new appliances. The actual technological implementation of the combustion process in a given appliance is just as important and has a profound impact on how the appliance will respond to changes in fuel. Two combustion systems may respond very differently, despite being confronted with the same change in fuel gas composition.

For this reason, extensive measurements of representative equipment are essential when discussing hydrogen admixture and its impact on appliances in the residential and commercial sector, as well as in other end-use sectors.

3.2. The Air Excess Ratio and the Impact of Combustion Control Systems

The air excess ratio λ is a crucial operational parameter for all kinds of combustion processes. Changes in the air excess ratio can impact temperatures, efficiency, heat transfer and pollutant formation, but also affect safety-related aspects such as flame stability. Residential and commercial appliances are usually adjusted on-site [26,27] to an air excess ratio specified by the manufacturer (based on prescribed O_2 or CO_2 concentrations in the flue gas) with the locally distributed gas at the time of adjustment. If the fuel gas composition changes, the actual air excess ratio of the system can also change. This would be the case in uncontrolled appliances. Modern appliances are often equipped with a combustion control system which adapts the air supply to the combustion process, based on an input signal. In this manner, these appliances always operate at the intended air excess ratio, even if the fuel gas composition changes [28]. There are, however, still many appliances in the field which have no such combustion control [8,29].

One consequence of the admixture of hydrogen to natural gas is that the minimum air requirement Air_{min}, i.e., the minimum amount of air that is necessary to achieve complete combustion, is reduced. In an appliance with combustion control, this is, in theory, counteracted by reducing the volume flow of air accordingly, but in an uncontrolled system where the volume flow of air remains constant, an increased H_2 concentration will lead to an increase of the air excess ratio λ.

This shift in the air excess ratio can be estimated by the following equation:

$$\frac{\lambda_2}{\lambda_1} = \frac{Air_{min,1}}{Air_{min,2}} \cdot \sqrt{\frac{d_2}{d_1}} = \frac{CARI_1}{CARI_2} \approx \frac{W_{S,1}}{W_{s,2}} \quad (1)$$

where λ is the air excess ratio, Air_{min} the minimum air requirement of a fuel gas (in volumetric terms), d the relative density and W_S the superior Wobbe Index of the fuel. *CARI* stands for the Combustion Air Requirement Index which is closely correlated to the Wobbe Index. This equation is valid for combustion systems with constant nozzle diameters and nozzle pressures, which is generally the case with appliances in the residential and commercial sector.

Similar to the (superior) Wobbe Index, which can be derived from Bernoulli's equation as

$$W_s = \frac{H_S}{\sqrt{d}}, \quad (2)$$

CARI is defined as

$$CARI = \frac{Air_{min}}{\sqrt{d}}. \quad (3)$$

Thus, if an appliance was adjusted to a gas with a given Wobbe Index and is then supplied with a fuel gas with a lower WI (e.g., due to hydrogen admixture), the air excess ratio will increase and vice versa. This means that if an uncontrolled appliance was originally adjusted with natural gas and is then supplied with a natural gas/hydrogen blend, it will operate at a higher air excess ratio and is thus even less likely to produce carbon monoxide (CO). However, the inverse is also true: if an appliance were to be adjusted in the field with a hydrogen/natural gas blend and the local fuel gas composition changes to lower hydrogen concentrations, the appliance's air excess ratio will be reduced, potentially leading to increased CO emissions. Given that today, the vast majority of gas appliances is adjusted in the field to an unknown local gas quality [26,27], common installation and commissioning practices may have to be re-considered if the widespread injection of hydrogen into natural gas grids is to take place in the near future.

Most burners in residential and commercial appliances are fully premixed. Therefore, any shift in the air excess ratio in a burner system will have a direct impact on the chemical processes in the flame front during combustion. This can have profound consequences, e.g., in the context of flame stabilization. Figure 4 shows that the laminar combustion velocity will increase with higher levels of hydrogen in natural gas, as long as the air excess ratio λ remains constant. The equivalence ratio φ (=$1/\lambda$) is used on the x-axis in this diagram here for better visibility.

In an uncontrolled system, this increase in S_L due to the presence of hydrogen will be counteracted by the shift of λ, so that the net change of S_L (and thus the propensity for flashback) is significantly reduced if the appliance is operated with air excess ratios higher than unity (or, correspondingly, equivalence ratios below 1). For most residential appliances, this is common practice: residential heating appliances are usually adjusted for λ values between 1.2 and 1.4 [30] to minimize carbon monoxide emissions. Gas hobs or other cooking devices may be an exception here, since they are often designed with partially premixed burner systems where regions with a sub-stoichiometric fuel-air mixture can exist, although the combustion process as a whole will be safely super-stoichiometric. Such systems are therefore more sensitive to flashback due to hydrogen admixture since in this case the change of the combustion velocity due to the shifting air excess ratio and the change in fuel composition will stack up, leading to a significant increase of the actual combustion velocity.

Combustion temperatures in uncontrolled appliances are also affected by the shifting air excess ratio: although hydrogen admixture leads to higher combustion temperatures of the fuel blend, this will be largely compensated if the air excess ratio is not actively controlled. Therefore, NO_X emissions in premixed uncontrolled appliances tend to decline as they are very much dependent on local temperatures.

These considerations also indicate that a combustion control system enforcing a constant air excess ratio may not be beneficial when it comes to hydrogen admixture, at least not for appliances in the residential and commercial sector, where premixed combustion is common. This is in contrast to non-premixed burners where combustion control generally helps reduce the increased NO_X formation due to hydrogen [31,32].

The different behaviour between these two forms of combustion can also be explained by the air excess ratio λ. In a premixed burner in which fuel and oxidizer are thoroughly mixed prior to injection into the combustion chamber, the air excess ratio is homogenously distributed in the reaction zone, there are no local differences in λ. This means that the actual combustion process will occur at the λ set point of the burner, and any change in the air excess ratio (e.g., due to hydrogen admixture into natural gas and the lack of a control system) will directly affect the chemical processes in the flame front.

In a non-premixed burner, however, fuel and oxidizer are injected into the combustion chamber separately, and the flows mix downstream of the burner, so that there is a non-uniform distribution of local λ inside the combustion chamber. A non-premixed flame will stabilise where the local λ equals unity, and most of the heat release and chemical conversion processes will occur there, always under roughly stoichiometric conditions. Thus, any change in fuel composition due to hydrogen admixture (and correspondingly, flame temperature) will directly affect the main combustion processes and also NO_X formation in such a burner system, while these effects are largely mitigated in an uncontrolled premixed burner system since the local λ shifts as well.

A premixed burner in an appliance with combustion control will behave similarly to a non-premixed burner in this regard, albeit at the chosen air excess ratio, not unity.

These effects are visualised in Figures 5 and 6 for combustion systems without, and with, air excess ratio control, respectively, where the composition of the supplied fuel gas switches from pure methane to a blend of CH_4 and 30 vol% H_2, and have been corroborated, e.g., in [33].

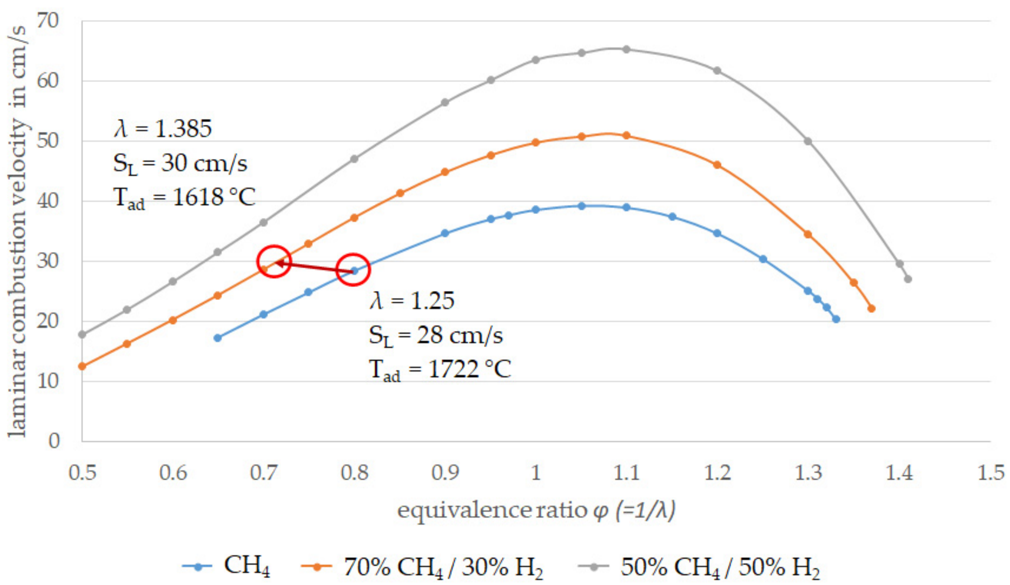

Figure 5. Effects of 30 vol.% H_2 admixture on laminar combustion velocity and adiabatic combustion temperature for an appliance without combustion control.

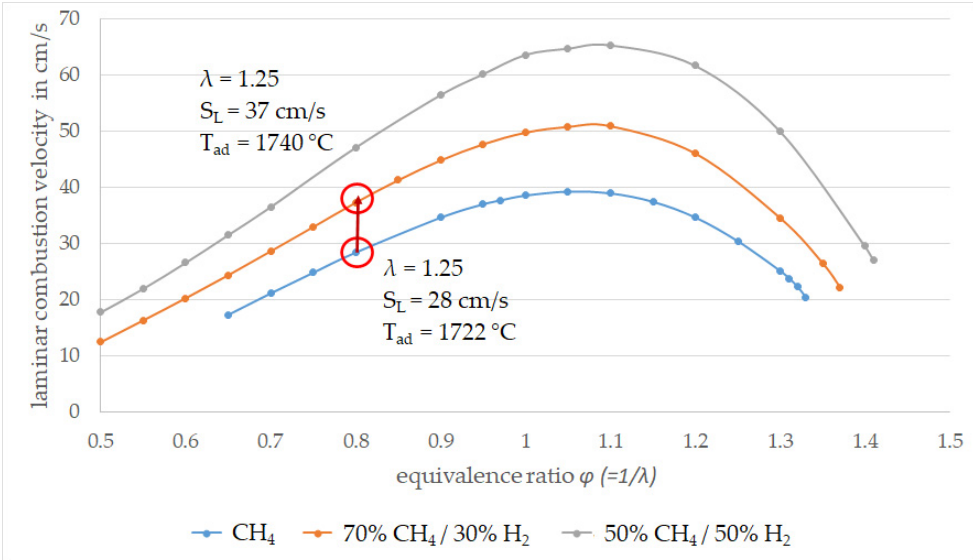

Figure 6. Effects of 30 vol.% H_2 admixture on laminar combustion velocity and adiabatic combustion temperature for an appliance with combustion control.

Another question in the context of combustion control is whether or not control systems that were originally developed to compensate for different natural gas compositions will also work reliably with hydrogen/natural gas blends. The primary purpose of a combustion control system in a residential appliance is to maintain a setpoint λ value, independent of the fuel gas that the appliance is supplied with and its original adjustment. It is, for the most part, a safety feature to prevent excessive CO formation.

Many control systems in the residential and commercial sector are based on measurements of the flame ionization current. This current will have a maximum at stoichiometric conditions, and the control system can use this information to re-adjust an appliance if the gas composition (and hence the minimum air requirement of the fuel) changes. However, measurements carried out within the THyGA project show that this approach can be unsuited for natural gas/hydrogen blends, as is visualized in Figure 7. This diagram shows measurements of how an appliance with combustion control responds to changing fuel gas compositions, both for minimum (Q_{min}) and maximum load (Q_{max}). For both loads, the hydrogen concentration was increased stepwise from 0 to 40 vol.%, the rest being methane (CH_4). The volume flows of fuel gas and the resulting air excess ratios (calculated from the measured O_2 concentration in the flue gas) are also shown. The plot shows that the control system is able to maintain a constant air excess ratio at minimum load, but fails to do so for maximum load, resulting in higher air excess ratio with higher H_2 concentrations.

Nevertheless, the control system has at least some effect. For example, in a completely uncontrolled system, a hydrogen concentration of 40 vol.% should have shifted the air excess ratio to a value of about 1.7. Instead, it was found to stabilise at 1.6 in the experiment.

The failure of the control system is probably due to the fact that hydrogen admixture does not only change the chemical processes during combustion, but also the shape and length of a flame, particularly in premixed burners. The flame ionisation current signal, however, is dependent both on the processes within the flame front, in particular the concentration of certain ions in the reaction zone, and on the relative position of the electrodes to the flame. If the flame position and shape change (e.g., due to a change in the fuel, or the thermal load of the appliance), this can impact the ionisation signal [34] and hence lead to an inappropriate response of the control system, as the effects of both the relative change of the flame position and the chemical effects in the flame front are superimposed.

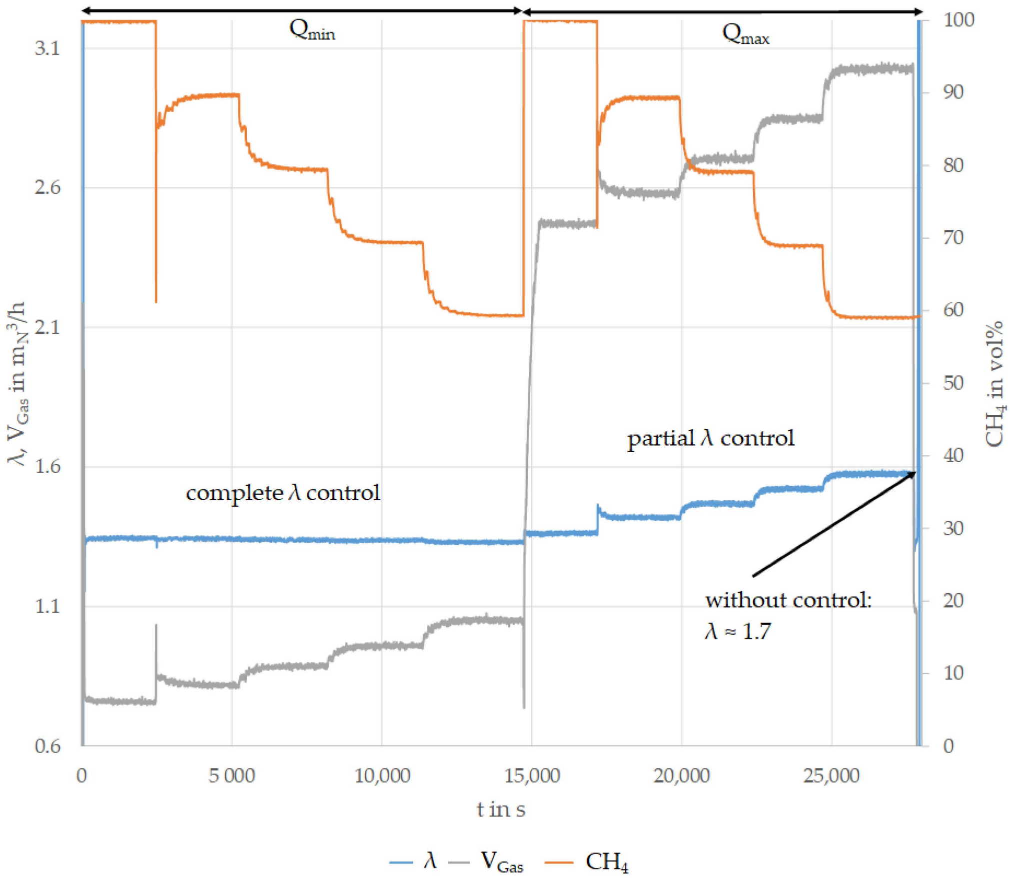

Figure 7. Response of a combustion-controlled appliance to various levels of hydrogen in methane at minimum and full load.

This effect is also shown in Figure 8, taken from [28], where several appliances with combustion control were investigated with fuel gases with different Wobbe Indices. While the appliances were able to maintain almost constant air excess ratios despite varying Wobbe Indices, this changed once the change in the Wobbe Index was caused by the admixture of hydrogen (highlighted data points). Again, the systems responded by shifting towards higher air excess ratios, indicating that the measurement and control systems were unable to detect the presence of hydrogen and react appropriately.

It is worth pointing out that shifting towards higher air excess ratios is generally not safety-relevant since a higher λ value usually leads to reduced CO emissions, unless the air excess ratio is extremely high. However, based on the first measurements both within the THyGA project and other investigations (e.g., [28]), hydrogen admixture can severely reduce the effectiveness of combustion control systems in residential and commercial appliances, at least for systems working with flame ionisation measurements. Control systems based on flue gas component measurement, e.g., by measuring the O_2 content in the exhaust gas, should perform better in this regard. This has already been demonstrated with industrial burner systems [31,35] where this control approach is very common.

The main issue is that if the air excess ratio is actually maintained at a set point value despite varying levels of H_2 in natural gas, the mitigating effects of the λ shift on combustion velocities and temperatures (and thus also NO_X formation, which, in gas combustion, is primarily dependent on temperatures) cannot be exploited.

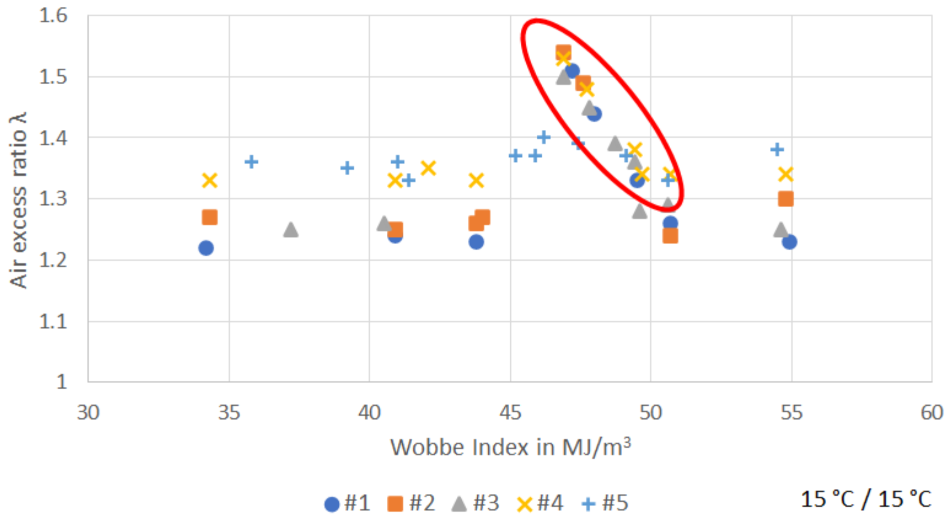

Figure 8. Impact of changing Wobbe Indices on the air excess ratio in gas appliances with combustion control. The highlighted data points show where the Wobbe Index change was due to H_2 admixture. The different colors indicate different combustion-controlled appliances. Recreated from [28].

4. Conclusions

It is likely that hydrogen will play a major part in future energy systems, for large-scale energy storage and transmission, and as a means to help decarbonise hard-to-abate applications, e.g., in the mobility and industrial sectors. There are also plans to promote the direct injection of hydrogen into the existing natural gas infrastructure. As a consequence, appliance and equipment populations in the EU could be supplied with hydrogen/natural gas blends in the near future, across all end-use sectors.

Given the significant differences between the physical and chemical properties of natural gas and hydrogen, switching from natural gas to hydrogen/natural gas blends or even pure hydrogen can affect combustion processes in residential and commercial appliances in terms of performance, but also in terms of safety. It is obvious that the consequences will become more pronounced with higher levels of hydrogen in the fuel gas. In many ways, the question of how appliances and equipment respond to higher levels of hydrogen in natural gas is a gas quality issue. Hydrogen admixture has an impact on gas quality criteria such as relative densities, calorific values or Wobbe Indices, but also on other combustion aspects such as adiabatic combustion temperatures and laminar combustion velocities. It can be shown that the Wobbe Index alone is not well-suited to assess the impact of the presence of hydrogen in a fuel on an appliance.

It is, however, important to not only look at the changing fuel properties, but also at how combustion processes are implemented in appliances and equipment across all end-use sectors.

Different combustion technologies will behave quite differently when supplied with hydrogen/natural gas blends. As most gas appliances in operation today were never designed with hydrogen in mind, it is therefore important to identify potential issues due to hydrogen admixture into natural gas, determine acceptable H_2 concentration limits and develop mitigation options where required.

Within the framework of the European project "THyGA", such investigations are being carried out for appliances in the residential and commercial sector, the biggest end-use sector for natural gas in the EU, both in terms of gas consumption and in terms of the number of installed devices.

Theoretical considerations and first measurements indicate that the effects of hydrogen admixture on combustion temperatures (relevant for potential thermal overheating of components and NO_X emissions) and the laminar combustion velocities (important for flame stabilisation) are often largely mitigated by a shift towards higher air excess ratios, at least in residential premixed gas appliances. This shift occurs when a combustion process was adjusted for a fuel gas and is then supplied with another fuel gas with a lower Wobbe Index and is inevitable in an appliance without combustion control (barring manual re-adjustment) but can also occur in controlled systems.

Current measurement technology installed in residential appliances is often unable to properly detect the changes caused by hydrogen admixture, so that the control systems fail to respond adequately. There is, however, the question of whether or not maintaining a constant air excess ratio is actually beneficial in this case. Partially premixed appliances (e.g., gas hobs or ovens) are likely to be more sensitive to the presence of hydrogen in natural gas than fully premixed systems (e.g., boilers and heating appliances) since partially premixed burners are at a greater risk to experience a flashback.

The mostly theoretical investigations presented here are only a first step in the THyGA project and will be followed up by extensive measurement campaigns for a variety of different combustion technologies and gas appliances typical for residential and commercial gas utilization. They give a first indication, however, that many existing appliance types can safely be operated with higher levels of hydrogen. These investigations also point to further relevant aspects, e.g., the performance of combustion control systems and the question of how to properly adjust appliances in a future where higher and fluctuating levels of hydrogen may be found in the gas grids.

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