Impact of Changing Natural Gas Qualities on Industrial Combustion Processes

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Abstract
The markets for natural gas in Europe are in a state of transition due to a number of reasons. Some traditional domestic sources, e.g. the L-gas fields in the Netherlands, are in decline while imports from sources outside Europe will play a bigger role for Europe's gas supply in the future. The continuing integration of gases from sustainable sources into the gas infrastructure as well as political developments, such as the intent of the European Union to harmonize European gas quality standards, will also lead to profound changes in the European gas market.
While this evolution offers a number of benefits, like stable gas prices, increased flexibility and security of supply as well as a reduced CO_2 footprint, it also means that gas consumers will be confronted with greater fluctuations of gas quality at any given location in the grid. For some, especially in regions which have traditionally enjoyed rather constant gas qualities in the past – for example many parts of Germany - this will be a new experience.
The combustion of natural gas plays an important role in many industrial production processes. In a multitude of applications, natural gas is used to provide heat for melting or heat treatment processes, for example in the glass, ceramics or metal industry. In the chemical industry on the other hand, natural gas serves both as fuel and feedstock for a variety of production processes. In general, these manufacturing processes are operated in a very narrow window of optimum performance with regards to fuel efficiency, product quality and pollutant emissions. Therefore, there is significant concern about the impact of fluctuating gas qualities on such sensitive processes. This is not a hypothetical scenario: for example, a 2011 poll among German glass manufacturers shows that many of them have already experienced problems due to gas quality changes, the main issues being reduced product quality and decreased process stability. Other industries have reported similar problems. A group of three German gas-related research institutes investigated the potential impact of changing natural gas qualities on industrial combustion processes in a research project funded by DVGW (the German Technical and Scientific Association of Gas and Water). Using literature reviews, experiments on a laboratory scale as well as measurements at semi-industrial test rigs and numerical simulations, various industrial combustion processes were analyzed and consequences of gas quality changes assessed. Also, compensation strategies were discussed. The consensus was that advanced measurement and control technologies will be required to compensate for gas quality fluctuations if the production process in question is known to be sensitive. Also, improved communication between gas suppliers and industrial gas consumers as well as a greater awareness of industrial operators concerning the issue of changing gas qualities will help mitigate their impact on industrial production processes.

Introduction

Natural gas is an important source of energy for many industries. In 2011, about 1/3 of Europe's gas consumption was due to various industrial applications (excluding power generation) [1], in particular the chemical industry and thermal processing industries. With regards to the generation of process heat in manufacturing processes, natural gas is in fact the most important source of energy in Germany [2]. These manufacturing processes are very diverse, ranging from low-temperature drying processes, for example in the food or paper industries, to extreme high-temperature melting and heat treatment processes which can be found in glass, ceramics and metals production. The predominance of natural gas for thermal processing applications in Europe is due to a number of factors. Pollutant emissions are low compared to other fossil fuels and the European gas infrastructure is well-developed, offering excellent availability and security of supply. One crucial aspect is the good controllability of gas burners: in many manufacturing processes, a very tight control of furnace temperatures and atmospheres is essential for high product quality, fuel efficiency and low pollutant emissions. Even small changes of the conditions inside a furnace can have a negative impact on the performance of the process. In ceramics manufacturing, for example, a small deviation in the furnace temperature can lead to a discoloration of the product or reduce on the quality of the glazing [3].

The European markets for natural gas are, however, in a state of transition for various reasons. L-Gas, for example, which is primarily produced in the Netherlands and the northwestern parts of Germany, will disappear from the European gas grids in the near future. It is estimated that the Netherlands will cease exporting L-Gas by 2030 [4]. This gas has to be replaced which means that Europe will become even more dependent on gas imports from non-European sources such as Russia or the Middle East. The shift in the U.S. markets on the other hand will make large amounts of LNG (Liquefied Natural Gas) available to the global markets.

Also, new types of gas will have a bigger share of the European gas supply: biogas is already being fed into the grid and it is expected that LNG with its often somewhat different physical and chemical properties will play a more important role in the years to come [5]. There is also the distinct possibility that increasing amounts of hydrogen will be fed into the European gas grids in the near future, which is produced by power-to-gas plants [6], [7]. Similar to the electricity market, the European markets for natural gas underwent a liberalization process. Integrated gas companies were "unbundled", leading to increased competition on the markets.

Finally, the so-called harmonization of H-Gas, will also have a significant impact on gas utilization, especially in the industrial sector. The European Commission intends to introduce a common European gas quality regulation [8], [9] to supersede the national regulations of the individual member states. As many of these national regulations are to a certain extent incompatible to one another [10], they are considered to be a trade obstacle by the Commission, interfering with the internal European market.

This evolution of the European markets for natural gas brings a number of benefits, such as stable prices and an increased security of supply due to more competition on the market as well as a better integration of regenerative energy sources into the gas infrastructure, leading to reduced CO_2 emissions. One consequence, however, will also be that fluctuations of gas qualities at any given location in the gas grid will increase both in amplitude and frequency in the years to come.

Gas Quality

Natural gas quality is usually not expressed in chemical compositions as it would be hardly feasible to maintain constant gas compositions in a complex gas grid. Instead, a small number of characteristic fuel gas properties is used to define gas quality. In Germany, for example, the Code of Practice DVGW G 260 [11], issued by the "Deutsche Verein des Gas- und Wasserfaches e.V." (DVGW) regulates the qualities of natural gas distributed in Germany and uses three characteristic fuel gas properties: the relative density d, expressed as the ratio of the standard densities of the natural gas and air, the gross calorific value H_S and the Wobbe Index as a fuel interchangeability parameter. All values are referenced to 25 °C / 0 °C for energy and volume respectively. While the applicability of the Wobbe Index for many industrial firing systems is not undisputed [3], [12], it is one of the most important gas quality parameters in the context of grid control and residential appliances.

Fig. 1 shows the ranges of permissible gas qualities in Germany, according to DVGW G 260 as well as gas qualities of some distributed gases. It is evident that these ranges are actually quite large; however, while there have always been differences in gas qualities at different locations, the quality of distributed gas at a given location in the distribution grid has remained rather constant in the past, a significant advantage especially for the operation of sensitive industrial combustion processes where tight control over furnace conditions is often crucial for product quality, fuel efficiency, but also pollutant emissions.

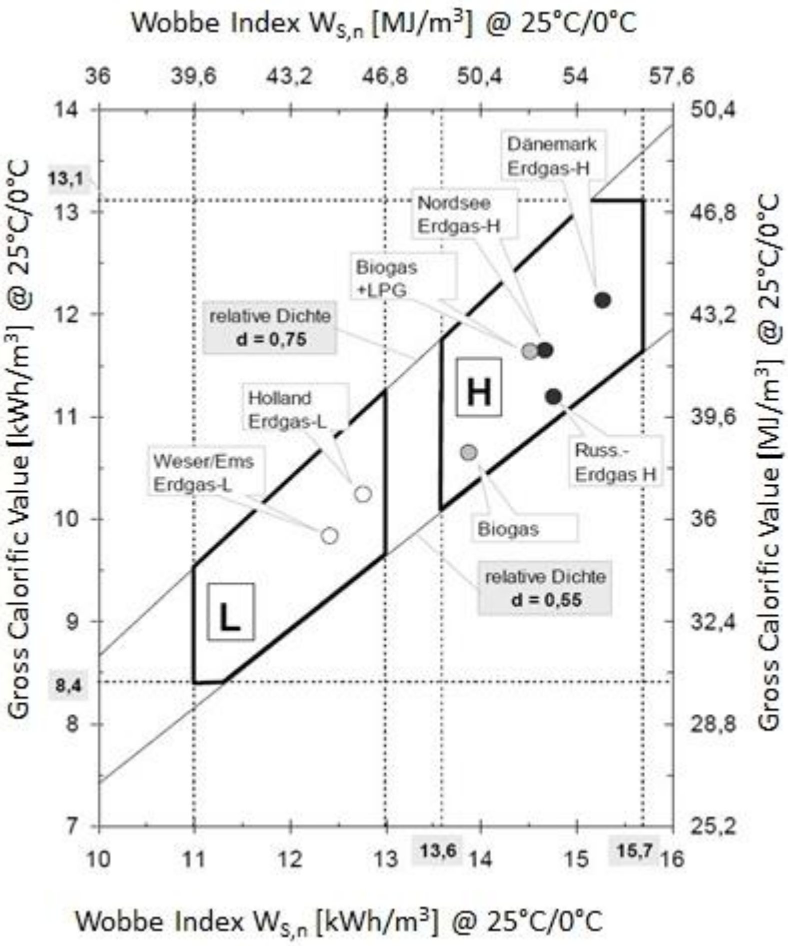

Figure 1: Permissible gas quality ranges in Germany [11]

Due to the changes in the European gas markets however, end users of natural gas are increasingly confronted with rapidly changing gas qualities and compositions. This is of particular concern for many industrial applications **Fig. 2** shows a gas chromatograph measurement of the chemical composition of natural gas supplied to a thermal processing plant near Leipzig, Germany. The measurements were taken in 2011 over a period of about 3 months and show the pronounced and rapid changes of local gas compositions. The methane content, for example, dropped from almost 98 vol.-% to less than 90 vol.-%, while the concentrations of higher hydrocarbons rose accordingly. Also, the steep gradients indicate that the gas quality changes occurred quite rapidly. While the supplied gas always complied with the limits defined by DVGW G 260, the plant in Leipzig experienced problems with product quality, pollutant emissions and overall efficiency due to sudden and unexpected changes of the fuel gas composition. A recent poll carried out by the “Hüttentechnische Vereinigung der Deutschen Glasindustrie” (HVG) in Germany showed that about 75 % of the participants of the poll (which corresponds to roughly 90 % of Germany’s glass manufacturing capacity) had already experienced production problems due to gas quality changes [13]. Problems ranged from reduced product quality and energetic efficiency to issues with process stability and pollutant emissions. It can be expected that other industries which rely on sensitive combustion processes are facing similar problems. At the moment however, changing natural gas qualities are often not yet considered as a possible cause for production problems. There is still a distinct lack of awareness amongst operators of gas-fired industrial applications.

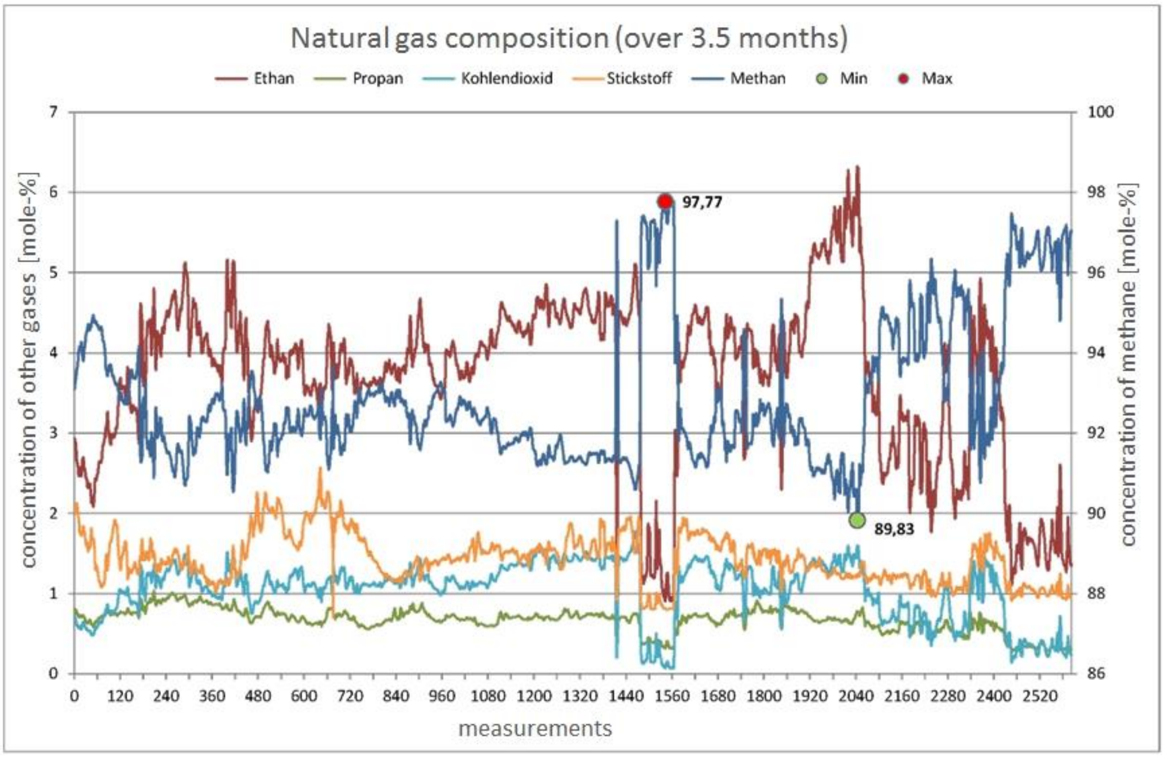

Figure 2: Temporal evolution of the composition of natural gas supplied to a thermal processing plant near Leipzig, Germany [3]

Effects of Changing Gas Qualities on Industrial Combustion Processes

In the course of a recent research project funded by DVGW [14], GWI, DBI and EBI investigated how changing gas qualities could impact a variety of different industrial combustion processes, using chemical kinetics simulations, experiments on both a work bench and semi-industrial scale and CFD simulations (CFD: computational fluid

dynamics) of operational industrial furnaces.
In one case study, the effects of fluctuating gas qualities on a regenerative glass melting furnace were analyzed, using CFD simulations. Since the glass melting process is particularly sensitive to changes in furnace conditions, it can serve as an excellent example to look into the effects of changing gas qualities on industrial combustion processes in more detail.

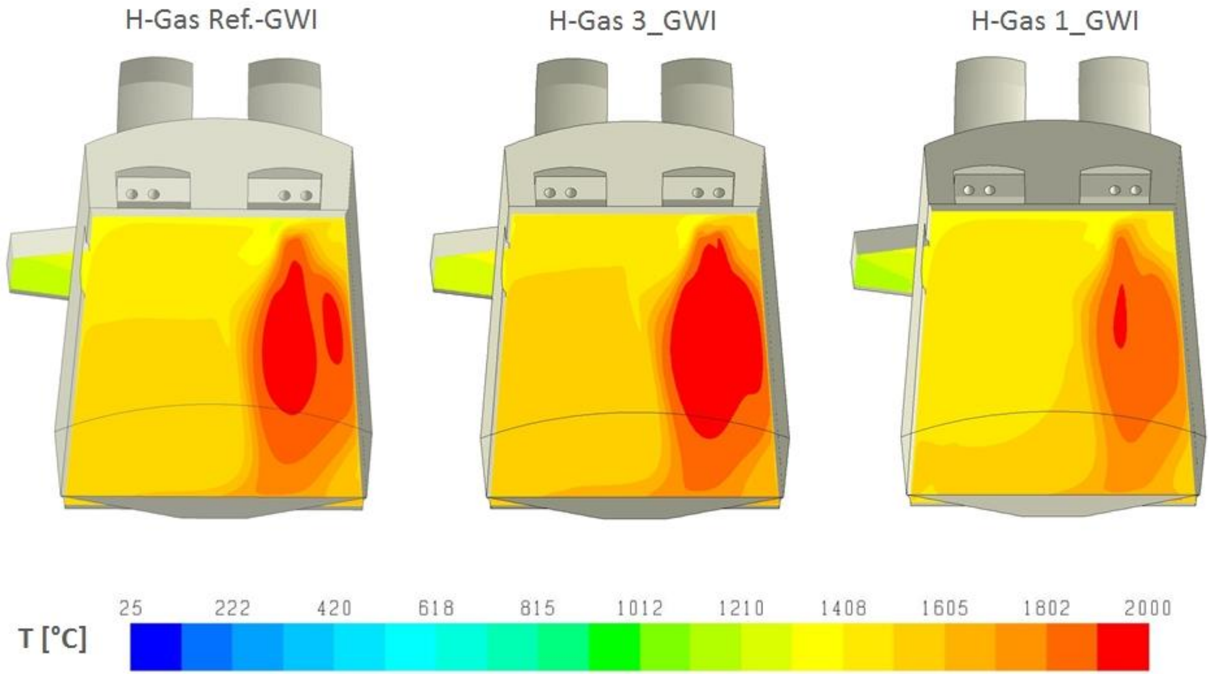

Figure 3: Temperature distribution above the glass melt for the first scenario (constant air ratios) (Source: GWI)

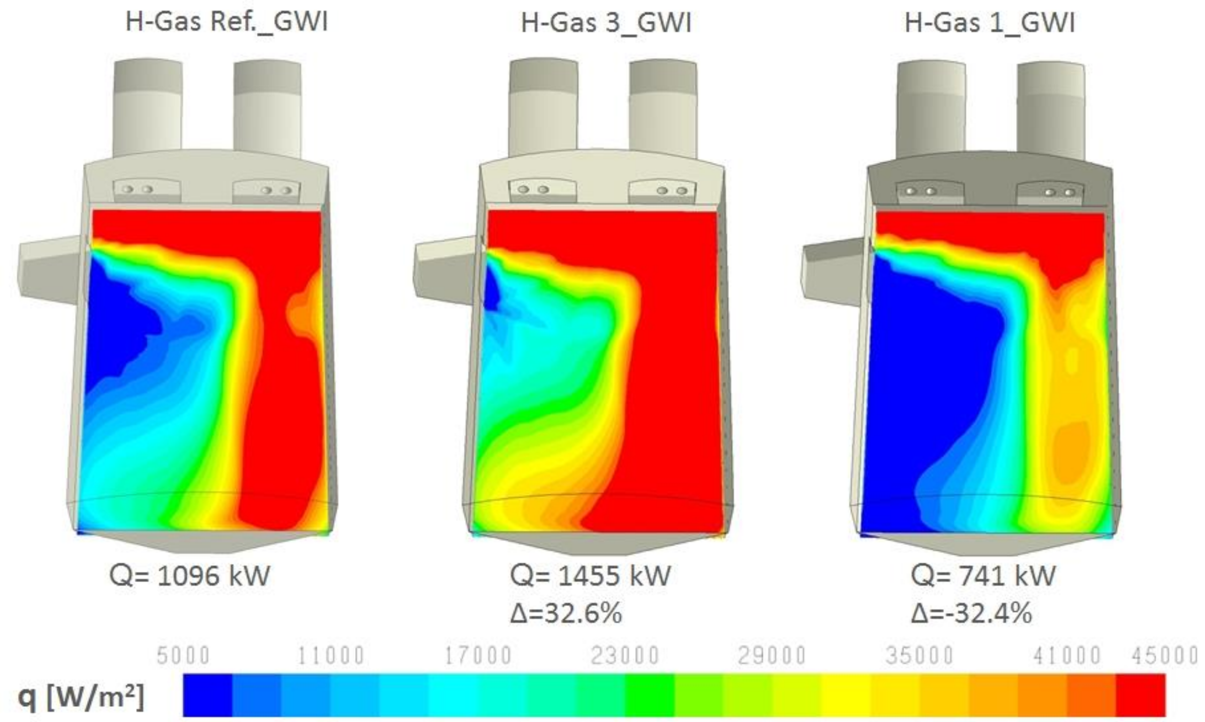

Figure 4: Heat flux distribution into the glass melt for the first scenario (constant air ratios) (Source: GWI)

The furnace was calibrated for optimum performance (burner load 4 MW, air ratio

1.05, air pre-heat temperature 1300 °C) using a reference gas (called H-Gas Ref._GWI) whose composition corresponds to the gas available at GWI's facilities at the time of the simulations. In addition to the reference gas, two additional gases were defined at the extremes of DVGW G 260's H-Gas range. H-Gas 1_GWI is a relatively low calorific natural gas while H-Gas 3_GWI has a rather high gross calorific value.

In various scenarios, the responses of the furnace to a sudden switch from the reference gas to either H-Gas 1_GWI or H-Gas 3_GWI were simulated.

In the first scenario, it was assumed that an oxygen sensor in the flue gas duct was used to constantly monitor the global stoichiometry of the system. The volume flow of air is then adjusted to maintain a constant air ratio while the volume flow of the fuel gas, however, remains constant. This is a common approach to control industrial furnaces. The simulations show, however, the limited success of such a control strategy to minimize changes caused by changing fuels. Due to the changed densities and calorific values of the various test gases, the energy input into the furnace changes quite drastically, leading to a shift in the overall energy balance of the system. Flow fields and temperature distributions in the furnace space change, as do the heat fluxes into the glass melt. The latter is of particular importance as it will have an impact on glass quality in a real glass melting furnace, increasing the rejection rate of the production process. **Fig. 3** and **4** show temperature distributions above the glass melt surface and the total heat flux distributions into the melt for this scenario.

In a second scenario, it was assumed that a change in gas quality occurs and the furnace control system does not intervene at all, for example due to a damaged oxygen sensor. This means that in this scenario the volume flows of both air and fuel remain constant. While all effects from the previously described scenario (changing temperature and heat flux distributions and hence reduced glass quality and fuel efficiency) still apply, the much more severe consequence in this scenario is that the global stoichiometry of the system changes since the minimum air requirements of fuel are dependent on its chemical composition. When switching to higher calorific fuel, the combustion in the furnace becomes sub-stoichiometric (λ = 0.93 in this case), causing significant CO formation. As carbon monoxide is highly toxic and can lead to an uncontrolled combustion in the regenerators used for air pre-heating, this is certainly a "worst-case" scenario. The consequences of a change towards a fuel with a reduced calorific value on the other hand are relatively benign: in addition to the reduced glass quality due to the reduced heat flux into the melt, the combustion process is also operated in a very inefficient manner, leading to an increased fuel consumption due to an increased air ratio (λ = 1.21).

While the previous scenario was a "worst-case" scenario, the third scenario is a "best-case" scenario. Here, it is assumed that sophisticated measurement equipment, for example a gas chromatograph, constantly monitors the fuel gas composition. The volume flows of both fuel and air are then adjusted accordingly to maintain constant burner loads and air ratios. The simulations show that in this manner, the effects of changing fuel gas compositions on the process can be minimized to a great extent (cf. **Fig 5**).

Despite a difference in the net calorific values of about 14 % (based on the reference gas H-Gas Ref._GWI), the change in the total heat flux into the glass melt is at less than 2 %, compared to the reference gas. While there are still some differences in the temperature distributions and NO_X emissions of the furnace simulations (confirmed by test rig experiments, as presented in [15]) in this scenario, the overall impact of a drastic gas quality change on the production process was mitigated to a great extent.

This comes at a price, however, as the necessary measurement and control equipment to implement such a control strategy in an industrial furnace is quite expensive.

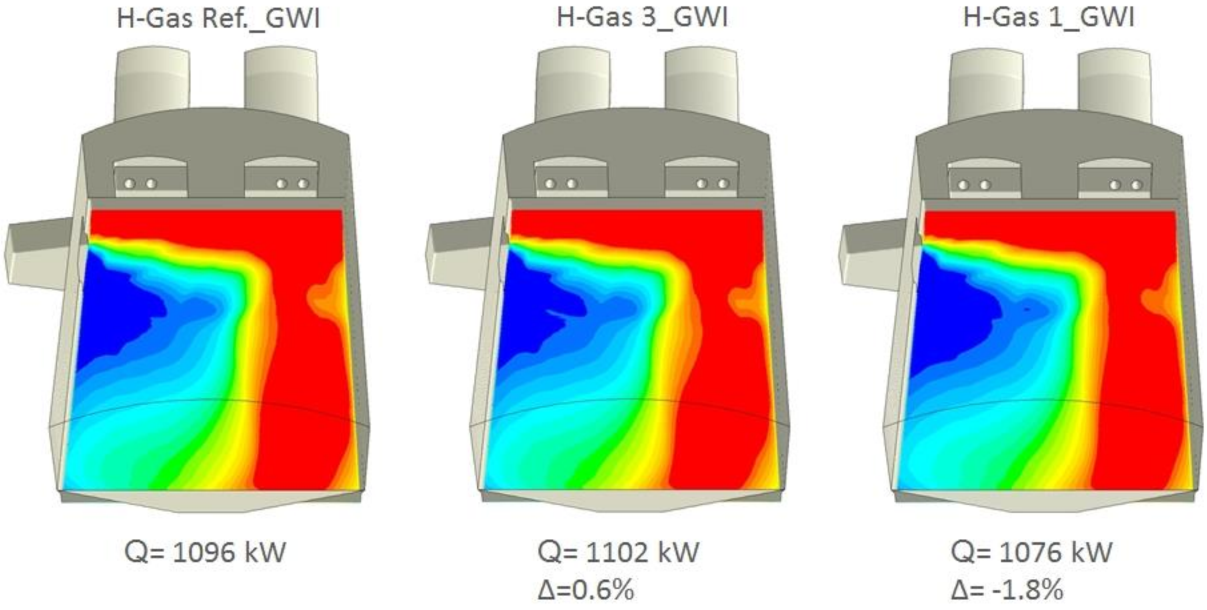

Figure 5: Heat flux distribution into the glass melt for the third scenario (constant burner loads and air ratios) (Source: GWI)

A gas chromatograph for example as gas quality sensor is a sophisticated, powerful but expensive piece of technology, which is usually recommended only for very complex or large processes. Other compensation approaches may be based on flue gas analysis (e.g. λ-probes) in combination with correlative gas quality sensors or in-situ temperature probes. These approaches are less powerful and comprehensive, but may very well help compensate gas quality changes in many applications.

In addition to the glass melting furnace, various other industrial combustion processes were investigated both experimentally and numerically within this research project. It could be shown that while there are some processes that are sufficiently robust to handle drastic gas quality changes, many cannot.

Fig. 6 visualizes the effect of adjusting burner systems to local gas qualities, usually without knowing the actual gas quality on-site. This is a common practice for industrial firing systems since they have to meet requirements for tight process control, efficiency and pollutant emissions using the local gas and are usually not designed with fluctuating fuel gas qualities in mind. Local gas quality is generally assumed to be rather constant. The figure shows the impact of a change in gas quality on an industrial boiler system that was originally adjusted for optimum performance for a gas at the lower limit of the German DVGW G 260 H-Gas range. When suddenly supplied with a fuel gas with a much higher Wobbe Index, the system responds not only with a rise in burner load (not seen in the diagram), but also with carbon monoxide concentrations in the flue gas. This underlines the very narrow operational range for optimum performance of many industrial combustion applications. The adjustment of the burners based on the local gas quality, while unavoidable for large scale combustion processes with challenging requirements regarding efficiency and emissions, makes these systems very susceptible to changing fuel qualities.

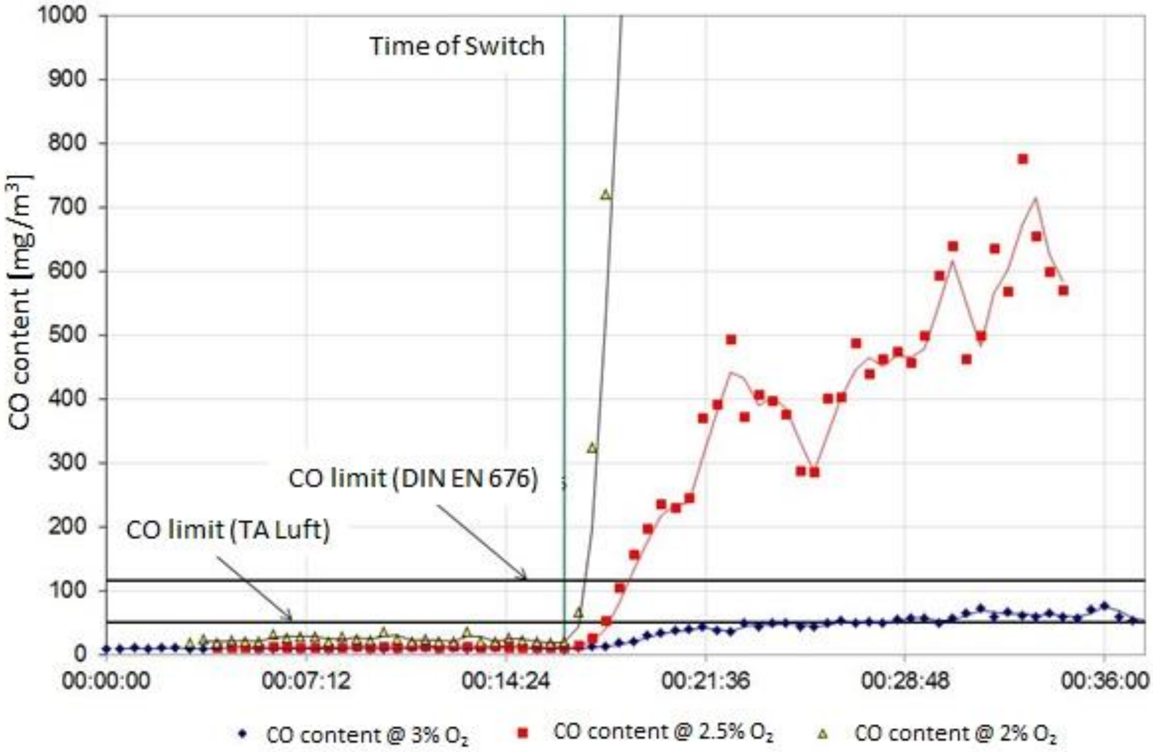

Figure 6: Effect of a gas quality change within the DVGW G 260 range on the performance of a boiler (Source: DBI). **Change from low-calorific gas H_DBI 1 to high-calorific gas H_DBI 3 on the DBI boiler test rig (100 kW burners) with different preset air ratios.**

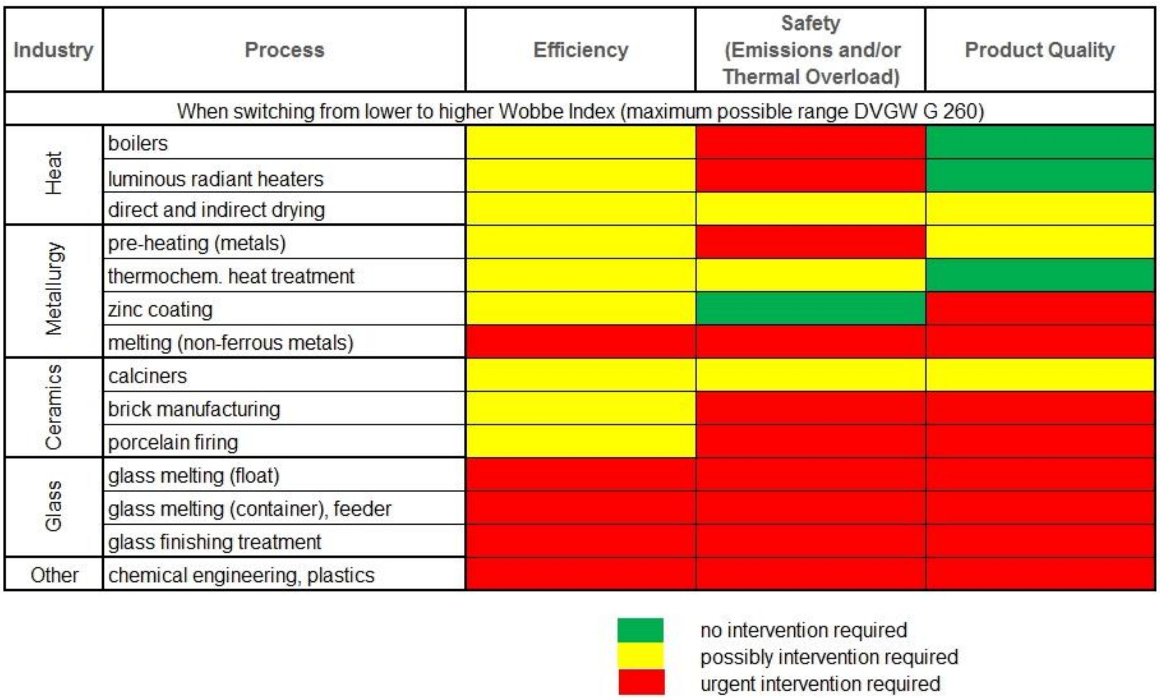

Figure 7: Assessment of the susceptibilities of various industrial combustion processes to gas quality changes over the entire range of German Code of Practice DVGW G 260 [14], if no gas quality compensation strategy is applied (which is often the case today).

These findings are corroborated by [16] who conclude that some kind of active control as well as continuous combustion monitoring are required to make such systems more robust with regards to gas quality changes.

However, there are still many industrial furnaces in the field that do not have this capability. Depending on the kind of measurement and control systems needed, retrofitting a furnace may well require a significant investment. There are also regulatory issues: commercially available gas chromatographs, for example, which could be used to determine the natural gas composition on-site, for now lack the SIL/PL certifications (SIL: Safety Integrity Level; PL: Performance Level) required to use them for the purpose of process control.
An assessment of various industrial manufacturing processes with regards to their susceptibility to gas quality changes is shown in **Fig. 7**. It shows the impact of gas quality fluctuation on industrial systems within the entire Wobbe Index range of DVGW G 260 [14].
This table, based on the findings of the DVGW research project [14], a literature review and discussions with the operators of industrial combustion applications as well as equipment manufacturers, demonstrates how very different various industrial processes can and will react to a gas quality change. This is not surprising, given the wide variety of gas-fired applications found in thermal processing industries. It means, however, that there is no general solution. Instead, each application will have to be analyzed individually.

Conclusions

The changes on the European gas markets bring a number of benefits to the end consumer: stable prices due to increased competition, increased security of supply as well as reduced CO_2 emissions by integrating regenerative gas sources. One consequence which is of particular concern to both the operators of industrial furnaces as well as equipment manufacturers, however, is that greater and more frequent fluctuations of local gas quality may occur anywhere within the gas grid, without warning. A relatively constant gas quality and hence rather constant combustion characteristics can no longer be taken for granted.
A recently concluded German research project shows that the effects of changing gas qualities on industrial combustion processes can vary: while some processes are sufficiently robust, others are quite sensitive, for example in the glass, ceramics or metals industries.
The impacts of changing gas qualities are very different, depending on the process in question. In the glass industry for example, the effects on the melting process are primarily seen in glass quality, process efficiency and pollutant emissions while the consequences for the combustion processes in the feeder systems usually express themselves through reduced flame stability and increased risk of flash-backs. Due to the very different applications of natural gas in various thermal processing industries, it is hardly possible generalize the effects and compensation strategies. Each process, even each plant and furnace is different and needs to be analyzed with regards to its specific requirements and the appropriate compensation strategy. Operators of industrial combustion processes as well as equipment manufacturers need to be aware that constant gas qualities can no longer be taken for granted and that measures to detect and compensate for gas quality fluctuations need to be developed and implemented. Gas suppliers, on the other hand, should take the specific needs of industrial customers into consideration. Improved communication (for example up-to-date information on gas qualities, or even better, compositions) can help mitigate the impact of changing gas qualities on gas-fired industrial manufacturing processes.

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