WP2
Gas Quality Requirement
Task 4 Solutions to equip sensitive appliances

November 2019

The report was prepared by:
Jean Schweitzer, DGC (*)
QA by Jan de Wit, DGC

*Dr. Neergaards Vej 5B, 2970 Hørsholm, Denmark, jsc@dgc.dk

1. Introduction

This report is part of FUTURE GAS WP2 (Gas Quality Requirement). It covers Task 4 (Solutions to equip sensitive appliances).
The objective of the work is to identify which solutions can apply for gas utilisations having proven to be too sensitive to gas quality change. The sensitivity of gas utilisation has been studied in detail in a previous report /1/.

Gas quality variations are challenging the end use and gas quality changes may impact the following areas:

- Safety
- Emissions
- Efficiency
- Product quality (manufacturing industry, e.g. glass)

However, several possible mitigation solutions may be implemented, either to reduce gas quality variations or to adapt the working conditions of the appliances to minimize the impact of the variation.

In the framework of the FutureGas project, the following were organized to clarify the question of mitigation.

1. **Overall mitigation solutions** were discussed in the report "WP2 Gas Quality Requirement: DELIVERABLE 2.2.1 Impact of gas quality on appliances (and utilisations)". /1/
2. A literature study and tests were carried out on **gas condensing boilers** in collaboration with several EU partners. Boilers represent a very large share of appliances used in the **domestic and commercial** sectors. The results of the work were extensively reported. /2/
3. Mitigation measures relating to gas quality variations **for industry and power generation** were studied in a more general way and were discussed in a note "Mitigation measures to gas quality variations in the process and power industry. Henrik Iskov, Danish Gas Technology Centre. /3/

The present document and the three documents above cover the task 4 of FutureGas WP2. In the present document, we discuss the main findings of the work done and elaborate on overall conclusions regarding mitigation.

2. Overall options of mitigation

There is not only one single option for mitigation, but a multitude of solutions that are adapted to different situations. There are technically simple solutions and more complex ones.

We can suggest an overall classification in two main classes:

- **Upstream** solutions that consist in modifying the gas before it is used (conditioning)
- **Downstream** solutions that apply at the end use (generally technical modification or monitoring of appliances or process)

Option 1: Upstream (supply): National, regional or local grid level conditioning of natural gas

National conditioning of the gas is for example done in Japan, where the gas quality is maintained within a narrow range. The tradition of implementing such a solution is linked to the fact that Japan has not a domestic production of gas (national production is in general rather stable in terms of gas quality) but only LNG that can be of rather different qualities due to different origins. Conditioning was here a way to cope with a large diversity in the supply.

Regional conditioning is done for example in some parts of the Netherlands where H gas is mixed with nitrogen to reach L gas specifications that is produced in Groningen and used in the Netherlands.

Another example of regional conditioning is in Copenhagen, where air is added to natural gas in order to conform with the desired gas quality ”town gas 2”.

In the two last cases the conditioning is resulting from a change in the supply of the gas (depleting production in Groningen, abandoning town gas production). In such situations, the conditioning is probably a cheaper option compared to modifying or replacing the many appliances that are already installed at the customers.

Conditioning can also be a solution implemented *locally*, and it can be a viable option for larger industrial use in a region where variations are too large for the customer need. Commercial air mixing units or other technology can be used in this case. /3/

Option 2: Downstream (end-use)

Solutions on the end-use side are aiming to mitigate the effect of gas quality change by appropriate action on the process (combustion etc.).
The figure below shows the various options that are available for example on gas appliances. In the present example, the gas quality variation effects are mitigated by the quantity of air mixed with gas entering the burner.

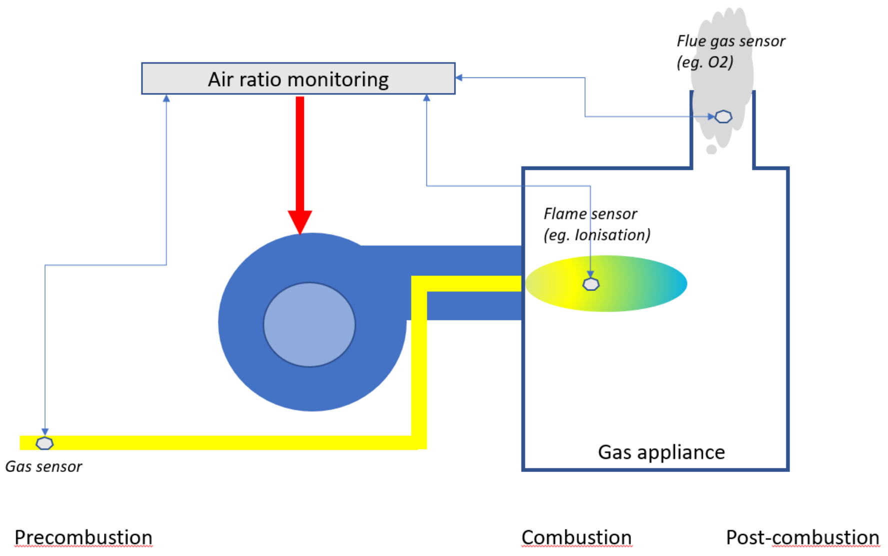

Figure 1 Principle of air ratio monitoring with different options

Downstream solutions can be either feedback control or feedforward control.

Feedback control (based on measurement in post-combustion or combustion zone)

A feedback control is using a feedback for example from a measurement in the combustion (O_2 etc.) or in the flame to control an action for example modifying the quantity of air mixed with gas.
Examples:

- Combustion measurement (in the post combustion zone)
- Flame sensor ionization) (in the combustion zone)

There are many different technologies, and they are discussed in /2/ and /3/.

Feedforward control (pre-combustion measurement)

A feedforward control is typically using information on the gas (e.g. Wobbe index), to control an action for example the quantity of air mixed with gas.
Example:

- Direct continuous measurement of GCV or the Wobbe (gas chromate graph, etc.)

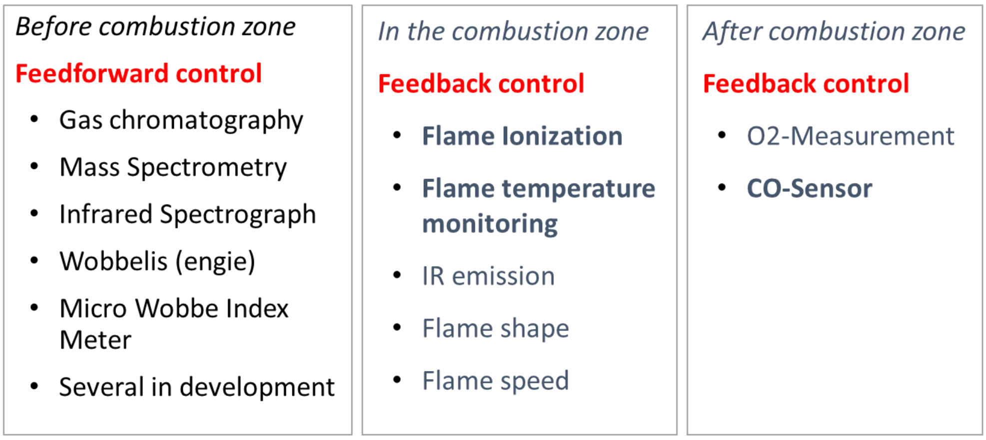

Figure 2 Example of technologies for controls /2/

In general, feedforward systems are costly and, therefore, more adapted to industrial applications (industry, power production). However, the development in sensor technology may change this in the future!
Feedback controls are presently less costly and, therefore, more adapted to domestic and commercial applications where appliance costs are lower.
Note that the two systems can be combined.
Some of the solutions are already integrated in new appliances sold on the market. Some of the solutions are adapted to the retrofit of existing installed appliances.

3. Summary of the main outcomes regarding mitigation from previous notes and reports (/1,2,3/)

1.1 Mitigation may not necessarily be needed!

The GASQUAL project /15/ investigated a quite large range of Wobbe index variations (variation of about 10% on each side of the nominal Wobbe index of pure methane).

The project, the scope of which was domestic and commercial appliances, has shown that many existing appliances can cope with wide variations of the Wobbe without any combustion control system. This means that without further action, already a large share of the population of installed appliances should be able to cope with variations of the Wobbe.

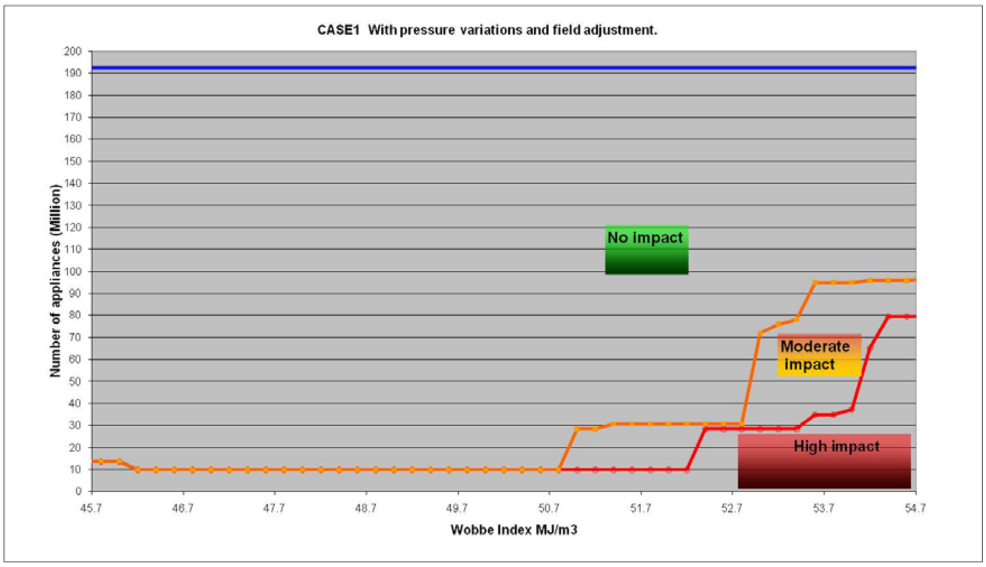

Figure 3 GASQUAL overview of overall impact of gas quality change for domestic and commercial appliances /15/

1.2 Mitigation technologies (INDUSTRIAL USE) /1/

There is a wide range of possibilities for industrial customers, for whom control systems represent a relatively low investment compared to the cost of the burners, boilers and other components used for the process and in regard to the gas consumption.

For example, ENGIE in France /11/ is developing and providing not only support to industrial customers comprising elements such as detailed and frequent information on gas quality and gas properties from TSOs/DSOs, but also control systems for an accurate control (1%) of Wobbe index in sensitive processes such as

- Glass industry feeders, bulbs and medical glassware
- Pottery and porcelain: batch furnaces
- Lime production

Similar solutions are also developed by manufacturers. /12/

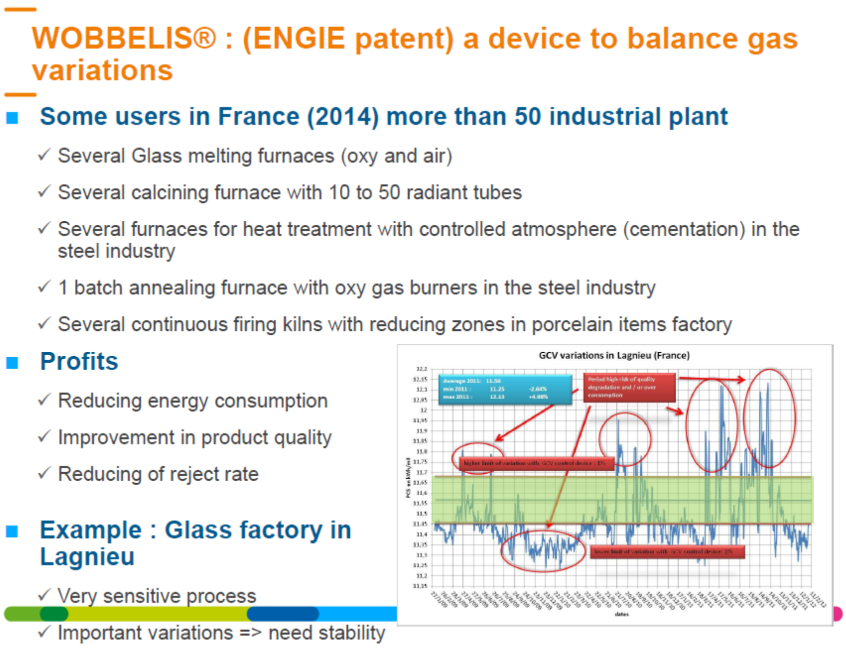

Figure 4 Example of mitigation technologies in the industry (source ENGIE)

1.3 Engines (/1/, /3/)

Gas engines can be sensitive to changes in the methane number if it approaches the design minimum value or if the gas composition changes too fast. Below the design minimum threshold value, knocking can destroy the engine. Countermeasures can be fitting of knocking detectors connected to a control system to adjust load and ignition timing. This system in combination with a methane number below the threshold value typically leads to reduced power and energy production and, therefore, often an economic loss (in periods with low Wobbe index) – but it safeguards the engine.

These measures have been used in Denmark in the nineties where gas from the Syd Arne field was introduced into the gas grid. The methane number of gas from the Syd Arne field was expected to be considerably lower (around 63 to 65) than the minimum design value (around 70) of many stationary gas engines installed at decentralized cogeneration plants in Denmark. It should be noted that the methane number is not part of the gas quality specs issued by the Danish Safety Technology Authority.

Hydrogen is expected to be injected into many European gas grids in the future. As the methane number of hydrogen is zero, there may be knocking problems with gas engines even at very low hydrogen additions if mitigation measures such as anti-knocking systems are not fitted.

So, if engines are fitted with advanced controls, optimum efficiency for every engine cylinder can be obtained based on operation feedback and cylinder specific adjustments. The latter is often based on feedback from knock sensors; in such implementation they act both as engine protection and efficiency optimization. /5/
New OEM stationary engines with controls can accommodate wider fuel compositional changes. Most modern engines have A/F (Air Fuel) ratio control systems and knock sensors that can reduce or eliminate the impact of even larger variations in Wobbe Index and Methane Number. /7/

A commercial example of a natural lean-burn stationary gas engine technology is the Jenbacher J620 GS-E. When engine knock is detected, the control responds by first retarding ignition timing, then increasing the Air/Fuel ratio (to reduce combustion temperature), and then finally reducing engine power. The control system automatically tries to re-establish engine power output until knock reoccurs. This control approach allows the engine to operate with a wide range of gas compositions without knocking problems. A detailed list of control systems for gas engines is studied in /7/.

Despite the solutions mentioned above (related to accommodation to methane number change), one of the most difficult challenges that is not necessarily addressed by knock sensors is the ability of controls to accommodate fast “rate of change” (ROC) of Wobbe index.

1.4 Gas turbines (/1/, /3/)

Gas turbines can be designed to burn any fuel, but the tolerance to fuel quality variations is relatively low. Stricter environmental requirements have led to introduction of lean premix systems, such as Dry Low NOx (DLN) combustion systems. These systems have narrowed the fuel quality tolerance. A typical limit for deviation from the fuel specs is around 2%. Gas turbines are especially sensitive to increased levels of higher hydrocarbons (C2+).

Due to expectations about much wider fuel quality variations in the future, considerable work has been done on increasing the fuel quality tolerance. Like gas engines, gas turbines can accept more variations when equipped with controls. Traditional gas chromatographs are not necessarily adapted to control the turbines, as the reaction time of chromatographs is in the range of 15 minutes /9/.
At slow changes they are very accurate, but for fast changes in fuel quality – which are expected to take place much more frequently in the future – gas chromatographs are too slow.

Therefore, some developments with IR (infrared) sensors that record and transmit changes of the gas composition very fast are used /10/ and can cope with high C2+ content fuels that may generate problems for the turbine if not detected rapidly enough. Infrared sensors have a response time of 20 seconds and can be almost considered as real time adaptation /9/.
Also as an example, ALSTOM has designed a fast system called FIRGAS aimed at C2+ measurements. E.ON Ruhrgas AG’s Gas-Lab has developed the Q1 system for fast measuring/determination of Gas Calorific Value, Wobbe Index and relative density (GCV, WI and RD) /4/.

The use of those solutions allows to cope with up to 10% changes in the Wobbe with no hardware modifications to the gas turbines.

1.5 Transport sector (/1/)

As for other gas consuming technologies, mitigation solutions are being developed in the transport sector.

For mobile applications, two main solution families can be used: Oxygen sensors (also-called “lambda sensor”) based on combustion control or sensors able to measure the gas characteristics. Sensors are not only increasing the acceptability to different gases, they are also optimizing the efficiency and emissions.

An example of gas sensors used in the automotive industry is the MEMS sensor that is based on correlation between gas composition and other physical properties of the gas. Measuring one of those properties is easier than making the gas analysis: The sensors are cheaper and smaller and react faster compared to e.g. gas chromatographs.
The MEMS technology was used in the INGAS project /6/.

The technology was tested under road conditions in different cars and a long-term test was conducted with a VW Passat with significant differences in gas quality and changes of Methane Number ranging from 70 to 100 MN. The cost of those sensors is estimated to be between €90 and €130 for a production of 1000.

1.6 Domestic and commercial sector (/2/)

The technology of ionization is working very well over a very wide range of gas quality variation and is already implemented on more than 10 boiler models on the market. The technology is simple and rather low-cost. Other technologies do exist and have already been used on some appliances, but at the moment the ionization seems to be the best available solution and it may very well also be used in other sectors of gas utilization.

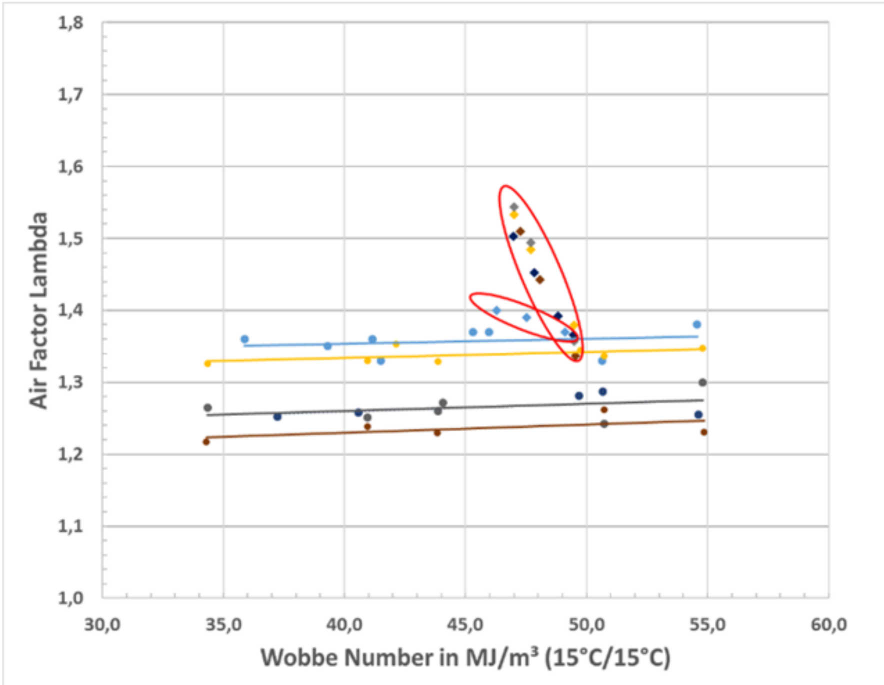

Figure 5 Measurement results from 4 boilers equipped with ionization sensors to monitor air/gas ratio

Figure 5 illustrates the ability of the boilers tested in the project /2/ to maintain the air factor almost constant over a very wide range of Wobbe index variation. As a result, safety, efficiency and emissions are maintained at a level close to the nominal ones.

The outlying points on the figure (marked with a red ellipse) are obtained with hydrogen/natural gas mix. The ionization technology is not working in this case and another technology needs to be implemented in appliances if H_2 is massively injected in the gas grid. H_2 sensor technology is developing rapidly /13/ and may provide solutions that may cope with the given challenge.

Biomethane composition is close to pure CH_4, and therefore mitigation solutions that are valid for natural gas will also be valid for the biomethane or for biomethane/natural gas mix.

4. Costs of mitigation

There is no simple answer regarding the cost of mitigation:

- for small appliances the technology is integrated in the appliance itself.
- for larger users the solution is often tailor-made.

It is generally cheaper to have mitigation technologies integrated in new applications. Especially for the domestic and commercial sectors, the retrofit of existing appliances can be costly (due to labour cost of the retrofit operation).

Looking at the market today we can see some trends:

- New technologies like condensing boilers are increasingly equipped with combustion controls. The cost does not seem to be an issue. The cost of a boiler is between €1000 and €3000, and the cost of a combustion control seems to be marginal.
- For existing appliances installed in homes (boilers, cookers, etc.) the retrofit with controls like ionization technologies may be expensive: Not only a new component needs to be bought, but it is to be installed in the existing appliance (labour cost). Moreover, it will not solve the issue of hydrogen.
- New gas turbines and engines are increasingly equipped with controls allowing a better acceptance of gas variation, but still many older appliances are on the market without being equipped with controls.
- For industrial use, solutions do exist and are used in practice.
- Due to the volume of gas used in non-domestic sectors of utilisation (gas turbines, engines, industrial uses), the cost of retrofit is supposed to be relatively lower compared to the domestic or commercial sectors of utilisation.

5. Conclusion

There are already many possibilities to mitigate the variation of gas quality, and we believe that the future will be a mix of:

1. Conditioning of the gas to reach a range where utilisations with a given gas are safe and efficient.
2. A development of integrated controls on new appliances and utilisations on the market.

The two above are complementary and in phase with the plans of harmonisation of gas quality in the EU where harmonized Wobbe index class system will be established allowing a flexibility where the Wobbe can evolve in time and place.

Integrated controls on new appliances and in general mitigation should be promoted as much as possible to achieve the highest flexibility for the gas distributed. The number of utilizations/appliances that can accept a wide Wobbe range will increase with the replacement of older technologies. This means that while the gas quality is going to vary more in the future, so will the tolerance of installed applications/ appliances.

The conditioning of gas can be envisaged in regions **not having a stable supply**:

- where a lot of sensitive domestic & commercial appliances are installed and where the replacement of those will be too expensive.
- or where large industrial users cannot implement cost-effective mitigation solutions.

This regional or local policy of conditioning of gas may by the way change with the time as there will be changes:

- in the gas supply (may also be more stable, even though not likely).
- in the population of appliances in the considered region (sensitive appliance population should decrease with time).
- in the technological development in the sensor and control industry, including the possibility of retrofit existing installations.

The uncertainties connected with injection of hydrogen is, however, a problem for the industry as the design of appliances and combustion controls will not be the same with natural gas when H_2 is also injected.

It is difficult to know how appliances must be designed if one does not know if there will be H_2 or not in the grid. If the industry is promoting ionization combustion controls, those will help the market at the condition that H_2 is not injected, but if H_2 is massively injected, the appliances with ionization controls will need to be modified.

Ideally it would be best to clarify the uncertainties about H_2 injection and future gas qualities as soon as possible to have the “right” appliances designed and installed possibly with the correct control systems. Alternatively, controls or appliances that can cope with any scenarios should be developed.

6. References

/1/ FUTURE GAS WP2 Gas Quality Requirement: DELIVERABLE 2.2.1 Impact of gas quality on appliances (and utilisations). 2019.

/2/ Self-regulated gas boilers able to cope with gas quality variation. State of the art and performances. Report, October 2018. Stéphane Carpentier, Engie Lab Crigen. Patrick Milin Engie Lab Crigen. Nourreddine Mostefaoui, CETIAT. Petra Nitschke-Kowsky, E.ON Jean Schweitzer, DGC. Negar Sadegh, DGC. Olivier Thibaut, Gas.be . The activity of DGC in this project is part of the FUTURE GAS project.

/3/ Mitigation measures to gas quality variations in the process and power industry. Henrik Iskov Danish Gas Technology Centre. 2018

/4/ The impact of natural gas composition variations on the operations of gas turbines for power generation. D.J. Abbott, J P Bowers and S R James. E.ON New Built & Technology. Presented at The Future of Gas Turbine Technology. 6th International Conference, October 2012, Brussels.

/5/ IUP18. Wit, J. d. and Christensen, O." Various parameters influencing efficiency of and emission from high efficient gas engines". IGRC 1995

/6/ IUT20. Integrated GAS Powertrain – Low emissions, CO2 optimised and efficient CNG engines for passenger cars (PC) and light duty vehicles (LDV) October the 1st 2008 to March the 31st 2012, Massimo Ferrera, Dr., Centro Ricerche FIAT Funding Scheme: FP7-SST-2007-RTD-1

/7/ IUG04. LNG Interchangeability/Gas Quality: Results of the National Energy Technology Laboratory's Research for the FERC on Natural Gas Quality and Interchangeability. June 2007 U.S. Department of Energy National Energy Technology Laboratory DOE/NETL-2007/1290/7/

/8/ IUT38. The Impact of Natural Gas Composition on Fuel Metering and Engine Operational Characteristics. King, S., SAE Technical Paper 920593, 1992, doi:10.4271/920593.

/9/ IUP04. Effects of Variation of Fuel Gas Composition and heating value on Gas Turbines in Korea. 2015. Joongsung Lee, Jaejeon Kim, Jinchul Kim Korea Gas Corporation

/10/ IUP01. Fuel flexibility and gas turbine technology (Externalities of fuel gas composition) 2006 Jonathan Lloyd, J.Fredrik Bok ALSTOM,

/11/ IUI14. Impact of natural gas 'quality' variations on industrial Uses. GDF SUEZ activities. Slides 2015

/12/ SOL13. Optimization of fired heater control utilizing the residual oxygen measurement principle." nov-09 A.J. Mouris. Hobre Instruments BV

/13/ HYD12. Hydrogen safety sensors and their use in applications with hydrogen as an alternative fuel. Ortiz Cebolla R., Weidner E., Buttner W., Bonato C. JRC 2017.

/14/ COB01. Gas quality harmonisation cost benefit analysis2012. Nigel Bryant, Angus Paxton and more. GL & POWRY

/15/ GASQUAL cen/bt wg197 adopted final report. 14 December 2011. GASQUAL.EU

/16/ Hydrogen gas as fuel in gas turbines report 2015:121. Elna Heimdal Nilsson, Jenny Larfeldt, Martin Rokka, Victor Karlsson. 2015 ENERGIFORSK

More reference related to mitigations (with FUTURE GAS reference nomenclature. See /1/):

- SOL01Development of new calorific value adjustment system for wide range operation. 2012 Naoya Iwata, Nobuyuki Sakakibara, Kazuo Ito. Toho Gas Co., LTD., JFE Engineering Corporation
- SOL02 New appliances and systems for Wobbe Index measuring and regulating in industry. 2008 Rémy CORDIER Gaz de France.
- SOL03 Gas quality: a growing concern for the end user 2015 Michel Eskes Hobré Instruments
- SOL04Service offer in combustion control of gas-fired industrial thermal processes: - applications in the glass industry (melting furnaces and feeders) 2009. Rémy CORDIER. GDF SUEZ / Direction Recherche et Innovation/CRIGEN
- SOL05 A control system for all gas compositions. 2015 Sander Gersen (DNV GL/Gasunie) Pieter Visser (DNV GL/Gasunie) Frits Bakker (ECN) Ger de Graaf (TU Delft) Reinoud Wolffenbuttel (TU Delft) Ruud Westerwaal (TU Delft) Bernard Dam (TU Delft)
- SOL06 Approaches to optimize natural gas utilization for varying operation conditions. 2014 Holger Dörr, Engler-Bunte DVGW, Institutes for Technologies, Karlsruhe, Germany
- SOL07 Tools for adjustment of gas appliances to new gas quality. 2014. Niels Bjarne K. RasmussenDGC
- SOL08 Microburner for Wobbe Index measurements ? Egbert Mekenkamp
- SOL09 LNG Interchangeability/Gas Quality: Results of the National. Energy Technology Laboratory's Research for the FERC on Natural Gas Quality and Inter-changeability. 2007. Daniel Driscoll, George Richards, Brad Tomer U.S. Department of Energy National Energy Tech-nology Laboratory
- SOL10 Development of a Fuel-Flexible Burner for Process Plants. 2012 Jamal Jamaluddin Charles Benson, Roberto Pellizzari Seth Marty, Thomas Young, Rex Isaacs Joseph Renk. Shell Global Solutions (US), Inc. etaPartners Zeeco US Department of Energy
- SOL11 Solutions related to reducing impact of gas quality variations on gas utilisations: WOBBELIS® or POCCILIS® 2016. ENGIE. Alice Vatin
- SOL12 Solutions related to reducing impact of gas quality variations on gas utilisations: indelis® 2016. ENGIE. Alice Vatin
- SOL13 Optimization of fired heater control utilizing the residual oxygen measurement principle. nov-09 A.J. Mouris Hobre Instruments BV
- SOS05 Capabilities and challenges of optical measurement of natural gas quality. 2014 Dr Jane Hodgkinson / Centre for Engineering Photonics. School of Engineering, Cranfield University (Marcogaz workshop 2014)
- SOS06 New technologies for extended gas analysis. 2014. Dr Joachim Kastner / Elster Gmbh (Marcogaz workshop 2014)

- SOS07 Project “Qualigas” funded by FOGA (Swiss gas industry Fund) and Wika related to the determination of Wobbe Index and gas quality by means of a cheap gas sensor based on correlative techniques. 2014 Pascal Favre / COSVEGAZ SA, Martin Seiffert / SVGW (Marcogaz workshop 2014)
- SOS08 Controls for Combustion Optimization. 2014 Dr.Bergemann- H.Petermann /AFECOR (Marcogaz workshop 2014)
- SOS09 GERG Project. The potential of MEMS for gas distribution systems. 27.02.2014. Erik Polman/Kiwa Technology (Marcogaz workshop 2014)
- SOS10 Integrated Micro Wobbe Index meter. 2014. Joost Lötters / Bronkhorst High-Tech (Marcogaz workshop 2014)
- SOS11 Managing alternating gas qualities with a self-calibrating multi gas control system. 27.02.2014. Gas- und Wärme- Institute Essen e.V. – Jörn Benthin (Marcogaz workshop 2014)
- SOS12 Ionization current sensing 2014 Mattias Svensson on behalf of Jakob Ängeby / SEM (Marcogaz workshop 2014)
- SOS14 Gas Quality Sensing (gasQS™) at MEMS AG. 2014. PRETRE Philippe. /Mems AG. (Marcogaz workshop 2014)
- SOS15 Microsystems for selective gas sensing. 2014 Dr Ulrike Lehmann /MiCROSENS SA. (Marcogaz workshop 2014)
- SOS16 Wobbe Index Sensor. 2014 FARINE Gaël / QuantitativeEnergy LPM. (Marcogaz workshop 2014)
- SOS17 GasPT instrument.2014 Terry Williams / Orbital Global Solutions. (Marcogaz workshop 2014)
- SOS18 Possibilities using non dispersive IR-technology for in vehicle meas-urement of methane gas quality. 2014. Henrik Rödjgård/Senseair. (Marcogaz workshop 2014)
- SOS20 Gaskvalitetssensorer. Screening af tilgængelige gaskvali-tetssensorer på markedet. 2013
- SOS22 A real-time method for determining the composition and heating value of opportunity fuel blends 2011
- SOS23 Gas Quality Sensor for Real Time Monitoring of Composition and Heating Value of Natural gas 2012
- SOS24 Gas Quality Sensor for Real Time Monitoring of Composition and Heating Value of Natural gas 2014
- SOS29 Combustion Control based on Ionization Current Detection: Application in Condensing Heating Appliances. 2014 Martin Kiefer / Bosch
- SOS30 Gas Quality Sensor for Real Time Monitoring of Composition and Heating Value of Natural and Renewable Gas. GTI 2014. IGRC paper.
- SOS31 A real-time method for determining the composition and heating value of opportunity fuel blends 2012
- SOS32 Gas quality sensor to improve biogas-fueled, GTI, 2010
- SOS33 Heating value sensor
- SOS34 Gaskvalitetssensorer Screening af tilgængelige gaskvalitetssensorer på markedet

- SOS35. Ionization current sensing. Jakob Ängeby, Anders Göras, Jan Nytomt Hoerbiger Control Systems AB Maj 2012 Rapport SGC 258
- SOS36 Wobbe test burner Niels Bjarne K. Rasmussen, Bjarne Spiegelhauer. DGC
- SOS37 New Gas Sensors. 2014. W.G. Haije (ECN) F.P. Bakker (ECN) S. Gersen (DNV GL) R. Wolffenbuttel (TU Delft) G. de Graaf (TU Delft) B. Dam (TU Delft) R. Westerwaal (TU Delft) EDGAR Project. ECN, DNV GL, TU Delft
- SOS38 Measurements of the flue gases oxygen concentration by Lambda sensor. 2010. Antonio Serafim de Souza Sobrinho, Rigo-berto Soares do Nascimento, Re-nato Silva Pinheiro, Lutero Carmo de Lima
- SOS39 The Effect of Blast Furnace Gas Quality·and Combustion Controls on Hot Blast Stove Performance 2003. lan J. Cox