Danish Gas Technology Centre

Adjustment of large burners – natural gas and hydrogen

June 2024

07-06-2024, T00020207, Niels Bjarne Rasmussen, DGC

Table of Contents

Table of Contents 2
Introduction 3
Adjustment of natural gas burners 3
Adjustment of hydrogen burners 6
Hydrogen quality 7
Digital tool for adjusting hydrogen burners 9
Conclusion 10

Introduction

This memorandum is derived from the desire to clarify the necessary precautions that must be taken when adjusting future burners on hydrogen-fired industrial boilers, so that the burner/boiler system is safe and (secondarily) performs with the highest possible efficiency. In addition, knowledge is wanted on what consequences even small amounts of "impurities" in hydrogen will have for the Wobbe index and other important factors for the gas.

When natural gas-based forced draft burners, which are often installed in larger boiler systems, are put into operation or serviced, the burners are set to a certain percentage of oxygen in the flue gas from the combustion. When the burner is in operation, the oxygen percentage is not constant, as it will vary depending on a number of factors, which are partly dependent on the weather and partly dependent on other conditions such as gas quality, gas pressure, etc.

In certain unfortunate coincidences of these factors, the oxygen percentage can drop so far that there is a danger of CO formation during combustion. CO is toxic and can in worst case result in death. Conversely, in other cases, high oxygen percentages may occur, which result in a lower efficiency for the burner/boiler system.

Therefore, the burners must be adjusted accurately and as far as possible in relation to the current circumstances in order to ensure high safety and aim for high efficiency. This also applies to hydrogen burners.

This memo describes the significant consequences of even small amounts of "impurities" and variations in the quality of supplied hydrogen for future industrial hydrogen burners. In addition, details are given of tools developed to adjust forced draft burners for industrial boilers to account for variations in gas quality and other factors.

Adjustment of natural gas burners

For many years, Denmark was supplied with natural gas from the Danish part of the North Sea. This gas has a very stable quality and a relatively high Wobbe index. Many appliances, including industrial burners with forced draft burners, were optimised for this gas quality. However, this caused problems when the gas quality changed in 2010. Since October 2010, part of the natural gas supply has been imported, and since 2012, biomethane from upgraded biogas has been introduced to the gas network. As a result, customers experience fluctuating gas qualities and Wobbe index variations of up to 10% are commonly observed. The transition to a more flexible gas supply was carefully prepared, and because of this work, the transition did not cause major problems for customers with forced draft burners.

In the previous set of regulations for adjusting forced draft burners on natural gas and methane, it was taken into account the variation of a number of factors that influence the air excess ratio. This applies, for example, to air temperature, barometric pressure, Wobbe index etc. Based on these factors, the oxygen percentage to which the given system must be adjusted on the given day can be calculated. An Excel spreadsheet and an app are available for these calculations. The calculation procedures were developed and corrected over a number of years, also depending on changes in the quality requirements for the natural gas.

A total of eight different factors with an influence on the air excess ratio are included in the calculations. In the table below, the assumed variations for these factors are shown. For the plant in question, it is assumed that the various factors do not deviate significantly from these variations. Over a full year, it is assumed that there is a 99% probability that the values are within the specified limits. To the right of the table is the air excess ratio variation that the individual factor would give independently of other factors.

Table 1 The 8 factors included

		Air excess ratio variation
Chimney draft	Δp_{tr} = ±0,25 mbar from mean	±1%
Barometer level	p_{air} = 1013 ± 27 mbar	±1.5%
Air temperature	Δt_{air} = ± 15°C from mean	±5%
Air humidity	x = 0 – 13 g H_2O/kg dry air	±0.5%
Gas temperature	Δt_{gas} = ± 5°C from mean	
Wobbe index number	W = ± 6% from mean	±6%
Pressure difference for gas	p_{diff} = ± 2% from mean	±1%
Mains voltage	ΔU = ± 15 V from mean	±1%

By measuring two of the factors during adjustment (air temperature and air pressure), the safety margin can be reduced for the influence of these two factors. The rest of the factors are combined for a statistical risk of CO formation of less than 9 hours per year on average for the individual plant (1 per mille risk). The air temperature and air pressure are chosen because these factors are easy to measure and they have a large influence on the air excess ratio.

The location of the "tipping point" must also be measured, i.e. the percentage of oxygen which, with a downward regulation, causes a sudden increase in CO formation for the current boiler/burner system. Here, the point is used where the measurement shows 500 ppm CO at low excess air. CO formation is the greatest risk in combustion systems, as CO is toxic and in the worst case can cause death.

Figure 1 schematically shows how the tipping point is found for the individual boiler/burner system.

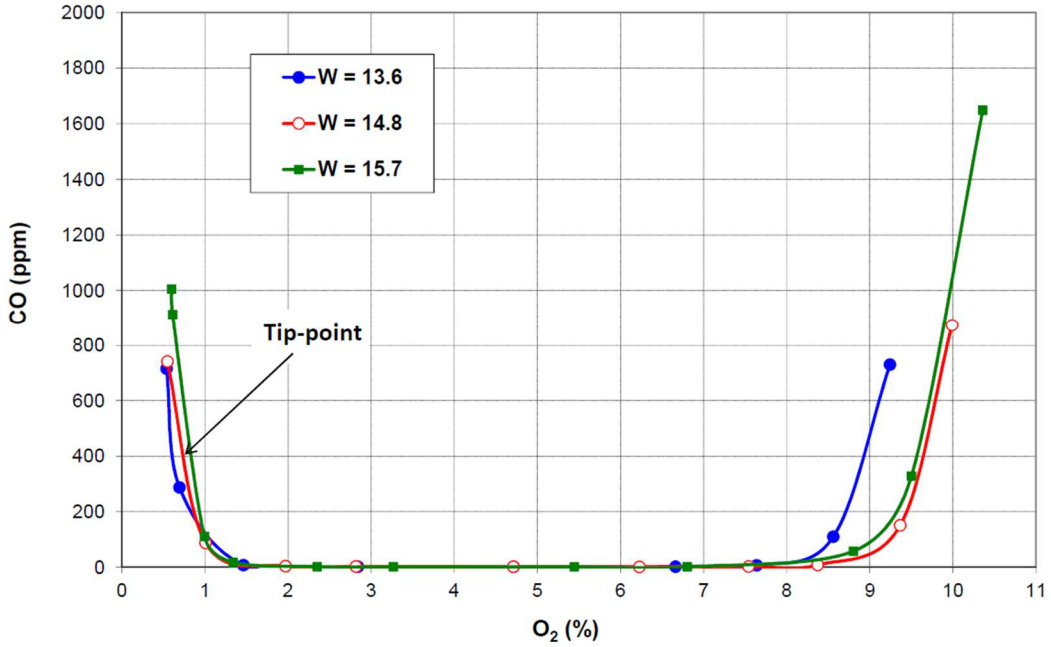


Figure 1 *Schematic view of the location of the tipping point.*

Figure 2 shows a copy of the spreadsheet for calculating the oxygen percentage to which the burner must be set.

Set-point for oxygen percent in adjustment of large forced draft burners for natural gas	**Unkown Wobbe index 13,9 - 15,5 kWh/m^3_n**	**Date** 18-07-2014

Middel forbrændingslufttemperatur i løbet af et år forudsættes at være ca. **15°C**
Variationen af forbrændingslufttemperatur i løbet af et år forudsættes at være 0°C til 30°C i 99% af tiden

Gule felter: indtast værdier

20	°C = den aktuelle forbrændingslufttemperatur før blæser (Ved forvarmet forbrændingsluft anvendes rumlufttemperaturen)	Kundeoplysninger mm.: <-- Combustion air temperature
1020	mbar = den aktuelle barometerstand på stedet	<-- Barometer reading

Lastpunkt min			CO	NOx	**Lastpunkt max**			CO	NOx
O_2 (%)	CO (ppm)	NOx (ppm)	(0%O_2) (ppm)	(0%O_2) (ppm)	O_2 (%)	CO (ppm)	NOx (ppm)	(0%O_2) (ppm)	(0%O_2) (ppm)
Kippunkt:									
1	500				0.9	400			
Der indstilles til følgende iltprocent:									
4.11					4.02				
Måling af CO og NOx i lastpunkter ved indstilling (målte værdier):									
4.1	59	61	73	76	4	90	100	111	124

<-- Tip-point giving high CO (measured)
<-- Set-point for adjustment of oxygen in exhaus
<-- Emissions at set-pionts

Luftvejledningens grænseværdier:

CO: max 75 mg/m^3_n	**NOx:** **Anlæg før 2001:** max 125 mg/m^3_n	**Anlæg efter 2001:** max 65 mg/m^3_n	**(alt ved 10% O_2)**
CO: max 115 ppm	**NOx:** **Anlæg før 2001:** max 115 ppm	**Anlæg efter 2001:** max 60 ppm	**(alt ved 0% O_2)**

Figure 2 *Copy of spreadsheet for calculating the set point for oxygen in a burner/boiler system for natural gas.*

Adjustment of hydrogen burners

Recently, hydrogen burners for industrial purposes are expected to be introduced. It is crucial for the safety and efficiency of the burner systems that the adjustment of the burners is prepared for possible variations in quality, which will depend on the quality specifications for the supplied hydrogen.

When burning hydrogen, large amounts of CO of course cannot be formed, as the only amount of carbon (C) present in the combustion system is what enters via CO_2 in either the gas or the air for combustion. However, when hydrogen is supplied, which is contaminated with CO_2, some CO can be formed at a low air excess ratio via a reverse water gas shift reaction. The order of magnitude of this risk is not currently known, but will depend on the permitted amount of CO_2 in the hydrogen.

The risk in hydrogen combustion is presumably primarily linked to any unburned hydrogen that escapes with the flue gas. Hydrogen is significantly more explosive than CO and methane, and in contact with air, any excess hydrogen in the flue gas can pose an explosion hazard. The level of this explosion hazard is not known, but the presence of hydrogen in significant quantities in the flue gas must be avoided.

In principle, the same calculation procedure can be used for adjusting hydrogen burners as for natural gas burners. Determining the tipping point for a boiler/burner system for hydrogen is supposed to be possible in the same way as for a natural gas system, namely by determining the point (the O_2 concentration) where a significant increase of measured hydrogen in the flue gas system starts at low oxygen concentrations.

It has been suggested that the same measuring instruments could be used for adjusting hydrogen burners as when adjusting natural gas burners. There may be cross-sensitivity between hydrogen and CO measurements. This could give an indication of too low an oxygen percentage when small amounts of CO are displayed on the CO meter when burning hydrogen, where unburnt hydrogen would "show up" as CO. However, this method has not yet been verified.

Hydrogen quality

There is so far no statistical material showing the variation of the hydrogen quality in a future hydrogen system with the supply of hydrogen to customers with forced draft burners. Therefore, one must initially assume a probable variation based on possible future standards for hydrogen in hydrogen supply systems.

When statistical material on hydrogen qualities in hydrogen systems becomes available at a later date, the calculation procedures can be corrected accordingly.

When adjusting a *natural gas* boiler/burner system, it is assumed that the various factors that influence the air excess ratio are normally distributed around a mean value. This has been verified by statistical data. However, we cannot know if this is the case with the hydrogen quality in a hydrogen supply system. Some existing or proposed hydrogen purity standards for various applications allow up to 2% CO_2 or other gases ("impurities") in the hydrogen.

A possible variation of 0-2% CO_2 in hydrogen may seem small, but it would give a density variation of 42% and a Wobbe index variation of 22%. Therefore, it has a major impact on the safety and efficiency of hydrogen burner/boiler systems. It is approx. twice the corresponding permitted variation for natural gas. Such a variation will require great accuracy on the adjustment procedure, as it will presumably be necessary to know the exact hydrogen quality during the adjustment. Alternatively, the burner has to be set to very high air excess ratio to avoid sub-stoichiometric combustion under all conditions. This would then lead to reduced efficiency for the boiler and a possible risk of poor combustion.

When adjusting *without* knowledge of the Wobbe index for hydrogen, in the worst case scenario, during the year you could end up hitting

$$\lambda = 1.75 \text{ corresponding to } O_2\% = 11\%,$$

if you have to adjust safely without the risk of hitting unburned hydrogen to the other side at low oxygen percentages.

Figure 3 shows the variation in Wobbe index for hydrogen mixtures with up to 2% "contamination" with other gases. It can be seen that the addition of CO_2 gives a large variation of the Wobbe index, while the addition of other flammable gases such as ethane, propane and butane has far less significance.

Figure 4 shows the possible loss of efficiency when adjusting safely a hydrogen burner/boiler system based on contamination of up to 2% CO_2 in the hydrogen [*Consequence of the choice of H_2 quality specification on gas consumption based on burner adjustment requirements*, Bela Sebok, DGC 2024]. This may cause an extra loss of efficiency up 2-4% in the range of 50-67°C flue gas temperature.

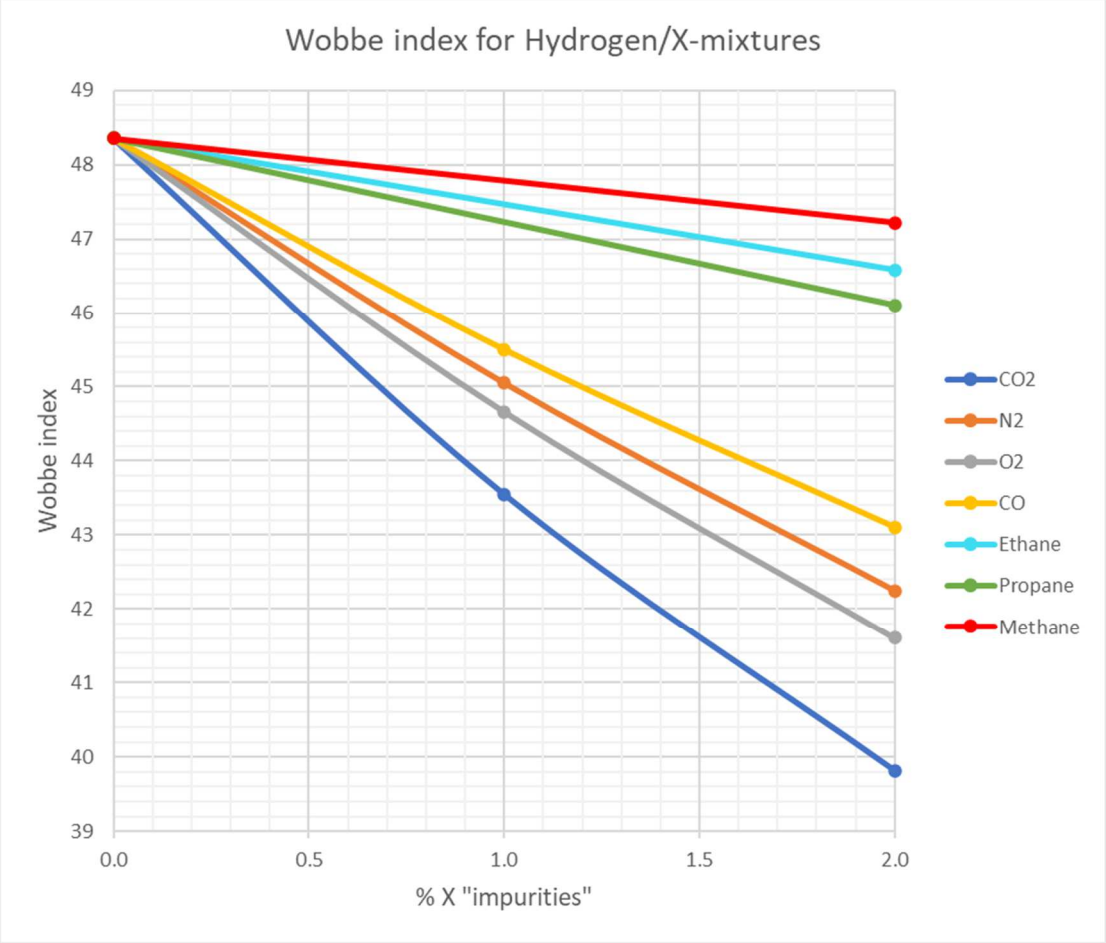


Figure 3 *Wobbe index for hydrogen mixtures with up to 2% "contamination" with other gases.*

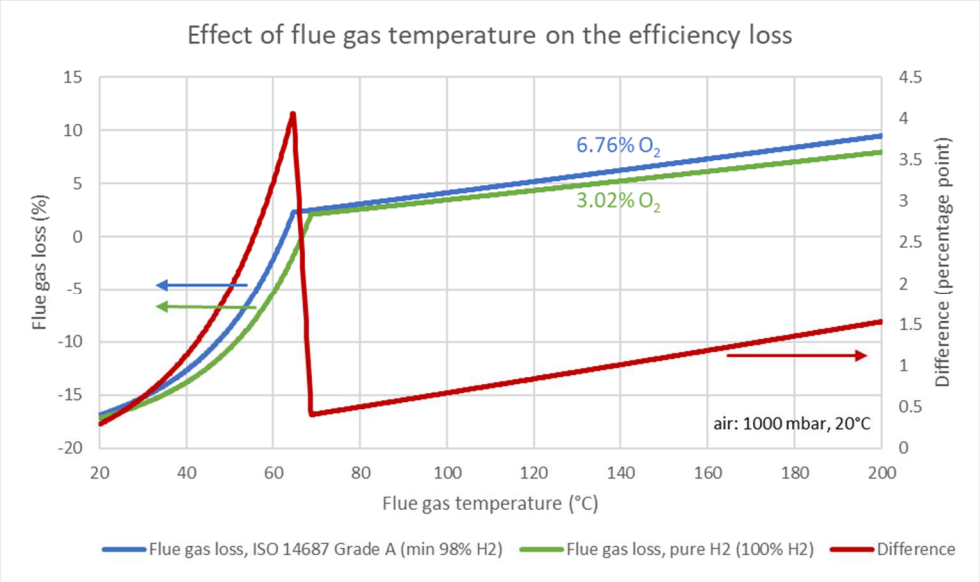


Figure 4 *Loss of efficiency based on safe adjustment of hydrogen burners under different standards.*

Digital tool for adjusting hydrogen burners

The spreadsheet for calculating the setting point for oxygen for natural gas combustion has been modified to a corresponding spreadsheet for adjusting hydrogen burners. In figure 5 below, a known Wobbe index for the hydrogen is included. Figure 6 shows a similar diagram for when the Wobbe index is not known. It can be seen that the set point for oxygen is higher if the Wobbe index is *not* known.

Set-point for oxygen percent in adjustment of large forced draft burners for hydrogen	**Wobbe index is known** **Max Wobbe index at pure H_2**	**Date** **14-03-2024**

Middel forbrændingslufttemperatur i løbet af et år forudsættes at være ca. **15°C**
Variationen af forbrændingslufttemperatur i løbet af et år forudsættes at være 0°C til 30°C i 99% af tiden

Gule felter: indtast værdier

0 °C = den aktuelle forbrændingslufttemperatur før blæser (Ved forvarmet forbrændingsluft anvendes rumlufttemperaturen)	Kundeoplysninger mm.: **<-- Combustion air temperature**
1030 mbar = den aktuelle barometerstand på stedet	**<-- Barometer reading**
44.00 MJ/m^3_n = Wobbe, T-ref-brændv = **25°C,** T-ref-vol = **0°C**	**<-- Wobbe index**

Lastpunkt min			CO	NO_x	**Lastpunkt max**			CO	NO_x
O_2 (%)	CO (ppm)	NO_x (ppm)	(0%O_2) (ppm)	(0%O_2) (ppm)	O_2 (%)	CO (ppm)	NO_x (ppm)	(0%O_2) (ppm)	(0%O_2) (ppm)
Kippunkt:									
1	5				0.9	5			
Der indstilles til følgende iltprocent:									
6.51					6.44				
Måling af CO og NO_x i lastpunkter ved indstilling (målte værdier):									
6.5	5	52	7	75	6.4	5	80	7	115

<-- Tip-point giving high CO (measured)
<-- Set-points for adjustment of oxygen in exhaust
<-- Emissions at set-points

Luftvejledningens grænseværdier:

CO: max 75 mg/m^3_n	**NO_x:** **Anlæg før 2001:** max 125 mg/m^3_n	**Anlæg efter 2001:** max 65 mg/m^3_n	**(alt ved 10% O_2)**
CO: max 115 ppm	**NO_x:** **Anlæg før 2001:** max 115 ppm	**Anlæg efter 2001:** max 60 ppm	**(alt ved 0% O_2)**

Figure 5 *Copy of spreadsheet for calculating the setting value for oxygen in a burner/boiler system for hydrogen where the Wobbe index is known.*

Set-point for oxygen percent in adjustment of large forced draft burners for hydrogen	Wobbe index is unknown CO_2 up to 2% in H_2	Date 13-03-2024

Middel forbrændingslufttemperatur i løbet af et år forudsættes at være ca. **15°C**
Variationen af forbrændingslufttemperatur i løbet af et år forudsættes at være 0°C til 30°C i 99% af tiden

Gule felter: indtast værdier

0	°C = den aktuelle forbrændingslufttemperatur før blæser (Ved forvarmet forbrændingsluft anvendes rumlufttemperaturen)									Kundeoplysninger mm.: <-- Combustion air temperature
1030	mbar = den aktuelle barometerstand på stedet									<-- Barometer reading
Lastpunkt min			CO	NO_x	**Lastpunkt max**			CO	NO_x	
O_2 (%)	CO (ppm)	NO_x (ppm)	($0\%O_2$) (ppm)	($0\%O_2$) (ppm)	O_2 (%)	CO (ppm)	NO_x (ppm)	($0\%O_2$) (ppm)	($0\%O_2$) (ppm)	
Kippunkt:										
1	500				1	400				<-- Tip-point giving high CO (measured)
Der indstilles til følgende iltprocent:										
8.11					8.11					<-- Set-points for adjustment of oxygen in exhaust
Måling af CO og NO_x i lastpunkter ved indstilling (målte værdier):										
8.2	3	61	5	100	8.1	2	100	3	163	<-- Emissions at set-points

Luftvejledningens grænseværdier:

CO: max 75 mg/m^3_n	**NO_x:** **Anlæg før 2001:** max 125 mg/m^3_n	**Anlæg efter 2001:** max 65 mg/m^3_n	**(alt ved 10% O_2)**
CO: max 115 ppm	**NO_x:** **Anlæg før 2001:** max 115 ppm	**Anlæg efter 2001:** max 60 ppm	**(alt ved 0% O_2)**

Figure 6 *Copy of spreadsheet for calculating the setting value for oxygen in a burner/boiler system for hydrogen, where the Wobbe index is unknown.*

Conclusion

Even small amounts of "contamination" with other gases can have a major influence on the characteristic properties of hydrogen as a fuel. Up to 2% CO_2 in hydrogen will give up to 42% change in density and up to 22% change in Wobbe index.

Calculation programs have been developed to find the optimal setting for forced draft burners on natural gas or hydrogen, so that the burner/boiler system operates safely with minimal risk of unburned fuel and CO emission and, secondarily, with the greatest possible efficiency.