MAIN EFFECTS OF GAS QUALITY VARIATIONS ON APPLICATIONS

1 INTRODUCTION

To improve the fluidity of the European gas market CEN has been mandated by the EU Commission to draw up standards for gas quality parameters for H-gas that are the broadest possible within reasonable costs. In the first phase of this mandate an analysis concerning the combustion parameters is elaborated. Its goal is to create an overview of:

1. The existing population of gas appliances falling under Directive 90/396/EECthat are certified for H-gas;
2. The current certification practices;
3. The installation and inspection rules and practice;
4. The behaviour of domestic appliances (falling under Directive 90/396/EEC) in terms of safety, efficiency and environmental performance, handling different gas qualities.

This analysis excludes applications that are outside the scope of GAD and it excludes from the testing programme non-domestic appliances. The main reason is that for practical reasons it is not feasible to test all non-domestic appliances. Non-domestic appliances falling under Directive 90/396/EEC are therefore taken into account in the part 1 to 3 of phase 1. Other non-GAD compliant appliances will be subject of study in the framework of the Cost-Benefit Analysis of the Interoperability project.

This latter project is conducted under direct supervision by the EU commission and aims at identifying the interoperability issues throughout the whole of the European Union and afterwards producing a cost/benefit analysis of potential solutions as proposed by stakeholders. It covers many topics but one important issue is gas quality. This analysis should identified cost and benefits associated with changing gas quality which then will be an input to the standardisation process.

Marcogaz WG "Gas Quality" would like to contribute to this analysis by giving a few guidelines about the effect of changing gas quality to applications in general. This study will target the combustion applications and will focus on Wobbe variations, as it is the main parameter impacting the combustion process. It excludes all applications where natural gas is considered as feedstock for these applications are generally concerned with the composition of the gas (and mainly its methane content) and consider all components that are not used in the processes as impurities that have to be removed prior to transforming the gas.

It will also give some idea on the effect of changing gas quality on turbine and compression engines, even if Wobbe changes do not account for defining the impact of gas quality changes on these applications entirely correctly. However it does not consider the effect of gas quality on vehicles.

2 EFFECT OF WOBBE VARIATIONS

2.1 Direct effects of Wobbe variations

The Wobbe index defined and used here is the ratio of the Gross Calorific Value to the square root of the gas relative density. For an appliance, domestic or industrial, with a constant input pressure where the gas flow is controlled by a pressure drop (see Figure 1), whether an injector or a regulation valve, it can be demonstrated that:

- The thermal input is directly proportional to the Wobbe index.
- The air gas ratio[1] is inversely proportional to the Wobbe index.

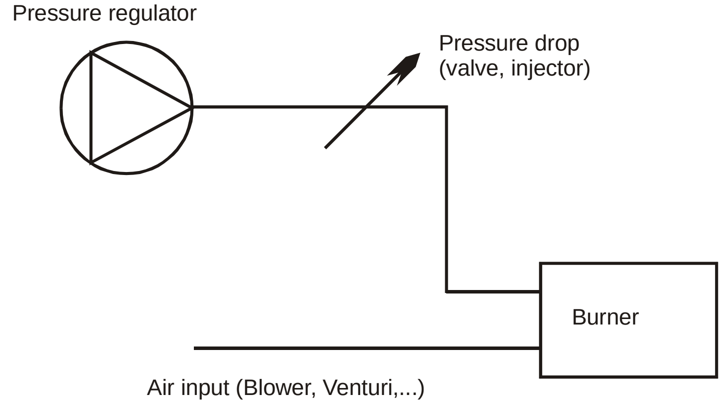

Figure 1: Schematic of the appliance design.

An increase in Wobbe index will lead to an increase of power input and a decrease of the air gas ratio. Main defects that can be observed are understoichiometric firing, CO production, soot, knocking, premature ignition in premix turbines, change in NO_x emissions. A decrease of Wobbe may lead to flame lift if the burner technology is sensitive to that. It may also lead to increased CO emissions.

Assuming that reference gas is pure methane (G 20), with a Wobbe number of 50.72 MJ/m^3, variations of the Wobbe number within the full range as presented by EASEE-gas[2] (46.45 – 54 MJ/m^3) will lead to:

- A decrease of the thermal input of 9 % at W = 46.45 MJ/m^3 when compared to pure methane,
- An increase of the thermal input of 6 % at W = 54 MJ/m^3 when compared to pure methane,

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[1] *The air gas ratio (or air factor) is defined as the ratio of the volume of air available for combustion by the volume of air necessary for a stoichiometric combustion. Equivalence ratio is 1/air factor*

[2] *Defined in EASEE-gas CBP "gas quality" between, 13.6 and 15.81 kWh/m^3 (25°C, 0°C, 1013.25 hPa)*

These variations are generally smaller than the load variations of any applications. However it means that the maximal power output of a given application can be ≈ 10% below the one given for reference conditions. This should be taken into account when designing a process or an installation.

As for the effect of Wobbe variations on air gas ratio, assuming that the amount of air available to the burner is constant and adjusted for an air gas ration of 1.2 for reference gas G20, then variations of Wobbe number within the range proposed by EASEE-gas (from 46.45 to 54 MJ/m^3) will change the air gas ratio from 1.31 to 1.13. Thus the maximum efficiency of the applications is expected to vary between the green and pink curves (square and triangle) in Figure 2. However, Wobbe variations are not the sole origin of air-gas ratio changes (see paragraph 2.2).

2.2 Influence of ambient conditions on the air-gas ratio

The effect of ambient conditions variations on air gas ratio is related to the variation of air density due to temperature, pressure and humidity variations. Without airflow control, the volume of air brought to the burner is related to the square root of its density. Theses variations of density means also that, the amount of oxygen per volume of air brought to the burner changes thus the air gas ratio. To assess and compare these effects to those of Wobbe variations conditions representative of typical summer, winter and average days have been considered (see Table 1). Considering that the oxygen content of dry air is 20.95%, the oxygen content of a cubic meter of dry air at normal condition is 299 g/m^3, the oxygen content of air at different pressure and temperature is obtained assuming that PV/T is a constant. Water vapour influence is only a second order effect.

Table 1: Oxygen content of a volume of air.

Conditions	Pressure (hPa)	Temperature (°C)	Humidity (%RH)	H2O Partial pressure (Pa)	Density (kg/m^3)	MO_2 g/m^3 humid air	O_2 relative flow rate
Average day (reference)	1013.25	15	50	7.6	1.225	280	100
Hot summer day (depression)	980	35	90	48	1.108	260	98
Cold winter day (anticyclonic)	1030	-10	20	0.5	1.364	320	108

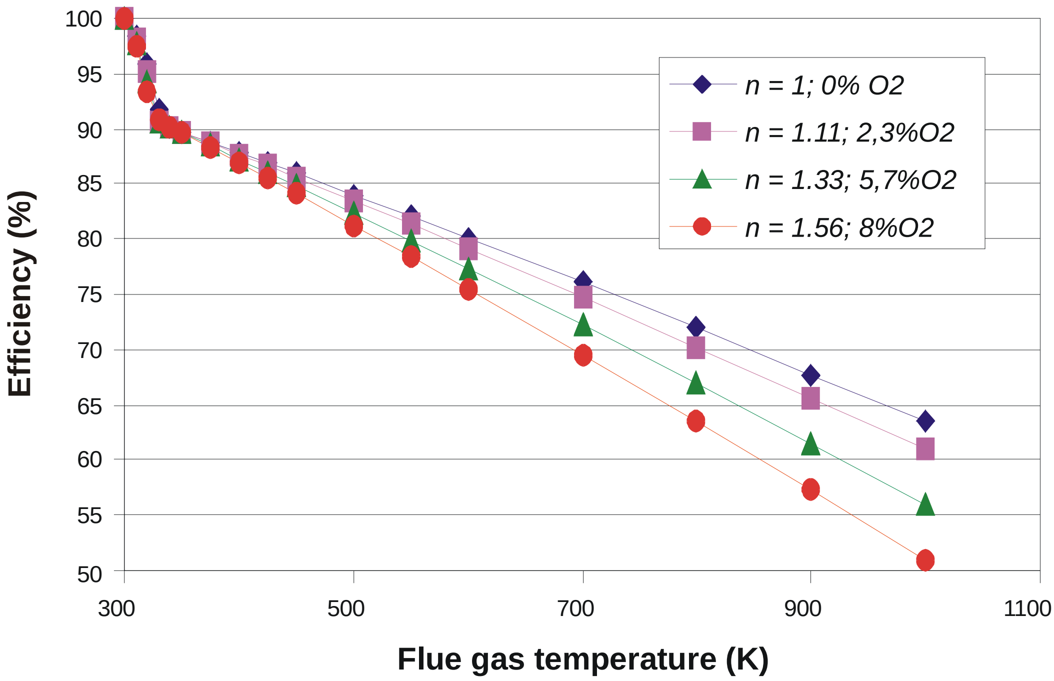
This means that a burner adjusted with ambient conditions of an average day will see a decrease of ≈ 2% on a hot summer day and an increase of ≈ 8% on a cold winter day of the real amount of air available for combustion. If the burner was set to an air-gas ratio of 1.2 then it can change from 1.18 to 1.30. These changes are slightly less than the ones observed for Wobbe variations within the EASEE-gas proposal. However, one must be aware that the effects of Wobbe and ambient conditions variations are additive.

3 EFFECT OF AIR GAS RATIO VARIATIONS

3.1 Effect of air gas ratio variations on efficiency

The efficiency of a gas-fired appliance depends on the energy lost in the combustion products. This is function of the temperature, mass and composition of the fumes, i.e. of the temperature and air gas ratio. Figure 2 presents the evolution of efficiency from 30 °C to 700°C for air gas ratio of 1 to 1.56. For low temperature applications, the difference is only about a few percent or lower while for high temperature applications it can reach 10 % in the range of air gas ratio considered.

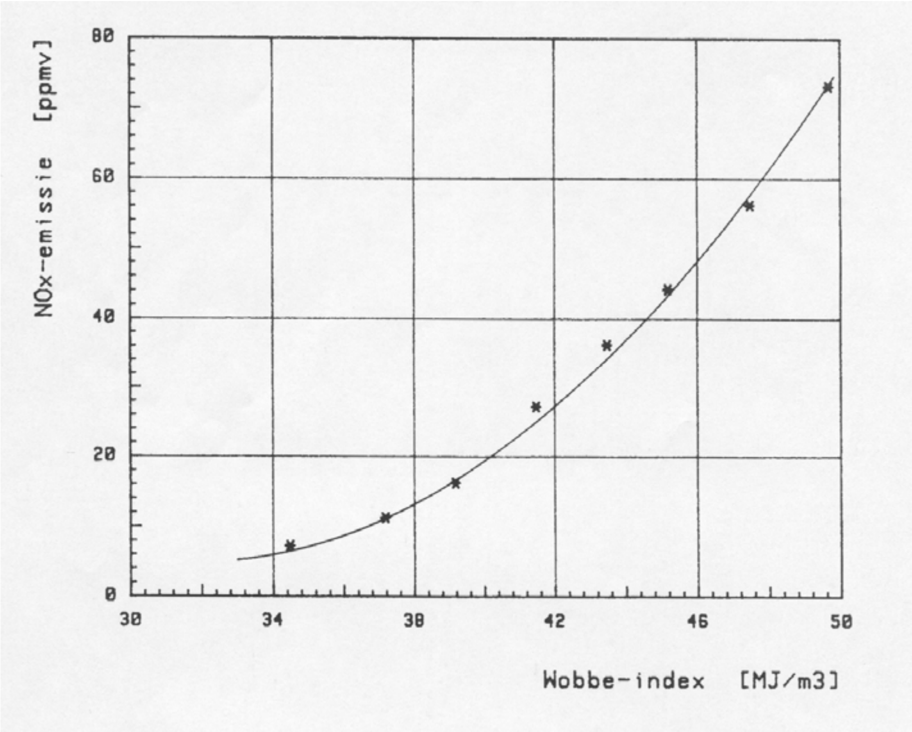
Figure 2: Efficiency as a function of exhaust temperature for different air gas ratio



3.2 Effect of air gas ratio on NO_x emissions

NO_x emissions are very much dependant on burner technology. In general for non-premixed burners, the NO_x emissions depend weakly upon the air gas ratio. However, there is data showing that some burners that are insensitive to air gas ratio are sensitive to the calorific value of the gas. The NO_x emissions from premixed burners, on the other hand, are as a rule strongly dependent on air gas ratio, and thus to Wobbe number. Figure 3 below shows typical data for a lean-premixed domestic central-heating boiler.

Figure 3: NOx emissions from lean-premixed domestic appliance as function of Wobbe number (data N.V. Nederlandse Gasunie).



Due to the near-exponential variation in NO_x emissions with air ratio (and thus with Wobbe number) that is seen in many burners, even the 8% decrease in air ratio caused by Wobbe variation alone can lead to an increase in NO_x emission of 60%; a decrease of 20% can nearly triple the emissions.

4 IDENTIFICATION OF THE SENSITIVITY OF APPLICATIONS

The sensitivity of an application to air gas ratio variations, and thus to Wobbe and ambient conditions variations, depends on the type of application and combustion process. In any case the first concern is that the appliance or process is adjusted in such a way that no understoichiometric combustion can occur. Such an adjustment can be done only if the gas and air characteristic at the time of adjustment are known. For instance, equipment set at an air factor of 1.05 under standard conditions will run understoichiometric by natural variation in ambient conditions alone.

Premixed burners are more sensitive than non-premixed burners. This is primarily because the actual burning velocity depends on the premixed air ratio. Thus as the air-gas ratio becomes leaner, due to a reduction in Wobbe number, the burning velocity will decrease, leading to instability, CO emissions and even blow-off. On the other hand, with increasing Wobbe number, the air-gas ratio moves closer to the stoichiometric value, and the burning velocity increases. This may lead to excessive heating of the burner and even to flashback.

As for the overall sensitivity of applications, the following classification can be proposed, based upon the temperature of the exhaust (see also Table 2).

- Low temperature applications (domestic appliances, hot water/steam preparation, etc.)
- High temperature applications (including steel, glass, ceramics)

In practice, for (large-scale) low temperature applications, the main effect of the variations will be on understoichiometric firing and NO_x emissions, as efficiency does not change much by air gas variation. Of course, the dependence of flame stability and incomplete combustion in domestic appliances on (primary) air ratio Wobbe number is well known and the basis for EN-437. For high temperature (non-premixed) applications, NO_x emissions and efficiency are affected by the variations of air gas ratio.

For all applications where the combustion products are not diluted (boiler, etc.) an oxygen sensor placed in the exhaust can be used to control the air gas ratio. However, the added price of the control systems can be a detriment for gas utilization.

For fully premixed burner if the combustion products may be diluted before sampling, or if the process may alter them, the air gas ratio can be obtained by using a "premix analyser". This will give a signal used to adjust the air gas ratio.

For all applications where no measurement representative of the air gas ratio can be made on the combustion products, the Wobbe number of the gas shall be determined, with a Wobbe meter along with air parameters (pressure, temperature, etc.) or a measurement of the mass air flow. This is used to adjust the air gas ratio.

If the adjustment of the air gas ratio is not possible for a sensitive application, then the Wobbe of the gas can be adjusted by injection of air or nitrogen in the gas line up stream of the burner.

5 OTHER GAS QUALITY VARIATIONS IMPACT

Whereas the emphasis thus far has been on the effects of varying Wobbe Index on combustion equipment, it is worthwhile to identify briefly effects that depend upon the actual composition of the gas that are not related to changes in thermal input or air gas ratio.

In addition to being sensitive to changes in Wobbe Index, sooting and CO-emissions in domestic appliances are also dependent upon the gas composition, in particular the fraction of higher hydrocarbons. The well-known UK specifications, the Gas Safety (Management) Regulations or “GS(M)R”, contain additional, composition-dependent, specifications to limit soot formation and CO-emissions. High heavy hydrocarbon content may also be a problem in large-scale combustion equipment.

Another well-known example is engine knock in gas engines, also a consequence of the identity and fraction of higher hydrocarbons. In this case, maintaining the air ratio or nitrogen dilution has little influence on the knock behavior, and readjustment of the engine, associated with significant loss of efficiency, is required to accommodate gases which are substantially different from those traditionally used in a given machine. Given the nature of the combustion process, it is anticipated that in non-premixed flames control of the air ratio will not substantially alleviate this problem. The dependence of

NO_x emissions on calorific value in many combustion systems is also not effectively controlled by maintaining the air-gas ratio.

Finally the CO_2 emission per unit of energy is also dependant on the gas composition. Gases with higher Wobbe index will emit more CO_2 for the same amount of energy because they have a higher content of C_2+ hydrocarbons. This difference may be of about 2 to 4 %.

Table 2 : Sensitivity of applications to Wobbe variations of industrial applications

Main category	Sub categories		Comment	Sensitivity	Possible solution
Low temperature (<200°C) industrial applications	Big boilers / large scale hot water & steam			Low for efficiency. May be high for NOx emissions	Air gas control via measurement of the oxygen in combustion products.
	Food industry	Green houses	NO_2 is a problem when combustion products are in contact with food. NO_2 is a plant hormone, and can damage crops. NO_2 emissions can also increase with gases having higher hydrocarbons (which facilitate the conversion of NO → NO_2).	High to NO_2 emissions	Adjustment of burners for reduced unburned fuel slippage (source of NO_2 production). New burners or air/gas ratio control
		Drying process		High to NO_2 emissions	
	Infra red	Drying	Low temp. combustion with potential presence of solvents. Radiant power/efficiency dependent on burning velocity.	High to burning velocity	In premixed radiant tiles, air/gas ratio and thermal input controls can minimize this effect.
		Heating			
High temperature (>200°C) industrial applications	Ceramic/Glass	Bulk (melting feeders)	Sensitive to flame temperature and radiative power. Finished product is also sensitive to flame geometry. Finished glass products sensitive to flame length (burning velocity). Soot formation (composition) and increased NO_x emissions (Wobbe/calorific value) possible. Control of under-/overstoichiometric firing essential in ceramics.	Soot formation often desired in bulk glass (heat transfer). Sensitivity to NO_x ? (temperature is already very high)	Gas quality (Wobbe Index) and air flow control. Air ratio and thermal input control should minimize effects. Air ratio control solves stoichiometry.
		Finished product (bulbs, etc.)		High sensitivity to burning velocity	
		Ceramic roofing tiles, bricks, etc.		High sensitivity to air ratio (over/under stoichiometry). High sensitivity to NO_x. High sensitivity to soot.	
	Metal oven		General for metal industry. Air factor, soot formation and NO_x important issues	High to soot and NO_x and oxygen in the oven atmosphere.	Solutions may be very specific according to the application

Engines	Fixed	Emissions and performances may vary. NO_x emissions and engine knock set boundary conditions for fuel sensitivity	High to NO_x High to knock	Air ratio control minimizes NO_x variations. Readjustment of engine necessary (with efficiency loss) for knock.
Turbines	Pre-mixed	Control system and machine design limit Wobbe variations, both stationary (power modulation) and dynamic (oscillations) ; NO_x emissions and combustion instability issues	High sensitivity to Wobbe variation (outside control range) Some machines have compositional limits (on higher hydrocarbons, e.g.) High to NO_x High to Wobbe/composition-induced oscillations	New control systems
	Non pre-mixed	NO_x (also at constant Wobbe) issue	High to NO_x. Thermal overload possible.	Readjust exhaust gas treatment ; retrofit combustion chamber.