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Impact of Gas Quality on Gas Engine Performance

By CIMAC WG17 'Gas Engines'

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Content

1 Introduction

This position paper describes how gas engines are influenced by the quality of the gaseous fuel provided. This topic is becoming increasingly important as highly fluctuating renewable energy resources call for quick reacting and reliable back-up power often provided by gas engines.

Important aspects of the quality of a gas, in addition to the heating value and the Wobbe Index, are: the composition of the combustibles which influences the combustion behaviour and knocking characteristics, the rate of change of the gas composition with time, and the concentration of impurities, for example sulphur. The knock characteristics of a gaseous fuel can be calculated for a given composition and the calculated Methane Number (MN) indicates the resistance of the given fuel to end gas knock. The Methane Number is comparable to the octane number for liquid fuels, which is typically used with gasoline fuels for passenger cars.

Information on the following topics can be found in other CIMAC Working Group 17 position papers:

- Information concerning the application of gas engines in the marine industry [PDF] (December 2013)
- Transient response behavior of gas engines. [PDF] (April 2011)
- The influence of ambient conditions on the performance of gas engines. [PDF] (March 2009)
- Information about the influence of ammonia in the fuel gas on NOx emissions. [PDF] (December 2008)
- Information about the use of liquefied natural gas as an engine fuel. [PDF] (December 2008)

The composition of pipeline quality gas is changing due to the increasing admixture of biogases, synthetic gases, hydrogen, new sources of natural gas and liquefied natural gas. It is therefore becoming ever more important to have a good understanding of the knock resistance of the gaseous fuel that is fed to a given engine. Special gases like biogases, synthetic gases, well head gases or associated petroleum gases have compositions that differ greatly from the composition of historic pipeline quality natural gas. The knock resistance of these special gases can only be determined correctly when the effect of each constituent of the gas is taken into account correctly.

Since gas engines are designed for an expected window of specific gas composition it is important that the actual gaseous fuel provided to a given engine lies within this window. Where the fuel composition falls outside of the design window, reduced power or shut down of the engine by the control system may result. In the worst case damage to the engine might occur. The presence of contaminants in a gaseous fuel affects engine wear, oil degradation and emissions while the composition of the combustibles affects the power, efficiency and emissions of the engine. Where fuel properties are not within the design specification, the engine operator will not be able to achieve the expected performance and revenue.

In Section 2 of this paper theoretical information about the effect of gas quality on engine performance is given. Section 3 provides information regarding engine knock and knocking characteristics of gaseous fuels. Section 4 gives an overview of existing MN calculation methods and their limitations. Section 5 provides information regarding current and historic pipeline gas composition, as well as some discussion of future Wobbe Index and knocking characteristics based on proposed changes to gas pipeline supply sources. Section 6 concludes with the CIMAC position on gas composition, Methane Number calculation programs, and required gas standards as regards the use of natural gas in reciprocating engines.

Variations in gaseous fuel composition present a number of challenges for engine operation. The change of the composition of hydrocarbons and inert gases like carbon dioxide and nitrogen from biogas admixture influences the ignitability and the combustion behaviour of the gas mixture. When variable quality fuels are provided, the engine controller must adapt operating parameters to prevent poor combustion, misfire or engine knocking. Changing combustion parameters influence the exhaust emissions, the cylinder peak pressure and the knock margin. High frequency fluctuations have an impact on the engine load controller and can result in unstable operation and varying emissions levels. Even low frequency variations in fuel quality have an impact on engine diagnostics and operation as regards the ability to achieve maximum efficiency, minimum emissions levels and optimum loading performance. The wider the variations are from the expected fuel quality, the more difficult it is for the engine controller to maintain acceptable engine operation.

The variation in the heating value impacts mainly the load controller of the engine. When the heating value increases the engine load control will be more aggressive than intended and this can lead to over fuelling during load increases and over-compensation when operating on variable load. At low engine loads the control of the gas quantity can be limited if the fuel heating value is greater than that for which the fuel system was designed. If the heating value decreases over time the engine load control can become slow and this may impact the capability of the system to take on load effectively. If the heating value is too low the capacity of the gas control system may restrict the available power output of the engine.

2 Impact of Gas Quality Variation

The Methane Number of the gas is of extreme importance for optimized engine operation. The knock resistance of the fuel must be known to set the operating space of the engine and the Methane Number available defines the engine calibration and component configuration to a high degree. When the Methane Number fluctuates the engine operating space changes and thus the engine performance deviates from the optimum design condition. Depending on how the Methane Number fluctuates, both the operating knock margin and ignition capability of the engine can be affected.

When sulphur appears in the gas supplied to the engine, the direct result is the emission of sulphur dioxide in the engine exhaust. Sulphur is present in some natural gas sources and biogas admixed to the natural gas, but is also added as an odorant for safety reasons. In addition to the emissions concerns surrounding sulphur containing fuels, the acids formed from sulphur have an impact on engine parts, lube oil lifetime and after-treatment components, such as exhaust oxygen sensors, catalytic converters and heat recovery systems. A higher content of sulphur results in rapid degradation of flue gas abatement systems with the consequences of higher emissions, reduced lifetime and higher operating costs.

3 Impact of Methane Number on Engine Performance

During normal spark ignited (or diesel pilot ignited) gas engine operation, a compressed mixture of fuel and air is ignited at a central point in the engine cylinder. Following this ignition event, a flame moves outwards through the cylinder, converting the chemical energy stored in the fuel into thermal energy. The release of thermal energy raises the pressure and temperature of the gases in the cylinder, which is used to drive the piston and produce work at the engine output shaft. Throughout the normal combustion process, the gas mixture in the cylinder which has not yet been consumed by the flame is driven to greater and greater pressures and temperatures by the advancing flame front. If the temperature and pressure of the unburned mixture reaches a critical level, the mixture will auto-ignite, causing a very rapid release of the chemical energy of the fuel. This auto-ignition process is known as engine knock. Engine knock causes a degradation of engine performance, increases emission levels and results in damage to engine hardware that cannot be tolerated.

Engine performance and emissions are generally optimum at the highest feasible temperatures and pressures; increasing the unburned gas temperature and pressure above their critical level will result in engine knock. The Methane Number and Octane Number are both measures of how resistant a given fuel is to auto-ignition, and thus how resistant an engine will be to engine knock when operated on the given fuel. Most people are well aware that high performance and high efficiency automotive engines require high Octane Number fuel, and the same is true of stationary natural gas engines. Natural gas generally has a very high resistance to engine knock (an Octane Number of ~130), and this resistance is key to the ability of modern gas engines to reach high performance with low emissions. If the knock resistance of available natural gas is reduced, existing engines will be forced to operate below their design capabilities in terms of efficiency, power density and emissions. In order to avoid engine failure, a given engine installation is typically designed and adjusted for the least knock resistant fuel on which it will be expected to operate. For this reason even the engine must be adjusted to accommodate the lowest expected Methane Number fuel being provided at a given site will cause a very predictable increase in fuel consumption by reciprocating natural gas engines and an associated rise in greenhouse gas emissions.

4 Methane Number calculation

Today there are many licensed MN calculation programs in use. The most widespread programs are based on the AVL method. Some gas suppliers and engine manufacturers use their own algorithm, mostly based on the data of the AVL work and the final report from 1971 [1]. The lack of information in the AVL work as regards the impact of higher hydrocarbons (hydrocarbon fuels with more than 4 carbon atoms per molecule) pressed some engine OEM’s to implement modifications to the basic calculations based on their own tests with higher hydrocarbons in order to cover a wider range of real world fuel compositions.

The Methane Number calculated with the different methods differs noticeably due to the different algorithms employed, as shown in Figure 1 [2]. For today's pipeline gas compositions the methods show minor differences in the calculated MN, but if higher hydrocarbons from other sources (for example LNG terminals) are added, differences of up to 14 MN are found. Issues also arise if hydrogen is added to the natural gas as the various available MN calculations are impacted differently by hydrogen. For the gas quality harmonization in Europe, EUROMOT recommended the MWM MN method, which will be offered as an open source calculation program, if accepted. As of today, this is the only freely available, proven method which considers the impact of higher hydrocarbons and also admixtures of hydrogen. The methodology of the program is described in Annex A of the CEN/TC234EN16726. New methodologies which are based on gas properties like reaction time for ignition are under investigation and could in the future perhaps reflect the gas properties in a better way than today's methodologies.

5 Gas Quality Today and in the Future

Natural gas will play a major role as a future energy source, due to the high available quantity for decades to come and the positive impact on emissions (CO_2- reduction by >20%, NOx and particulate reduction as well) compared to liquid fuels. LNG imports, bio-methane and hydrogen admixture from renewable energy will also change the future composition of pipeline natural gas. Gas quality is linked to the source of the gas supply. For this reason, the limits for gas properties in countries in the European Union differ substantially. Figure 2 shows the actual values and proposed rules for the Wobbe Index (W_s) in Europe [3]. This figure does not imply that a given customer will experience the actual range shown, as locally the gas composition can be relatively constant. The gas specification in most countries allows a higher variation for W_s. Figure 3 shows the actual Methane Number range for 5 countries in Europe, as well as typical ranges for Japan and the United States [4 and 6].

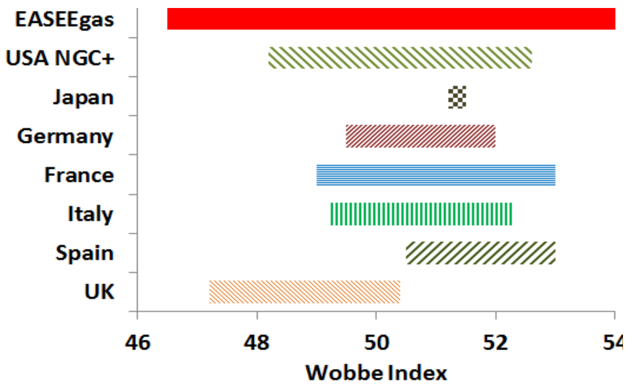

Fig. 2: Actual values for W_s and proposed rules Fig. 3: MN range for different countries

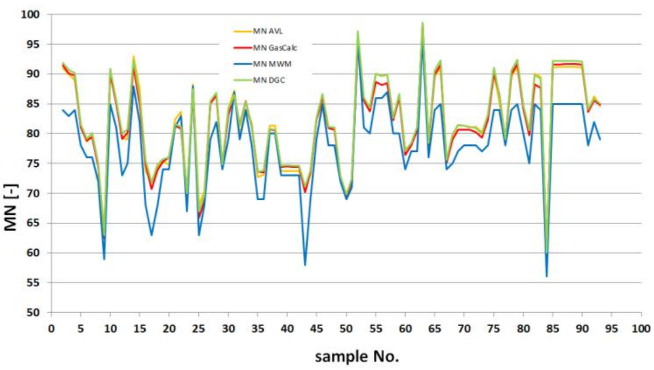

Fig.1: comparison of different MN calculation methods

Impurities in pipeline gas, mainly sulphur from the source but also from odorant, are today in most countries less than 5 mg/m³. In some exceptional gases, values as high as 20 mg/m³ are seen. The EASEEgas (European Association for the Streamlining of Energy Exchange) have proposed a limit of 30 mg/m³.

In today's gas specification there are no limits for the speed of variation of the parameters and Methane Number is not even covered by the specification. The given limit values for lower heating value (LHV) and Wobbe Index do not correlate to the MN with any given composition, as demonstrated in Figure 4 [5], but it can be seen that the proposed upper level of 54 for the Wobbe Index results in a Methane Number of less than 65, which is unacceptable for most high efficiency natural gas engines.

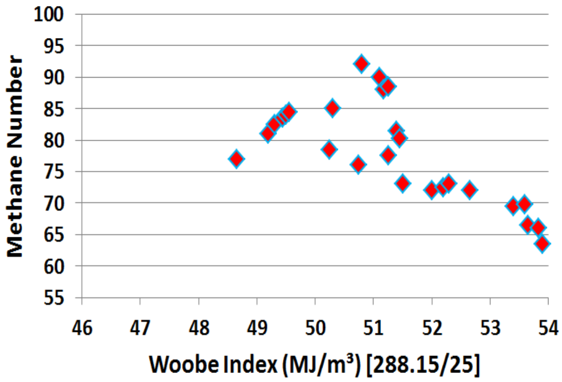

Fig. 4: Methane number vs. Wobbe Index

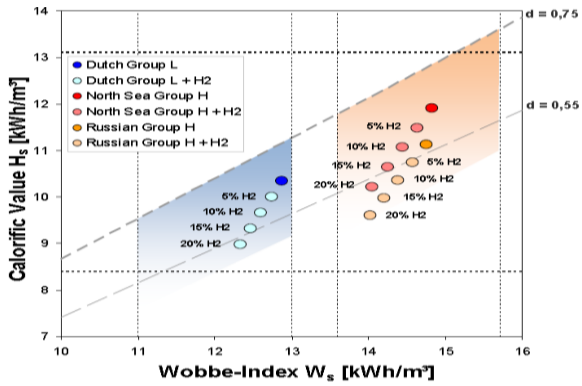

Fig. 5: impact of hydrogen on HV, W_s and density

The higher hydrocarbons (C4 and C4+) sometimes found in LNG fuel will lower the MN and the admixture of hydrogen has a comparable effect. A 10% limit for hydrogen is under discussion from the gas industry while manufacturers of gas turbines and engines have specified limits between 1% and 5%. Even with 10% admixture the resulting density of the mixed gas will be for some base gases out of the current specification for density ratio (0.55<d<0.75) as shown in Fig.5 [7]. The admixture of bio-methane can bring additional impurities such as siloxanes and sulphur to the gas network which would have a negative impact on all consumers, but would have especially profound effects for gas engines.

6 Conclusions

Gas engines are producing ecologically friendly and economically sound electrical energy and in CHP (**C**ombined **H**eat and **P**ower) and therefore their popularity increases world-wide. Also for the changing electricity market, with increasing energy from renewables, gas engines provide a growing portion of the required back-up infrastructure due to their operational flexibility.

Gas engines can accept, within their design limits, a wide range of gas quality, but fluctuation of the fuel quality harms their performance. Rapid changes present serious engine control challenges and can have a substantial impact on engine performance and emissions. The most important fuel property for gas engines is the knocking characteristic (Methane Number). Highly developed engines are designed for specific MN ranges like MN > 80 for Western Europe and MN around 65 for Japan, to achieve a high power density, low emission levels, and excellent fuel efficiency and economy for the expected engine conditions and fuel. To ensure reliable and economic operation of gas engines the knocking characteristic of natural gas has to be addressed in the natural gas specification. Impurities such as sulphur or siloxanes in natural gas from biogas admixture have a negative impact on the engine condition and the required maintenance.

To fulfil the expected requirements like:

- Safe and reliable operation
- Economic operation
- Ecologically friendly with low emissions
- Long maintenance intervals

well-defined fuel and specifications are mandatory:

- MN should be close to 80 or higher for highest efficiency, economy and lowest GHG emissions
- For the installed fleet, MN must be maintained near the historical value as this will in most cases be the design point of the engines
- a standard calculation method for MN needs to be defined
- Wobbe Index, Methane Number and flame speed at the operating site must be held within a narrow range for stable operation, low emissions and high economy
- Fluctuation of gas parameters only over long period of time (low frequency) is required for stable operation
- Impurities in the gas, especially sulphur should be as low as possible to reduce SO2-pollution to the environment and to reduce deterioration of abatement systems

With a well-defined high quality pipeline gas the gas engines will perform as expected by their users, safe and reliable, preserving the environment with economically and ecologically friendly operation.

7 Literature

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[2]: P. Zepf, K. Stellwagen, EUROMOT „ MWM MN Calculation Method", European Sustainable Shipping Forum 7/2014

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[7]: M. Specht, F. Baumgart, B. Feigl, V. Frick, B. Stürmer, U. Zuberbühler, M. Sterner, and G. Waldstein, "Speicherung von Bioenergie und erneuerbarem Strom im Erdgasnetz", Forschungsvereinigung Erneuerbare Energien, 2010.

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