Operational tests of an innovative fuel supply system for an industrial 4-stroke gas engines

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Abstract. The modern power generation solutions focus on several key factors: economy, efficiency, reliability as well as environmental impact. The natural way to protect environment and secure project feasibility is to move from more and more expensive conventional fuels like oil, coal and natural gas towards unconventional and more environment friendly fuels. That group includes many fuels that are currently mainly disposed without usage which means creating direct pollution without any direct value. The main problem is that there are many problems with such fuels and practical usage requires lot of investments and operational costs. The innovative fuel supply system HE-MUZG designed for 4-stroke gas engine developed together by Horus-Energia and Cracow University of Technology enables wide range of gas fuels to be used for power generation. This paper will present results from operational tests of the HE-MUZG system installed on gas genset. The test program covered many various fuels, which are problematic for typical modern gas engines, due to fuel low calorific value, low methane number or wide and rapid fluctuations of fuel properties. The presented results show main achievements obtained during HE-MUZG system development. Additionally the article describes some engine modifications implemented to optimise engine operation and to improve the efficiency.

1. Introduction
The HE-MUZG fuel supply and control system description and basic advantages of the system proven during industrial test were already presented [1, 2]. The innovative control system monitors continuously and with very short time step several engine operation parameters. These inputs are processed very fast and settings for fuel supply system, ignition system can be changed even from cycle to cycle to adjust mixture composition and engine operation for current properties of the fuel. The HE-MUZG system can be combined with gas-air mixer or multipoint gas injection solution. Even though the system development origins from gas injection fuel system, much more benefits can be achieved when gas-air mixer is used. However, important to remember, the HE-MUZG is successfully operating for more than 4 years on engines equipped with gas injection system for post-processing gas containing 85-95% hydrogen, nevertheless gas-air mixer solution, due to its simplicity, seems to have much bigger potential for significant improvements.

2. Test equipment
The operational tests were carried on in Horus-Energia test facility and the genset equipped with one of the most common modern 4-stroke gas engines were used. The main difference between original configuration and tested one was the replacement of the fuel supply and control systems with components of the HE-MUZG system. Additionally some components of the ignition system were
replaced, for example spark plugs for higher durability, but all other components of the genset were same as in original configuration. Basic data of the genset are presented in the Table 1.

Table 1. Basic data of the engine and the genset in original configuration [3].

| Engine type                  | 4-stroke, turbocharged, spark-ignition, 2-stage mixture cooler |
| Cylinder configuration       | 6 cylinders in-line                                         |
| Compression ratio            | 11:1                                                        |
| Mean effective pressure      | 13.1 bar                                                    |
| Nominal engine speed         | 1500 rpm                                                    |
| Nominal genset power         | 200 kW                                                      |
| Genset efficiency            | 37.1% (at 100% load)                                       |

3. Results from tests of fuels with significant methane content
The most common non-fossil fuels contain quite much methane. Many of these fuels come from natural biological processing of bio-waste, for example biogas, sewage gas, landfill gas. Also industry can create fuels where methane is one of main components. Into this group we can include coal mines, coke industry, wood gasification, pyrolysis etc. Altogether, most of unused waste gases contain methane, which has over 20 times stronger influence on greenhouse effect than carbon dioxide. There are two main reasons why these fuels are still used in very limited way: low calorific value due to low methane content plus high content of inert gas (biogas, syngas) and wide and fast composition fluctuations (coal mine gas).

The tests of the HE-MUZG system with methane based fuels were carried in a way that the genset was always at the beginning load to its nominal power on pure methane. Then the inert gas was added gradually until engine speed fluctuations were observed. Additionally for mixture of methane with air rapid change of gas composition was tested with similar procedure – the genset was operating at full load on pure methane and its content was changed between 100% and 43% up and down with more and more rapid change as long as stable engine speed was possible to maintain. The test results are shown in Figures 1 and 2.

![Figure 1. Methane content range required for stable genset operation at full load. Comparison of the HE-MUZG with the original setup [4].](image)

For the original fuel system the gas composition needs to be defined in advance and then the gas-air mixer will be specified accordingly. When fuel composition (mainly methane content or calorific value) will change too much, the fuel system will not cope and engine operation will be limited or even
impossible. This is the reason why there need to be installed different mixer for high calorific value gas (usually pure natural gas) and another one for low calorific value gas like bio-gas.

The HE-MUZG system has unique ability to adopt extremely fast to gas composition fluctuations and its wide operational window allows to use gases with low methane content and low calorific values, even as low as 9 MJ/m$^3$. The results show that the HE-MUZG system has very wide operational window and it doesn’t need to be modified when new kind of fuel is used. The same setup can be used for natural gas or biogas, which in typical fuel systems is impossible. Moreover, the minimum methane content required for engine stable operation is much lower than typical natural gas dedicated fuel system and lower even than limits for biogas fuel system.

![Graph showing rapid change of methane content in fuel allowed for stable genset operation at full load. Comparison of the HE-MUZG with the original setup [4].](image)

**Figure 2.** Rapid change of methane content in fuel allowed for stable genset operation at full load. Comparison of the HE-MUZG with the original setup [4].

A typical gas fuel system is very sensitive for gas composition fluctuations. Available methane content range is one of limitation but more important is how fast changes are acceptable for stable engine operation. Figures above show rapid change of methane content in the fuel compared to rate allowed for original fuel and control system. The line for original setup seems to be flat only because the rate allowed for original setup is very low – it is up to 0.3% per minute. The average methane content change rate for methane decrease is about 97% per minute and for methane increase is about 45% per minute. This is over 300 times faster change for methane decrease and over 150 times faster for methane increase than allowed for original fuel and control system.
4. Results from tests of other fuels and additional features

There is a huge stream of waste- or by- product gases which have quite low methane content. And these gases are produced by various industries, like oil fields, refineries, chemical industry etc. These gases contains either a lot of higher hydrocarbons or a lot of hydrogen. In general, these fuels have quite good combustion properties but very low knock resistance. Typical approach from OEMs is to investigate most challenging case and lock engine performance for that case. In this research the engine performed at its best possible conditions, which were monitored by the HE-MUZG system, and in case of improper combustion the HE-MUZG reacted to prevent engine from failure.

The tests with carbon monoxide were challenging also from personnel safety point of view. The gas is toxic and additional precautions had to be implemented. One of them was to never leave gas installation at the test facility filled with carbon monoxide. The simplest solution was to switch always flush gas installation with methane before engine was stopped – the methane was supplied to the gas installation at each start and stop of the genset but the loading and unloading was always done with pure carbon monoxide. The tests results are presented in the Figure 3.

![Figure 3. The genset efficiency for operation on pure methane and pure carbon monoxide.](image)

The same fuel and control system was used for operation on pure methane and then for operation on pure carbon monoxide. There were no modifications done in the engine controls or hardware. However, for the carbon monoxide operation maximum available power was only about 100kW, which is 50% of nominal load. It might seem that the limitation comes from low calorific value of carbon monoxide, which is about 12.6 MJ/m$^3$, but the genset in that configuration was operating in stable manner with fuel with much lower calorific value – 9 MJ/m$^3$ for mixture of 25% of methane and 75% of air. The real reason for this is much lower exhaust gas energy when methane is replaced by carbon monoxide and thus less energy is available for turbocharger. This is also the reason why efficiency is much lower for carbon monoxide operation in comparison with methane operation, which was not observed during operation with 25% of methane and 75% of air.

During tests of various fuel system configurations and settings several features were found that improve genset operation. The most important from universal application point of view are possibility to cope with gas pressure fluctuations and second gas line to support the main line when main fuel is too lean. The typical gas-air mixer requires 50 to 250 mbar gas overpressure otherwise mixing of air and gas won’t be possible. The HE-MUZG system was tested with gas pressure changing from 60 mbar overpressure to 10 mbar underpressure and gas mixing with air was still possible and engine operation was very stable. Results of these tests are shown in Figure 4.
As the last stage of tests second gas line was implemented. The working principle is such that when there is not enough energy in the main fuel (main gas line), the control system HE-MUZG will activate automatically second gas line to support stable engine operation. The secondary fuel is used only to compensate lack of energy in main fuel, which means that dosing of secondary fuel is continuously monitored and adjusted to minimize its consumption. Nevertheless, if needed, secondary line can take over fuel supply completely – for example when for some reason there will be no energy in main fuel or main fuel flow will stop. Results of these tests are shown in Figure 5.

![Figure 4. The change of gas pressure and its influence on genset operation stability](image-url)
5. Summary
The HE-MUZG system has proved its unique features allowing much wider fuel composition variations, much faster fuel properties change and automatic continuous monitoring of fuel energy content. The available range is not only wider than for typical bio-gas tuned mixer but without any modification covers also the operation window reserved for natural gas tuned mixer and allows much lower methane content than bio-gas tuned mixer. The HE-MUZG system can adopt much faster to fuel calorific value fluctuations and accepts changes even 300 times faster than acceptable for standard fuel and control system.

The HE-MUZG system can be used for special fuels containing carbon monoxide (even pure carbon monoxide can be used). Additionally the system can cope with significant gas pressure fluctuations and can manage even with gas pressure lower than air pressure. The ability to manage two gas lines gives extraordinary possibility to optimise usage of low quality fuel supported by good quality one with limited and controlled consumption of the good one.

References
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