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A 4-stroke spark-ignition engine fuelled with low quality gas

Huge amount of by-products is still considered as waste and is simply disposed, for example by-product gas is usually flared. Political and social pressure to reduce air pollution and national needs for energy security make these waste fuels interesting for near-future power generation. Unfortunately most of these waste fuels, even when liquefied or gasified, have very low quality and can hardly be used in high-efficiency power systems. Among main challenges are low calorific value and composition fluctuation. Additionally very often there is a high content of sulphur, siloxanes, tars, etc., which have to be removed from the fuel.

Modern 4-stroke gas engines designed for power generation applications provide very high efficiency, high reliability and availability. Unfortunately, these gas engines require high quality fuel with stable composition. Horus-Energia together with Cracow University of Technology developed a novel gas supply system HE-MUZG that can adapt to current gas quality and change engine settings accordingly.

This article will present results from the HE-MUZG system tests on modern 4-stroke spark-ignition gas engine. Tests focus on low quality gas, such as gas with low calorific value, gas with very low methane number and gas with very big variations of calorific value. Test results compared with performance of that engine in the original configuration show huge improvements. Moreover the HE- MUZG system is easy to implement in commercial gensets.

Key words: *engine, genset, low quality gas*

1. Introduction

Modern 4-stroke gas engines are designed to operate with high reliability and high efficiency. It is possible due to fact that they utilise advanced combustion systems supported by sophisticated control system. For example, a 20-cylinder spark-ignition gas engine can be equipped with more than 200 various sensors which gather continuously information about engine operation, combustion characteristics and help to optimise control settings such like air-fuel-ratio, ignition advance etc. On one hand such complex control systems provide ultimate engine performance but on the other hand high quality of gas is required. Usually gas quality requirements include calorific value, methane number, methane or inert gas content etc. It is possible to tune engine for specific fuel but tuning may influence engine performance: available power, efficiency, emissions etc. There is a strong limitation for using fuels with very low methane number or very low calorific value, because these parameters determine available power of the engine. Operation at very reduced power makes solution not feasible – engine becomes very expensive in respect to available power and additionally engine efficiency decreases significantly. Even more problematic is situation when gas parameters change significantly or if the changes are rapid because control systems of typical gas engine can hardly adopt.

Novel gas supply system HE-MUZG was developed by Horus-Energia together with Cracow University of Technology. The system can be mounted on typical stationary gas engine and can automatically adjust own settings if fuel properties change. The results of broad tests are presented in this paper.

2. Test facility

The tests were held at Horus-Energia test facility, which is arranged for genset testing. The test facility is equipped with gas mixing station that creates possibility to mix several components and create almost any gas composition required for tests. Additionally, the gas mixing station is equipped with specially built control system that can generate very rapid change of fuel composition between set points defined by user. The test engine MAN E2876 LE302 was combined with Marelli MJB 250 LB4 generator as it is in the original genset configuration. The basic data of the engine and the genset in original configuration are presented in the Table 1 and the Figure 1 shows general view of the test facility.

Table 1. Basic data of the engine and the genset in original configuration (provided by manufacturer) [1, 5]

Engine type	4-stroke, turbocharged, spark-ignition, 2-stage mixture cooler
Cylinder configuration	6 cylinders in-line
Cylinder bore	128 mm
Piston stroke	166 mm
Compression ratio	11:1
Mean effective pressure	13.1 bar
Fuel supply system	Gas mixer in front of turbo-charger's compressor
Nominal air-fuel equivalence ratio (λ)	1,6
Engine speed (50 Hz genset application)	1500 rpm
Nominal power (engine)	210 kW
Nominal power (genset)	200 kW
Genset efficiency (at 50% load)	32.0%
Genset efficiency (at 75% load)	35.2%
Genset efficiency (at 100% load)	37.1%

The test program covered following stages:

- engine optimisation for operation on methane,
- engine operation on gas with very low calorific value,
- engine operation on gas with very low methane number,
- engine operation on gas with significant and fast change of calorific value.

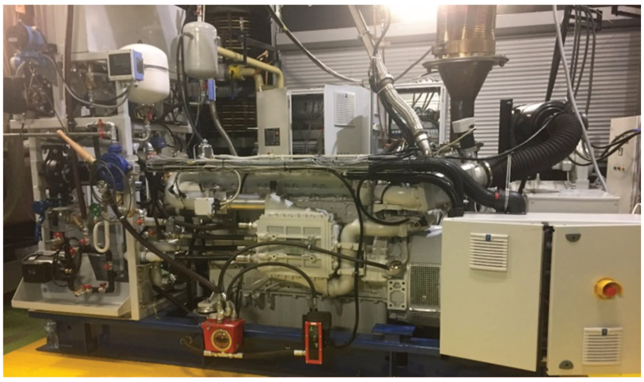

Fig. 1. General view of the MAN E2876 LE302 engine at the Horus-Energia test facility

2. Test results

The first stage of tests showed that HE-MUZG fuel supply system enables operation with higher genset efficiency than with original fuel system. The results are presented in Table 2 and in the Figure 2.

Table 2. The genset efficiency measured during tests with HE-MUZG fuel supply system

Engine load	Genset efficiency
0%	0.00%
25%	27.00%
50%	35.30%
75%	37.80%
90%	38.41%
100%	38.63%

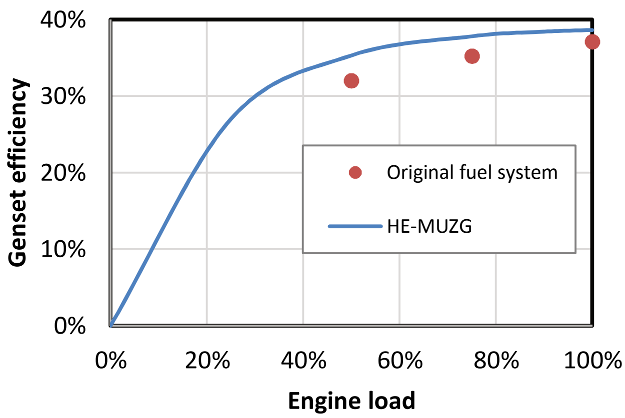

Fig. 2. The genset efficiency for original fuel system and measured during tests with HE-MUZG fuel supply system [1]

In the second stage methane was mixed with carbon dioxide to reduce gas fuel calorific value. The main target was to check how low can be gas calorific value that still enables stable genset operation. According to the engine manufacturer requirements, the gas with lower heating value (LHV) at least 32 MJ/m^3 is required for engines tuned for natural gas and the gas with LHV higher than 18 MJ/m^3 is required for engines tuned for bio-gas [4]. During test it was important not only to achieve stable engine operation but also to keep NO_x emission within allowed limit, i.e. 250 ppm at 5% oxygen content in the exhaust gas [2]. The results are presented in Table 3 and in the Figure 3.

Table 3. NO_x emissions for genset operation on fuel with wide range of LHV

CH_4 content in fuel	CO_2 content in fuel	Fuel LHV [MJ/m^3]	NO_x emission [ppm] (adjusted to 5% O_2)
100%	0%	36.0	146
75%	25%	27.0	165
65%	35%	23.4	171
50%	50%	18.0	185
43%	57%	15.5	207

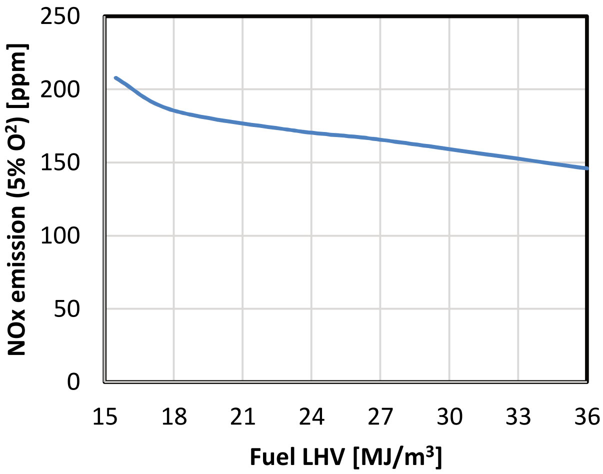

Fig. 3. NO_x emission at 5% O_2 for wide range of fuel LHV

Results show that the HE-MUZG system enables stable engine operation in wide range of fuel calorific value. It is important to highlight that the test genset was equipped with the engine originally tuned for operation on natural gas and the HE-MUZG system enabled operation with range of fuel calorific value wider even if compared with tuning of that engine for operation on biogas. Moreover NO_x emissions do not cross allowed level for whole fuel calorific value range. However at very low LHV NO_x emissions are significantly higher. The reason is that for fuel with very low LHV engine was tuned to operate at richer mixture than for fuel with higher LHV.

The next stage of tests was focused on low methane number. This is very important aspect, because lot of waste gas fuels contain heavier hydrocarbons or significant amount of hydrogen. These components reduce fuel methane number rapidly which creates problems with engine stable operation, engines cannot reach nominal power or operation can be simply impossible. According to manufacturer's requirements, engine can reach nominal power for fuels with methane number at least 80 and for pure propane engine can reach maximum 71% of its nominal load, which corresponds with 143 kW of the genset electrical power [4, 6]. As fuel for these tests pure propane was used. The results are presented in Table 4 and in the Figure 4.

Table 4. The performance of the genset fuelled with propane

Genset power [kW]	Engine load	Genset efficiency
0	0%	0%
45	23%	27.24%
90	45%	34.48%
135	68%	37.41%
162	81%	38.55%
180	90%	38.63%

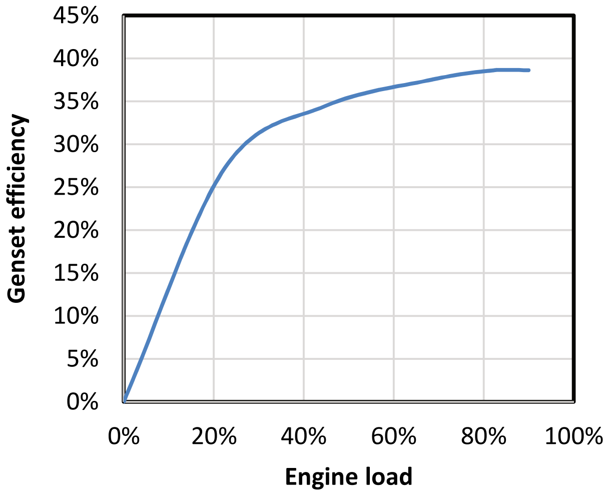

Fig. 4. The efficiency of the genset fuelled with propane

It was impossible to reach engine nominal power when engine was fuelled with propane due to the engine knocking, but the engine with the HE-MUZG system easily reached power higher than guaranteed by manufacturer for original fuel supply system. Moreover, the genset efficiency reached during operation on propane was higher than during operation on methane.

The last stage covered tests of engine operation during very fast changes of fuel composition. For this purpose mixture of methane and carbon dioxide was used. The original fuel supply system can tolerate changes of gas calorific value not faster than 0.002 MJ/m^3 per second and not more than 20% of the LHV set point. The gas composition was changed in a way that methane content was decreasing from 90% to 50% and then it was increasing from 50% to 90% with the same rate upwards and downwards. This corresponds to change of gas LHV between 32.337 MJ/m^3 and 17.965 MJ/m^3. The tests covered ramp times from 167 s down to 29 s, which covers methane content fluctuations from 0.24% per second to 1.38% per second. It can be presented also as fuel LHV variation from 0.086 MJ/m^3 per second to 0.496 MJ/m^3 per second. As the acceptance criteria for stable genset operation the generated electricity frequency variation (ßf) was selected, according to ISO 8528-5 norm. The norm defines operation as stable when ßf parameter is not greater than 2.5%. The shortest ramp time when the genset could fulfil stable operation criteria was 38s, which corresponds to CH_4 content change 1.05% per second and LHV change 0.378 MJ/m^3 per second. This results is approximately 190 times faster and covers range twice wider than allowed for standard engine setting. Moreover, for ramp time equal to 29 s, the ßf parameter was equal to 3%, which means only slight deviation from the norm and fluctuations of methane content of 1.38% per second and LHV fluctuations even 0.496 MJ/m^3 per second can be accepted in other applications for the engine.

Conclusions

The HE-MUZG fuel supply system tests showed that system improves gas engine operation characteristics and makes engine more flexible for fuel quality. Even for good quality gas the system brings benefits by improving engine performance.

The HE-MUZG extends limits for accepted fuel parameters. The system makes possible use of fuels with LHV 15.5 MJ/m^3, improves engine operation with fuels with low methane number providing better knock resistance and higher efficiency. Additionally system is very adaptive and fast responding for current gas quality, which is reflected in enabling the engine stable operation even when fuel LHV fluctuates almost 0.5 MJ/m^3 per second. The HE-MUZG fuel supply system can tolerate not only 200 times faster fluctuations but can also adopt do LHV changes in twice wider range than standard fuel supply system.

As next steps further system tests and optimisation are scheduled.

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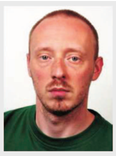

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