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# Co-firing of mixtures agricultural biogas with LNG or LPG as an alternative to injection of biogas to the grid

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**Abstract**

The paper presents results of tests carried out on household appliances used for food preparation which were powered by mixtures of agricultural biogas with LNG or LPG. The main aim of the study was to check whether a mixture of this gases can be safely burned in devices designed to burn gas groups E or Lw. Prepared gas mixtures had energy parameters corresponding to the minimum parameters for second family gases groups E and Lw. The paper presents the energy parameters and gas mixtures used in the study, and the mixing ratio of biogas and LNG or LPG. Pieces of legislation that refer to the development of renewable energy sources, including increasing the use of biogas in Poland, have been presented. The obtained results show that among the draIR up blends of agricultural biogas with LNG or LPG the most promising for further research and, consequently, to use them in the future, are mixtures named B+LNG$_{(E)}$ and B+LPG$_{(E)}$. Studies have shoIR that these blends can be safely burned in household appliances used for food preparation, designed to burn group E gas without modification.

**Keywords:** Agricultural biogas; LNG; LPG; Gas mixtures; Co-firing

## 1 Introduction

The document 'Polish Energy Policy Till 2030' [1] includes basic directions of this policy, such as:

- improvement in the energy efficiency,

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- increase in the fuels and energy supply security,
- development of renewable energy sources use, including biofuels,
- development of competitive fuel and energy markets,
- reduction of the energy sector environmental impact.

The main policy objectives should include:

- increase in the share of renewable energy sources (RES) in the final energy consumption at least to the level of 15% in 2020 and a further increase in this factor in the following years,
- reaching a 10% share of biofuels in the transport fuels market in 2020,
- greater diversification of energy sources and development of optimum conditions for the dispersed power industry based on locally available raw materials.

Another document, which applies directly to agricultural biogas is the document 'Directions for Agricultural Biogas Plants Development in Poland in the Years 2010–2020', approved by the Council of Ministers on 13 July 2010 and prepared by the Ministry of Economy in cooperation with the Ministry of Agriculture and Village Development. It states that the main objectives for agricultural biogas plants development include:

- ensuring the supply of the energy carrier to residents of villages and small toIRs distant from gas transmission and distribution grids;
- improving the energy security through diversification of energy sources and their generation places [2].

The document states that it will be the investors' decision, how this gas is to be utilised – be it by injecting to the national distribution grid or the distribution infrastructure of the gas administered by local governments, or by generation of electricity or heat [2].

In the case of biogas pumping to the national distribution grid, the biogas shall be cleaned to parameters of natural gas distributed by this grid. Therefore, apart from removing from the biogas the sulphur compounds, moisture and other pollutants harmful to the operation of equipment, it is also necessary to remove $CO_2$.

The paper suggests a solution consisting in blending pre-cleaned agricultural biogas (cleaned of sulphur compounds, moisture and other pollutants harmful to the operation of equipment, without elimination of $CO_2$) with the gas from

LNG regasification or with the LPG gas in such proportions, that parameters of created blends would correspond to energy parameters required for gases of the second family group E and group Lw. After the analysis of test results on selected domestic appliances it will be possible to assess, whether the suggested blends are fit for burning in the equipment adapted to group E and Lw gases without the need to modify it.

## 2 Agricultural biogas

Biogas, including agricultural biogas, consists mainly of methane and carbon dioxide and smaller amounts of hydrogen sulphide, carbon oxide, ammonia, and oxygen. The content of the most wanted component, i.e., methane, in the biogas falls within a pretty wide range, because from approx. 40% up to even 75%. Methane determines the calorific value of the biogas – the more methane – the higher is the value.

Agricultural biogas may be obtained:

- in the process of anaerobic digestion of biomass originating from energy crops, residues of farming and from animal excrements;
- in the process of anaerobic digestion of biomass originating from waste in slaughterhouses, breweries and the other food sectors.

Table 1 presents percentage composition of biogas acc. to various sources.

Table 1: Percentage content of biogas components acc. to various sources.

| Biogas component | Share, % vol. [3] | Share, % vol. [4] |
|---|---|---|
| Methane | 45–75 | 50–75 |
| Carbon dioxide | 28–45 | 25–45 |
| Moisture | Saturated | Saturated |
| Hydrogen sulphide | $<$ 10 ppm | 0–1 |
| Nitrogen | $<$ 3 | 0-3 |
| Oxygen | $<$ 2 | 0–1 |
| Hydrogen | Trace amounts | 0–1 |

The biogas composition depends on the technological process and also on substrates used for its production. In most of agricultural biogas plants in Poland the produced biogas is used now for cogeneration of electricity and heat in cogeneration systems based on a combustion piston engines. The paper [5] presents results of research focused on experimental investigation of combustion of biogas fuels in a combustion piston engine. Apart from that agricultural biogas may be used:

- to produce electricity in gas turbines,
- to produce heat in adapted gas boilers,
- as a fuel for cars,
- to inject to gas grids after previous treatment to parameters of gas distributed by that grid,
- in technological processes, e.g. in methanol production [6].

The choice of agricultural biogas management way depends on many factors, the most important of them include:

- possibility to sell surpluses of the generated electricity to the grid;
- possibility to use the generated heat for process or social purposes;
- distance between the biogas source and industrial plants, housing estates [6].

As mentioned earlier, the agricultural biogas contains, beside methane and carbon dioxide, a number of pollutants, which are specified in Table 1. In addition, the biogas may contain pollutants that do not occur in typical natural gases and which may have an adverse impact both on the gas transport infrastructure and on its recipients safety. Such pollutants include siloxanes, halogenated hydrocarbons, ammonia or microgoranisms [7]. Sulphuric acid formed e.g. in a reaction with oxygen and water vapour has a damaging effect on individual elements of the installation [8]. Therefore biogas shall be cleaned before using. Biogas, void of water vapour and hydrogen sulphide and also of other pollutants, is a mixture of methane and carbon dioxide, which may be fired in cogeneration systems or gas boilers adapted to that. An assumption is made that biogas containing more than 40% of methane may be used for energy purposes.

Considering that water vapour, hydrogen sulphide and other pollutants harmful for the equipment operation will be removed, having averaged compositions given in Tab. 1, we obtain biogas containing roughly 65% of methane and 35% of carbon dioxide. Biogas with such parameters may be used to fire in energy equipment, while in the case of planned introduction of the gas to the grid as a transport fuel it is necessary to process biogas to biomethanole, i.e., to remove also carbon dioxide [9]. Table 2 provides minimum parameters of natural gas – high-methane E and nitrogen containing Lw – as well as the composition and parameters of agricultural biogas cleaned to minimum parameters of natural gas from groups E and Lw.

Table 2: Composition and parameters of agricultural biogas cleaned to minimum parameters of natural gas from groups E and Lw.

| Parameter | | Unit | Minimum parameters for gas E* | Agricultural biogas with minimum parameters for gas E | Minimum parameters for gas Lw* | Agricultural biogas with minimum parameters for gas Lw |
|---|---|---|---|---|---|---|
| Gas composition | Methane | %vol | – | 91.00 | – | 81.00 |
| | Carbon dioxide | %vol | – | 9.000 | – | 19.00 |
| Gross calorific value $H_S$ | | MJ/m$^3$ | 34.00 | 36.25 | 30.00 | 32.26 |
| Net calorific value $H_i$ | | MJ/m$^3$ | 31.00 | 32.66 | 27.00 | 29.07 |
| Gross Wobbe index $W_S$ | | MJ/m$^3$ | 45.00 | 45.22 | 37.50 | 37.51 |
| Net Wobbe index $W_i$ | | MJ/m$^3$ | – | 40.75 | – | 33.80 |
| Density | | kg/m$^3$ | – | 0.831 | – | 0.957 |
| Relative density | | – | – | 0.643 | – | 0.740 |

Note: energy parameter and density are given for temperature °C and pressure 1013.25 hPa
* – Source: PN-C-04753:2011 Natural Gas – Quality of the Gas Supplied to Consumers from a Local Distribution System[1] (in Polish).

The biogas blending with gas originating from LNG regasification or LPG gas could be another way to enrich biogas void of moisture and hydrogen sulphide, to obtain blends of energy parameters corresponding to minimum requirements specified for gases of the second family group E and group Lw. The gas prepared in such a way could be distributed by local distribution grids administered by local governments and used in the equipment adapted to those groups of gases without the need for its modification. The assessment of such prepared blends use in domestic appliances adapted to fire natural gas of the second family group E and Lw was performed on selected domestic appliances used for food preparation.

[1]PN-C-04753:2011 Gaz naturalny – Jakość gazu dostarczanego odbiorcom z sieci dystrybucyjnej, p. 5.

# 3 Agricultural biogas production potential in Poland

Agricultural biogas in Poland has still a modest share in the energy balance of the country. According to the register of companies involved in the agricultural biogas production (as of 19 February 2016), kept by the President of the Agricultural Market Agency (ARR), 73 agricultural biogas plants were registered, with the total electric power of 87.942 $MW_{el}$ and the annual output of agricultural biogas plants of approx. 340 million $m^3$ [10]. According to the data published by the ARR in 2014 in Poland approx. 174 million $m^3$ of agricultural biogas were produced, of which around 355 GWh of electricity and around 374 GWh of heat were generated.

The agricultural biogas production potential in Poland is the highest share in the overall estimated biogas potential in the country. We refer here both to the farm waste, such as animal excrements and plant crops, as well as to crop waste, food production waste and also energy crops, intended for the energy carriers production.

Poland is the third largest agricultural area in the EU. Arable land covers approx. 17 million ha, while fallow and idle land makes another 1 million ha [11]. It is estimated that approx. 1.9 million ha of arable land is necessary to generate 10 billion $m^3$ of methane; at 1 million ha of idle land [1] that means that Poland has an appropriate acreage, guaranteeing a growth in agricultural biogas production.

# 4 Determination of agricultural gas proportions to blend with LNG or LPG

To realise assumptions of this study, proportions of blending pre-cleaned agricultural biogas with the gas from LNG regasification or LPG were determined, so as to achieve in the final effect the gas of energy parameters corresponding to minimum requirements specified for gases of the second family group E and group Lw in accordance with the standard PN-C-04753:2011 (see Tab. 2).

The assumption made of treating biogas to obtain minimum energy parameters for individual gases results from the fact that such gases are most difficult to be fired in the equipment adapted to a specific gas group.

For the study needs an assumption was made that blends would be created based on biogas containing 65% of methane and 35% of carbon dioxide, to which gas from LNG regasification or liquid LPG, having compositions given in Tab. 3, would be added. Compositions of the formed blends and their energy parameters are specified in Tab. 4.

Table 3: Compositions of LNG and LPG used to blend with agricultural biogas.

| Gas | Composition | | | | $H_s$ | $H_i$ | Gross $W_s$ | $\rho$ | $d$ |
|---|---|---|---|---|---|---|---|---|---|
| | Methane | Ethane | Propane | Butane | | | | | |
| | %vol | %vol | %vol | %vol | MJ/m$^3$ | MJ/m$^3$ | MJ/m$^3$ | kg/m$^3$ | – |
| LNG | 89.1 | 7.2 | 3.7 | – | 44.30 | 40.06 | 55.92 | 0.811 | 0.627 |
| LPG | – | – | 50 | 50 | 117.36 | 108.22 | 86.90 | 2.358 | 1.824 |

Note: energy parameters and density are given for reference conditions of 0 °C and pressure 1013.254 hPa

Table 4: Gas compositions after blending agricultural biogas with LNG and LPG, corresponding to minimum requirements specified for gases of the second family group E and Lw.

| Parameter | | Unit | Gas notations and parameter value | | | |
|---|---|---|---|---|---|---|
| | | | B+LNG($_E$) | B+LNG($_{Lw}$) | B+LPG($_E$) | B+LPG($_{Lw}$) |
| Gas composition | methane | % vol. | 81.1 | 74.9 | 49.8 | 56.6 |
| | ethane | %vol | 4.8 | 3.0 | – | – |
| | propane | %vol | 2.5 | 1.5 | 11.8 | 6.5 |
| | butane | %vol | – | – | 11.8 | 6.5 |
| | carbon dioxide | %vol | 11.6 | 20.6 | 26.6 | 30.4 |
| Gross calorific value, $H_S$ | | MJ/m$^3$ | 38.21 | 33.46 | 47.53 | 37.80 |
| Net calorific value, $H_i$ | | MJ/m$^3$ | 34.53 | 30.21 | 43.42 | 34.38 |
| Gross Wobbe index, $W_S$ | | MJ/m$^3$ | 45.14 | 37.76 | 45.04 | 37.50 |
| Net Wobbe index, $W_i$ | | MJ/m$^3$ | 40.79 | 34.09 | 41.14 | 34.11 |
| Density, $\rho$ | | kg/m$^3$ | 0.926 | 1.015 | 1.439 | 1.314 |
| Relative density, $\boldsymbol{d}$ | | – | 0.717 | 0.785 | 1.114 | 1.016 |
| Proportions of LNG or LPG blending with biogas | | m$^3$LNG or LPG/ m$^3$ biogas | 2 | 0.7 | 0.31 | 0.07 |

Note: energy parameters and density are given for reference conditions of 0 °C and pressure 1013.25 hPa

For the purpose of this study the LNG gas composition was limited to three components (see Tab. 3) and the fraction of hydrocarbon higher than propane was added to the propane share in the gas.
Gas notations:

- B+LNG$_{(E)}$ – a blend of agricultural biogas and gas from LNG regasification corresponding to minimum requirements for the gas of the second family group E,
- B+LNG$_{(Lw)}$ – a blend of agricultural biogas and gas from LNG regasification corresponding to minimum requirements for the gas of the second family group Lw,
- B+LPG$_{(E)}$ – a blend of agricultural biogas and LPG gas corresponding to minimum requirements for the gas of the second family group E,
- B+LPG$_{(Lw)}$ – a blend of agricultural biogas and LPG gas corresponding to minimum requirements for the gas of the second family group Lw.

An assumption was also made that parameters, significant because of the gas quality change, should be tested. This would comprise:

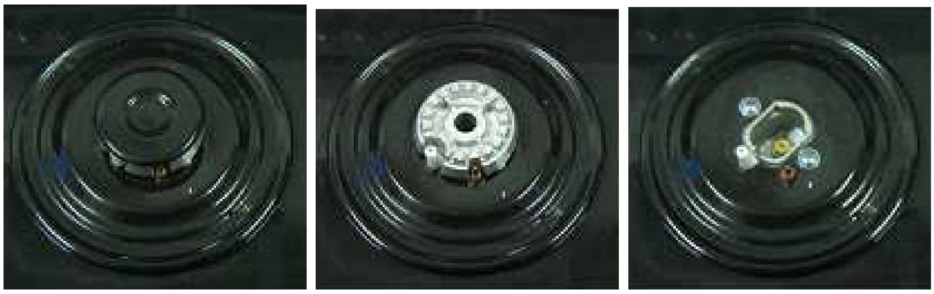
- heat input at normal pressure;
- CO concentration at the maximum pressure and at a reduced (minimum) heat input;
- ignition, cross-lighting and flame stability:
  - ignition and cross-lighting at the normal pressure,
  - flame lift at the maximum pressure,
  - light back at the minimum pressure and the power controller set to the minimum position.

The testing procedures were selected from the harmonised standard PN-EN 30-1-1 +A3:2013 'Domestic cooking appliances burning gas – Part 1-1: Safety – General'

# 5 Selection of burners for tests

Appliances with bucket-type burners (2 appliances) and pipe-type burners (1 appliance) were selected for tests of the high-methane natural gas composition influence on the quality of burning in burners of gas cooking plates or ovens.

The first type of bucket burners was represented by burners installed in gas

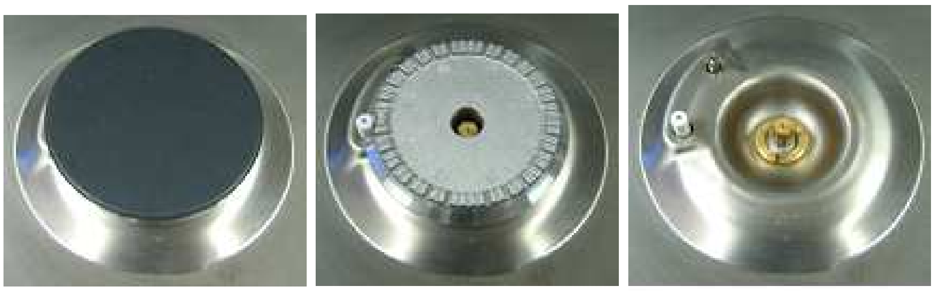


a) b) c)

Figure 1: Auxiliary burner of gas cooking plate No. 1: a) auxiliary burner – general view, b) auxiliary burner – flame ring without cover, c) auxiliary burner – diffuser body.

cooking plate No 1. These burners basically consist of three parts: diffuser body, flame ring and cover. Fig. 1 shows an example of such burner.
The primary air for combustion in such burners is sucked in from above the burner plate, hence these burners cannot be 'sunk' in the plate and they work best in recently fashionable glass or ceramic under-burner plates. The control of primary air inflow because of the gas type is carried out by special injector designs (with double or even triple drilling and appropriately chosen height).

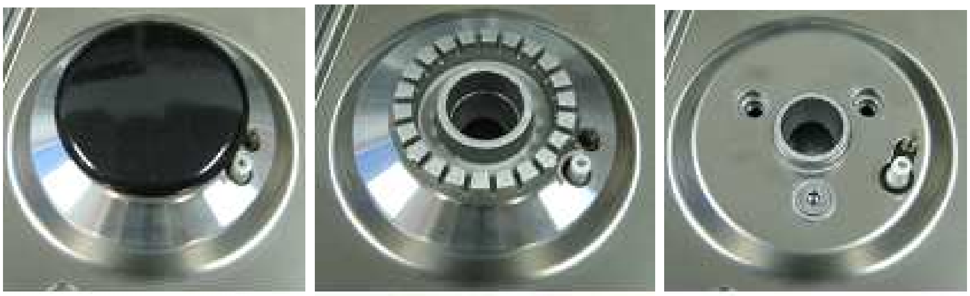
The second type of 'bucket' burners installed in gas cooking plate No 2 has the feature that its 'bucket' part, fulfilling the injector role, is draIR directly in the burner plate. Figure 2 shows an example of such burner.



a) b) c)

Figure 2: Semi-rapid burner of gas cooking plate No 2: a) semi-rapid burner – general view, b) semi-rapid burner – flame ring without cover, c) semi-rapid burner – diffuser body.

So-called pipe burners were installed in gas cooking plate No 3. They are characterised by a better mixing of gas with the primary air as a result of an elongated diffuser. The mixture of primary air and gas flows to the burner injector, and not only gas, like in the case of typical bucket burners. Such burners suck in more air for combustion than typical bucket burners, which makes them more susceptible to unstable operation, but at the same time they feature a higher combustion quality, translating into a lower carbon oxide content in the flue gas. Figure 3 shows an example of such burner.



a) b) c)

Figure 3: Semi-rapid burner of gas cooking plate No 3: a) semi-rapid burner – general view, b) semi-rapid burner – flame ring without cover, c) semi-rapid burner – diffuser body.

Selected burners, fed with mixtures prepared for the needs of this study, were equipped with the following:

- injectors for high-methane gas E burning – burners prepared in this way were fed with B+LNG$_{(E)}$ and B+LPG$_{(E)}$ blends
- injectors for nitrogen containing gas Lw burning – burners prepared in this way were fed with B+LNG($_{Lw)}$ and B+LPG$_{(Lw)}$ blends

# 6 Results of measurements

The obtained results of measurements are specified in Tables 5–10.

# 7 Conclusions

When analysing results of measurements carried out on three selected gas cooking plates, with burners most frequently encountered on the Polish market, it is possible to state that:

- burners of all tested gas cooking plates fed with B+LNG$_{(E)}$ i B+LPG$_{(E)}$ blends were igniting with certainty, flames were stable and calm,

Table 5: Test pressure, heat input and quality of combustion for gas cooking plate No. 1 (results for gases G20, B+LNG$_{(E)}$, B+LPG$_{(E)}$,G27, B+LNG$_{(Lw)}$, B+LPG$_{(Lw)}$).

| Test pressure [hPa] | | | | | | | |
|---|---|---|---|---|---|---|---|
| Gas group | | E | | | Lw | | |
| Name | | Normal pressure | Minimum pressure | Maximum pressure | Normal pressure | Minimum pressure | Maximum pressure |
| Symbol | | $p_{nom}$ | $p_{min}$ | $p_{max}$ | $p_{nom}$ | $p_{min}$ | $p_{max}$ |
| Value | | 20 | 17 | 25 | 20 | 16 | 23 |
| Corrected heat inputs ($Q_c$) [W] at $p_{nom}$ | | | | | | | |
| Gas symbol | | G20 | B+LNG$_{(E)}$ | B+LPG$_{(E)}$ | G27 | B+LNG$_{(Lw)}$ | B+LPG$_{(Lw)}$ |
| Burner | Rapid | 2367 | 2018 | 1979 | 2230 | 2166 | 2202 |
| | Semi-rapid | 1362 | 1151 | 1169 | 1320 | 1124 | 1161 |
| | Auxiliary | 539 | 474 | 451 | 630 | 565 | 589 |
| Quality of combustion at $p_{max}$ | | | | | | | |
| CO content converted into dry non-diluted flue gas* [ppm] | | | | | | | |
| Burner | Rapid | 133 | 77 | 54 | 251 | 51 | 66 |
| | Semi-rapid | 47 | 32 | 38 | 199 | 23 | 40 |
| | Auxiliary | 64 | 76 | 62 | 191 | 42 | 70 |
| Minimum heat inputs ($Q_{min}$) [W] at $p_{nom}$ | | | | | | | |
| Gas symbol | | G20 | B+LNG$_{(E)}$ | B+LPG$_{(E)}$ | G27 | B+LNG$_{(Lw)}$ | B+LPG$_{(Lw)}$ |
| Burner | Rapid | 656 | 609 | 620 | 660 | 610 | 604 |
| | Semi-rapid | 442 | 429 | 423 | 450 | 351 | 356 |
| | Auxiliary | 370 | 328 | 325 | 380 | 323 | 352 |
| Quality of combustion at $Q_{min}$ | | | | | | | |
| CO content converted into dry non-diluted flue gas* [ppm] | | | | | | | |
| Burner | Rapid | 82 | 196 | 90 | 204 | 68 | 110 |
| | Semi-rapid | 126 | 336 | 137 | 240 | 542 | 534 |
| | Auxiliary | 321 | 207 | 158 | 237 | 79 | 139 |

(heat inputs are given converted to temperature 15 °C and pressure 1013.25 hPa)
* limit value converted into dry non-diluted flue gas – 1000 ppm [12]

cross-lighting was smooth, no effect of flame lift from the burner crown was observed,

- in the case of feeding the burners with B+LNG$_{(Lw)}$ i B+LPG$_{(Lw)}$ blends in particular the auxiliary burners were showing problems with the stability of operation. There were problems with their ignition, flames were unstable

Table 6: Assessment of gas cooking plate No. 1 burners operation stability.

| Flame stability | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Ignition and cross-lighting | | | | | | | | |
| Burner | B+LNG($_E$) | | B+LNG($_{Lw}$) | | B+LPG($_E$) | | B+LPG($_{Lw}$) | |
| | Pressure | Result | Pressure | Result | Pressure | Result | Pressure | Result |
| Rapid | $p_{nom}$ | CR | $p_{nom}$ | CR | $p_{nom}$ | CR | $p_{nom}$ | CR |
| Semi-rapid | | CR | | CR | | CR | | CR |
| Auxiliary | | CR | | **IR** | | CR | | **IR** |
| Flame lift | | | | | | | | |
| Burner | B+LNG($_E$) | | B+LNG($_{Lw}$) | | B+LPG($_E$) | | B+LPG($_{Lw}$) | |
| | Pressure | Result | Pressure | Result | Pressure | Result | Pressure | Result |
| Rapid | $p_{max}$ | CR | $p_{max}$ | CR | $p_{max}$ | CR | $p_{max}$ | CR |
| Semi-rapid | | CR | | CR | | CR | | CR |
| Auxiliary | | CR | | **IR** | | CR | | **IR** |
| Light back | | | | | | | | |
| Burner | B+LNG($_E$) | | B+LNG($_{Lw}$) | | B+LPG($_E$) | | B+LPG($_{Lw}$) | |
| | Pressure | Result | Pressure | Result | Pressure | Result | Pressure | Result |
| Rapid | $p_{min}$ | CR | $p_{min}$ | CR | $p_{min}$ | CR | $p_{min}$ | CR |
| Semi-rapid | | CR | | CR | | CR | | CR |
| Auxiliary | | CR | | CR | | CR | | CR |

CR – consistent result; IR – inconsistent result

and were not cross-lighting, and after the ignition they were showing a trend to lift. The problems disappeared, when a pot with water was put on the burner, however the reference standard requires to perform such tests also without it.

Analysing the measurement results in terms of CO emission, in no case a significant change of this emission was observed, which is very important from potential users of such appliances point of view.

With respect to heat inputs, because the prepared blends had energy parameters corresponding to minimum requirements set to gases from the second family group E and Lw, the obtained heat inputs were appropriately lower than the values obtained for the reference gases. A decline of heat input was always around a few to a dozen or so percent, however, as the tests have shown, it does not influence the burners operation safety.

A longer time necessary to achieve the expected temperature of the prepared food will be the only inconvenience resulting from the reduction of burners heat

Table 7: Test pressure, heat input and quality of combustion for gas cooking plate No. 2 (results for gases G20, B+LNG$_{(E)}$, B+LPG$_{(E)}$,G27, B+LNG$_{(Lw)}$, B+LPG$_{(Lw)}$).

| Test pressure [hPa] | | | | | | | |
|---|---|---|---|---|---|---|---|
| Gas group | | E | | | Lw | | |
| Name | | Normal pressure | Minimum pressure | Maximum pressure | Normal pressure | Minimum pressure | Maximum pressure |
| Symbol | | $p_{nom}$ | $p_{min}$ | $p_{max}$ | $p_{nom}$ | $p_{min}$ | $p_{max}$ |
| Value | | 20 | 17 | 25 | 20 | 16 | 23 |
| Corrected heat inputs ($Q_c$) [W] at $p_{nom}$ | | | | | | | |
| Gas symbol | | G20 | B+LNG$_{(E)}$ | B+LPG$_{(E)}$ | G27 | B+LNG$_{(Lw)}$ | B+LPG$_{(Lw)}$ |
| Burner | Very rapid | 3626 | 3033 | 2940 | 3861 | 3631 | 3676 |
| | Rapid | 2242 | 2057 | 2060 | 2486 | 2312 | 2327 |
| | Semi-rapid | 1480 | 1360 | 1334 | 1697 | 1623 | 1619 |
| | Auxiliary | 886 | 792 | 793 | 1038 | 996 | 1010 |
| Quality of combustion at $p_{max}$ | | | | | | | |
| CO content converted into dry non-diluted flue gas* [ppm] | | | | | | | |
| Burner | Very rapid | 1306 | 620 | 647 | 949 | 977 | 945 |
| | Rapid | 96 | 80 | 102 | 97 | 44 | 100 |
| | Semi-rapid | 18 | 36 | 36 | 72 | 29 | 34 |
| | Auxiliary | 25 | 45 | 52 | 90 | 39 | 50 |
| Minimum heat inputs ($Q_{min}$) [W] at $p_{nom}$ | | | | | | | |
| Gas symbol | | G20 | B+LNG$_{(E)}$ | B+LPG$_{(E)}$ | G27 | B+LNG$_{(Lw)}$ | B+LPG$_{(Lw)}$ |
| Burner | Very rapid | 1860 | 1581 | 1552 | 1644 | 1581 | 1436 |
| | Rapid | 1031 | 897 | 912 | 818 | 773 | 769 |
| | Semi-rapid | 737 | 641 | 646 | 606 | 567 | 579 |
| | Auxiliary | 451 | 393 | 402 | 386 | 362 | 377 |
| Quality of combustion at $Q_{min}$ | | | | | | | |
| CO content converted into dry non-diluted flue gas* [ppm] | | | | | | | |
| Burner | Very rapid | 503 | 114 | 69 | 155 | 114 | 148 |
| | Rapid | 110 | 413 | 155 | 321 | 274 | 302 |
| | Semi-rapid | 134 | 253 | 200 | 372 | 217 | 365 |
| | Auxiliary | 428 | 68 | 98 | 183 | 127 | 181 |

(heat inputs are given converted to temperature 15 °C and pressure 1013.25 hPa)
* limit value converted into dry non-diluted flue gas – 1000 ppm [12]

input, and hence from a decrease of the heating power. However, as practice shows, in such appliances the full heat input of burners is very seldom used,

Table 8: Assessment of gas cooking plate No. 2 burners operation stability.

| Flame stability | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Ignition and cross-lighting | | | | | | | | |
| Burner | B+LNG$_{(E)}$ | | B+LNG$_{(Lw)}$ | | B+LPG$_{(E)}$ | | B+LPG$_{(Lw)}$ | |
| | Pressure | Result | Pressure | Result | Pressure | Result | Pressure | Result |
| Very rapid | $p_{nom}$ | CR | $p_{nom}$ | CR | $p_{nom}$ | CR | $p_{nom}$ | CR |
| Rapid | | CR | | CR | | CR | | CR |
| Semi-rapid | | CR | | CR | | CR | | CR |
| Auxiliary | | CR | | **IR** | | CR | | **IR** |
| Flame lift | | | | | | | | |
| Burner | B+LNG$_{(E)}$ | | B+LNG$_{(Lw)}$ | | B+LPG$_{(E)}$ | | B+LPG$_{(Lw)}$ | |
| | Pressure | Result | Pressure | Result | Pressure | Result | Pressure | Result |
| Very rapid | $p_{max}$ | CR | $p_{max}$ | CR | $p_{max}$ | CR | $p_{max}$ | CR |
| Rapid | | CR | | CR | | CR | | CR |
| Semi-rapid | | CR | | CR | | CR | | CR |
| Auxiliary | | CR | | **IR** | | CR | | **IR** |
| Light back | | | | | | | | |
| Burner | B+LNG$_{(E)}$ | | B+LNG$_{(Lw)}$ | | B+LPG$_{(E)}$ | | B+LPG$_{(Lw)}$ | |
| | Pressure | Result | Pressure | Result | Pressure | Result | Pressure | Result |
| Very rapid | $p_{min}$ | CR | $p_{min}$ | CR | $p_{min}$ | CR | $p_{min}$ | CR |
| Rapid | | CR | | CR | | CR | | CR |
| Semi-rapid | | CR | | CR | | CR | | CR |
| Auxiliary | | CR | | CR | | CR | | CR |

CR – consistent result; IR – inconsistent result

therefore the users may even not notice this decrease.

Summing up, among blends of agricultural biogas with LNG or LPG, blends marked as B+LNG$_{(E)}$ and B+LPG$_{(E)}$ have greatest prospects to continue tests and as a result - to use them in the future. As the tests have shown, these blends can be safely burned in domestic appliances used to prepare food, adapted to burn gases of the second family group E without the need to modify them.

We draw attention to the fact that only one group of domestic appliances has been tested. Similar tests should be performed on selected pieces of equipment used to heat premises and to prepare domestic hot water as well as on the equipment used in catering.

In the case of positive results the suggested solution could be an alternative to the agricultural biogas injection to the distribution grid. Based on agricultural biogas plants producing biogas, which would be enhanced with LNG or LPG gas,

Table 9: Test pressure, heat input and quality of combustion for gas cooking plate No. 3 (results for gases G20, B+LNG$_{(E)}$, B+LPG$_{(E)}$,G27, B+LNG$_{(Lw)}$, B+LPG$_{(Lw)}$).

| Test pressure [hPa] | | | | | | | |
|---|---|---|---|---|---|---|---|
| Gas group | | E | | | Lw | | |
| Name | | Normal pressure | Minimum pressure | Maximum pressure | Normal pressure | Minimum pressure | Maximum pressure |
| Symbol | | $p_{nom}$ | $p_{min}$ | $p_{max}$ | $p_{nom}$ | $p_{min}$ | $p_{max}$ |
| Value | | 20 | 17 | 25 | 20 | 16 | 23 |
| Corrected heat inputs ($Q_c$) [W] at $p_{nom}$ | | | | | | | |
| Gas symbol | | G20 | B+LNG$_{(E)}$ | B+LPG$_{(E)}$ | G27 | B+LNG$_{(Lw)}$ | B+LPG$_{(Lw)}$ |
| Burner | Rapid | 3480 | 3001 | 2918 | 3160 | 2773 | 2922 |
| | Semi-rapid | 1780 | 1516 | 1469 | 1630 | 1425 | 1462 |
| | Auxiliary | 1138 | 959 | 947 | 1030 | 962 | 983 |
| Quality of combustion at $p_{max}$ | | | | | | | |
| CO content converted into dry non-diluted flue gas* [ppm] | | | | | | | |
| Burner | Rapid | 73 | 24 | 28 | 195 | 19 | 21 |
| | Semi-rapid | 17 | 45 | 35 | 276 | 39 | 37 |
| | Auxiliary | 32 | 45 | 50 | 412 | 48 | 58 |
| Minimum heat inputs ($Q_{min}$) [W] at $p_{nom}$ | | | | | | | |
| Gas symbol | | G20 | B+LNG$_{(E)}$ | B+LPG$_{(E)}$ | G27 | B+LNG$_{(Lw)}$ | B+LPG$_{(Lw)}$ |
| Burner | Rapid | 1161 | 1023 | 1018 | 157 | 1064 | 965 |
| | Semi-rapid | 462 | 435 | 450 | 555 | 513 | 536 |
| | Auxiliary | 441 | 422 | 431 | 380 | 353 | 374 |
| Quality of combustion at $Q_{min}$ | | | | | | | |
| CO content converted into dry non-diluted flue gas* [ppm] | | | | | | | |
| Burner | Rapid | 245 | 399 | 317 | 544 | 348 | 503 |
| | Semi-rapid | 78 | 130 | 16 | 353 | 89 | 84 |
| | Auxiliary | 54 | 87 | 97 | 540 | 105 | 115 |

(heat inputs are given converted to temperature 15 °C and pressure 1013.25 hPa)
* limit value converted into dry non-diluted flue gas – 1000 ppm [12]

local distribution networks could be created, not connected to the national gas system, and managed by, e.g., local governments. Such a way of biogas management can provide many benefits both to local communities and to the whole country. Firstly, it will contribute to increased accessibility of gas in the areas, which have not been supplied with gas so far, where because of economic reasons gas grids, distributing the systemic gas, have not been constructed. Secondly, such a sys-

Table 10: Assessment of gas cooking plate No. 3 burners operation stability.

| Flame stability | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Ignition and cross-lighting | | | | | | | | |
| Burner | B+LNG$_{(E)}$ | | B+LNG$_{(Lw)}$ | | B+LPG$_{(E)}$ | | B+LPG$_{(Lw)}$ | |
| | Pressure | Result | Pressure | Result | Pressure | Result | Pressure | Result |
| Rapid | $p_{nom}$ | CR | $p_{nom}$ | CR | $p_{nom}$ | CR | $p_{nom}$ | CR |
| Semi-rapid | | CR | | CR | | CR | | CR |
| Auxiliary | | CR | | **IR** | | CR | | **IR** |
| Flame lift | | | | | | | | |
| Burner | B+LNG$_{(E)}$ | | B+LNG$_{(Lw)}$ | | B+LPG$_{(E)}$ | | B+LPG$_{(Lw)}$ | |
| | Pressure | Result | Pressure | Result | Pressure | Result | Pressure | Result |
| Rapid | $p_{max}$ | CR | $p_{max}$ | CR | $p_{max}$ | CR | $p_{max}$ | CR |
| Semi-rapid | | CR | | CR | | CR | | CR |
| Auxiliary | | CR | | **IR** | | CR | | **IR** |
| Light back | | | | | | | | |
| Burner | B+LNG$_{(E)}$ | | B+LNG$_{(Lw)}$ | | B+LPG$_{(E)}$ | | B+LPG$_{(Lw)}$ | |
| | Pressure | Result | Pressure | Result | Pressure | Result | Pressure | Result |
| Rapid | $p_{min}$ | CR | $p_{min}$ | CR | $p_{min}$ | CR | $p_{min}$ | CR |
| Semi-rapid | | CR | | CR | | CR | | CR |
| Auxiliary | | CR | | CR | | CR | | CR |

CR – consistent result, IR – inconsistent result

tem guarantees a greater energy security in a specific area, because shortages of biogas, if any, resulting from its insufficient production, could be covered by the gas from LNG regasification or by LPG.

On the national scale, that would lead to an increased share of renewable energy in the energy balance, which is enforced by the obligations related to the European Union accession. In Poland, which is to achieve 15% of RES share in the national energy balance by 2020, the development of biogas plants seems a very natural solution due to a high agricultural potential of our country.

The adopted solution of enhancing agricultural biogas to reach minimum parameters of group E high-methane natural gas by means of gas from LNG regasification should contribute to meeting the requirement of 15% share of energy originating from RES in the final energy balance, because the share of biogas in a blend prepared this way is around 22.4%. Creation of gas blends based on LPG is even a more favourable solution from the point of view of biogas share in the created blend. In this case the biogas share in the energy amount is as high as approx. 37.6%.

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