Nafta-Gaz 2019, no. 8, pp. 465–473, DOI: 10.18668/NG.2019.08.03

An analysis of the effects of hydrogen addition to natural gas on the work of gas appliances

Analiza wpływu dodatku wodoru do gazu ziemnego na pracę urządzeń gazowych

Robert Wojtowicz

Oil and Gas Institute – National Research Institute

ABSTRACT: Investigation results of hydrogen addition to natural gas 2E on the work of selected gas appliances for both domestic (gas hob with burners equipped with adjustable combustion air aperture, gas-fired air heaters for space heating, air heater type balanced flue, gas fireplace) and commercial (gas stock pot range, gas-fired overhead luminous radiant heater) use have been presented in this paper. A brief description of gas appliances chosen for testing has been given. Gas burners and automation installed in the above mentioned appliances were prepared for natural gas combustion. The tests were carried out with three mixtures of natural gas with 10%, 15% and 23% of hydrogen. Approximate compositions of gases used in the tests and their energy parameters were provided. The following parameters were checked: combustion quality, ignition, cross lighting and flame stability, nominal heat input and thermal efficiency. The results obtained for each device, with consideration of all tested operational and safety parameters, were discussed. When analyzing the results, special attention was given to the matter of heat input of appliances, lowering with decreasing energy parameters of particular gases with hydrogen addition and to the effect of the above on thermal efficiency of the appliance tested. The results were presented on diagrams. The conclusions were formulated considering why, depending on the construction of a particular appliance, the decrease in heat input differently effected its thermal efficiency. By basing on the obtained results the following questions were answered:
- Whether the safe and proper operation of domestic appliances might not be affected by hydrogen addition to natural gas;
- What amount of hydrogen could be added to natural gas in order to ensure safe and not requiring any modification operation of appliances adapted to natural gas combustion.

Key words: hydrogen, natural gas, Power to gas.

STRESZCZENIE: W artykule przedstawiono wyniki badania wpływu dodatku wodoru do gazu ziemnego wysokometanowego 2E na pracę wybranych domowych urządzeń gazowych (płyta gazowa z palnikami wyposażonymi w regulowaną przysłonę powietrza do spalania, gazowa nagrzewnica powietrza do ogrzewania pomieszczeń, ogrzewacz powietrza typu *balanced flue*, kominek gazowy) oraz urządzeń do zastosowań komercyjnych (taboret gazowy oraz promiennik gazowy). W artykule podano krótką charakterystykę wytypowanych do badań urządzeń gazowych. Palniki gazowe oraz automatyka zainstalowane w wyżej wymienionych urządzeniach przystosowane były do spalania gazu ziemnego wysokometanowego. Badania przeprowadzono z wykorzystaniem trzech mieszanin gazu ziemnego wysokometanowego z wodorem o zawartości wodoru odpowiednio: 10%, 15% i 23%. Podano przybliżone składy gazów użytych w badaniach oraz ich parametry energetyczne. Na wybranych do badań urządzeniach sprawdzano takie parametry urządzeń jak: jakość spalania, zapalanie, przenoszenie i stabilność płomienia, znamionowe obciążenie cieplne oraz sprawność cieplna. Wyniki badań uzyskane dla każdego urządzenia omówiono odnosząc się do wszystkich sprawdzanych parametrów użytkowych i bezpieczeństwa. Analizując wyniki badań, szczegółowo poruszono kwestię obniżenia się obciążenia cieplnego urządzeń w miarę spadku parametrów energetycznych poszczególnych gazów z dodatkiem wodoru i wpływ tego zjawiska na uzyskiwaną sprawność cieplną przez badane urządzenia. Otrzymane wyniki badań zobrazowano na wykresach. Sformułowano także wnioski na temat tego, dlaczego w zależności od konstrukcji urządzenia spadek obciążenia cieplnego ma różny wpływ na osiąganą przez urządzenie sprawność cieplną. Na podstawie uzyskanych wyników udzielono odpowiedzi na pytania:
- czy dodatek wodoru do gazu ziemnego nie wpłynie na prawidłową i bezpieczną pracę urządzeń gazowych użytku domowego;
- jaką ilość wodoru można zatłoczyć do gazu ziemnego wysokometanowego, aby urządzenia przystosowane do spalania gazu ziemnego pracowały bezpiecznie bez potrzeby ich modyfikacji.

Słowa kluczowe: wodór, gaz ziemny, *Power to gas*.

Corresponding author: R. Wojtowicz, e-mail: *robert.wojtowicz@inig.pl*

Article contributed to the Editor 11.01.2019. Approved for publication 10.07.2019 r.

Introduction

An development of renewable energy sources connected to the energetic system in our country, especially to the wind-powered sources, causes some temporary power surplus not easy to be stored. In recent years this increase tendency has aroused an interest in the projects of *Power to gas* type where hydrogen is produced as a result of water electrolysis, by using energy originating from renewable sources. This tendency complies with the guidelines for the Polish power policy, till 2050 included in the strategy: *Energetic safety and environment* (BEiŚ), one of nine so called integrated strategies of development accepted by the Council of Ministers on 15.04.2014 (Ciechanowska, 2014). The main BEiŚ guidelines for the energy policy are, among others, the development and modernisation of fuels and energy production, transmission and storage infrastructure (Ciechanowska, 2014).

According to one of the assumptions of the *Power to gas* project, hydrogen thus produced, serving as an energy agent will be mixed with natural gas, then stored and transported through existing gas network. As it was mentioned by Piskowska-Wasiak (2017), the standards in regard to allowable hydrogen content in the gas network vary in different countries. For example in Holland the maximum hydrogen content in the gas network is 2%. The same value is presently permitted in gas-fired cars, in Germany but the tolerance range in regard to both the gas networks and modern gas burners may be higher. The value presented in the technical standard DVGW G262 is 5% (Piskowska-Wasiak, 2017). Thus the *Power to gas technology* presents a promising solution in regard to the possibilities of balancing the electric energy system as well to the energy storage.

Compositions of investigated gas mixtures

In the presented paper it has been assumed that the investigation of the effects of hydrogen addition to natural gas on the work of gas appliances should be conducted using the following gas types:

- natural gas 2E in regard to monitoring of the nominal parameters of investigated appliances and eventual correction of device settings in such a way to make the change of gas always take place at nominal settings, not susceptible to alteration during further tests;
- natural gas with increasing hydrogen content:
  – 90% gas 2E + 10% hydrogen (GH10),
  – 85% gas 2E + 15% hydrogen (GH15),
  – 77% gas 2E + 23% hydrogen (GH23).

When determining the percentage of hydrogen content in mixtures with natural gas 2E, the following aspects were taken into account:

- **10% hydrogen in the mixture:** due to the leading methods (AGA8-92DC and SGERG-88) conversion of compressibility factor in settlements for gas using the energy method. These methods allow a maximum hydrogen molar fraction of 10% (Łach, 2016);
- **15% hydrogen in the mixture:** 15% was selected as an intermediate value between 10% and 23% of the hydrogen content in the mixture with natural gas 2E;
- **23% hydrogen in the mixture:** due to the operational safety of gas appliances. During tests of type of gas appliances adapted to the combustion of natural gas 2E based on the test methods included in the reference standards, G222 gas containing CH_4 = 77% and H_2 = 23% is used as light back limit gas (PN-EN 437 + A1:2012). Therefore, a value of 23% was assumed as the upper value of the addition of hydrogen to natural gas 2E.

It has been also assumed that the parameters important in regard to the change of gas quality, to be investigated due to their changes in the appliance, are the following:

- nominal heat input at nominal pressure;
- thermal efficiency;
- CO and NOx concentrations and not combusted hydrocarbons (CnHm) at maximum pressure and reduced heat input (depending on the appliance);
- flame stability:
  – flame lift at maximum pressure,

Table 1. Parameters of natural gas 2E and of gases with increased hydrogen content
Tabela 1. Parametry gazu ziemnego oraz gazów o podwyższonej zawartości wodoru

Parameter		Unit	Gas symbols and parameter's value			
			2E*	GH10	GH15	GH23
Gas components	hydrogen		–	10.01	15.01	23.00
	methane	%	97.34	87.59	82.73	74.95
	nitrogen	%	1.15	1.04	0.98	0.89
	others	%	1.51	1.36	1.28	1.16
Gross calorific value H_S		MJ/m³	37.90	35.32	34.03	31.96
Net calorific value H_i		MJ/m³	34.17	31.78	30.58	28.66
Gross Wobbe index W_S		MJ/m³	50.16	48.94	48.33	47.35
Net Wobbe index W_i		MJ/m³	45.26	44.04	43.44	42.47
Density ρ		kg/m³	0.700	0.638	0.607	0.558
Relative density d		–	0.571	0.521	0.496	0.456

Remark: physico-chemical values given for conditions: t = 15°C and p = 1013.25 mbar
* Typical composition of natural gas presently used in Poland (INiG – PIB data)

– light back at minimum pressure and the power controller set in a minimum position.

Investigation procedures were chosen from standards set for particular appliances (PN-EN 30-1-1 + A3:2013, PN-EN 30-2-1:2015, PN-EN 203-1:2014, PN-EN 203-2-1:2015, PN-EN 613:2002, PN-EN 1020:2010, PN-EN 419-1:2012). Measurements of particular parameters were carried out with the use of devices generating maximum uncertainty of measurement also in accordance with those standards. Composition, density and energy parameters used in the analysed gas mixtures were presented in Table 1.

Gas appliances selected for the investigations

In the aim to investigate the effect of hydrogen addition to natural gas 2E on the work of a gas appliance, the following were selected:

- domestic gas appliances used for cooking (gas hob with burners equipped with adjustable combustion air aperture) and air heaters for space heating (gas-fired air heater, air heater balanced flue type and a gas fireplace);
- Appliances for commercial use (gas stock pot range and gas-fired overhead luminous radiant heater).

Gas burners and automation installed in the above appliances were adjusted to natural gas combustion. Tests were first conducted for natural gas, then, without changing the setting of the appliances and at the same pressure as for 2E gas, a mixture of natural gas with hydrogen in proportion presented at point 2 was introduced.

Gas hob

The gas hob selected for investigations was equipped with so called pipe burners for hob. Thanks to their long injector, their characteristic feature is better mixing of gas with the primary air. A burner's nozzle receives the gas already mixed with primary air, a not with gas only, as it is in the case of typical cup burners. These burners suck in more primary air for combustion than typical bucket burners, so they are more liable to work unstably but, at the same time they possess better combustion quality. Hence a lower content of carbon monoxide in the exhaust gases. An auxiliary burner (Q_{zanm} = 1050 W), semi rapid (Q_{zanm} = 1600 W), and a very large one (Q_{zanm} = 3300 W) were tested.

Photo 1. A gas hob (by the author)
Fot. 1. Widok ogólny płyty gazowej

Gas stock pot range

One- burner gas stock pot range for commercial use, adapted for natural gas combustion, was tested. The appliance was equipped with a burner of construction similar to those of the investigated gas hob but of much higher heat input (Q_{zanm} = 14000 W) than the burners on the gas hob.

Photo 2. A gas stock pot range (by the author)
Fot. 2. Widok ogólny taboretu gazowego

Air heater of „balanced flue" type for space heating

The investigated appliance is an air heater of balanced flue type for space heating, with closed combustion chamber, equipped with concentric system of air-exhaust pipes with natural gravitation (without fan) The gas valve of the appliance is equipped with a gas pressure regulator keeping constant pressure on the nozzle, irrespective of gas supply pressure changes

Photo 3a. Front view
Fot. 3a. Widok od frontu

Photo 3b. Back view
Fot. 3b. Widok od tyłu

Photo 3. A gas-fired air heater (by the author)
Fot. 3. Widok ogólny ogrzewacza gazowego

provided for the 2E (p_{min}= 17 mbar, p_{max} = 25 mbar) group. The heat input of the investigated appliance is Q_{zanm} = 2400 W.

A gas fireplace

A gas fireplace with closed combustion chamber, equipped with concentric SPS air-exhaust pipes system with natural gravitation (without a fan). The heat input of the investigated appliance is Q_{zanm} = 5800 W.

Photo 4. A gas fireplace (by the author)

Fot. 4. Widok ogólny kominka gazowego

A gas-fired air heater

A gas-fired air heater with an open combustion chamber and forced convection, for interior heating, possible to be assembled in non-residential spaces, was investigated. The appliance is equipped with a gas valve with gas pressure regulator holding constant pressure on the nozzle irrespective of gas supply pressure changes provided for natural gas 2E (p_{min}= 17 mbar, p_{max} = 25 mbar) group. The heat input of the investigated appliance is Q_{zanm} = 31 400 W.

Photo 5a. The view with uncovered cavities

Fot. 5a. Widok z odkrytymi wnękami

Photo 5b. Heat exchange unit

Fot. 5b. Zespół wymiennika ciepła

Photo 5. A gas-fired air heater (by the author)

Fot. 5. Widok nagrzewnicy powietrza

A gas-fired overhead luminous radiant heater

The subject of investigation was a gas-fired overhead luminous radiant heater for commercial use. The heat input of the appliance is 6.8 kW. It is equipped with piezoelectric ignition system and a gas valve connected to the flame monitoring thermocouple.

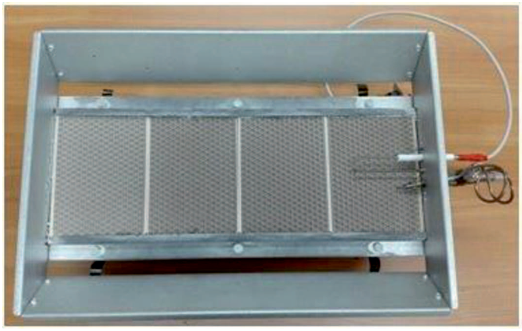

Photo 6. Gas-fired overhead luminous radiant heater seen from the side of the burner (by the author)

Fot. 6. Widok promiennika od strony palnika

Experimental

When comparing the composition of exhaust gases emitted from the investigated appliances when using natural gas with hydrogen addition as well as those combusting natural gas only, it can be noticed that in regard of none of the investigated components a significant increase of their concentration was observed. That regards carbon oxide, nitrogen oxides as well as not combusted hydrocarbons, checked in the exhaust within this investigation. The testing of appliances with gas fuel combustion is conducted by basing on requirements and methods included in relevant standards, and the permissible level of carbon dioxide emission, converted into dry, undiluted exhaust is 1000 ppm (0.1%). During the investigations this value was never exceeded. In regard to the standards of a domestic gas hob (PN-EN 30-1-1 + A3:2013, PN-EN 30-2-1:2015) and gas stock pot range (PN-EN 203-1:2014, PN-EN 203-2-1:2015) there are no requirements concerning the emission level of NOx and hydrocarbons unburned.

However, during the tests also the content of those components in combustion products was checked, where the level of reference for mixtures GH10, GH15 i GH23 were the values obtained for natural gas. In the standards determined for a gas-fired air heater (PN-EN 1020:2010), gas-fired overhead luminous radiant heater (P1N-EN 419-1:2012), gas fireplace (PN-EN 613:2002) and balanced flue type air heater for space heating (N-EN 613:2002) there are requirements in regard to the permissible level of NOx content in the exhaust gases but they are measured at different heat input levels and the final result is calculated by the weighted average method. Because all the appliances accepted for the investigation were CE marked, the level of NOx content in the exhaust gases had to be in accordance with the requirements of relevant standards. In regard to these investigations it was more interesting whether an addition of hydrogen into natural gas would not cause an increase in NOx propagation in comparison with the results obtained for natural gas only. As it has been mentioned, such phenomenon was not observed.

The conducted tests of flame stability showed that an addition of hydrogen to natural gas did not weaken the flame stability of the investigated appliances' burners. Neither flame lift nor light back were observed, also cross-lighting was correct.

When analysing the heat input values it can be clearly seen that in the case of natural gas mixtures with hydrogen, characterized by lower energy parameters than in case of natural gas only, the heat inputs of the burners of investigated appliances also had a decreasing tendency. On the diagrams below the percentage reduction of gross Wobbe index of natural gas mixed with hydrogen in relation to that of natural gas only and the effect it had on both the heat input and thermal efficiency gained by the appliances was shown. It should be added that a decrease in gross Wobbe index in relation to the amount of hydrogen added to natural gas is: 2.4% for the mixture containing 10% H_2, 3.6% for the mixture containing 15% H_2 and 5.6% for the mixture containing 23% H_2.

Presented diagrams (Fig. 1 and 2) show how the reduction of Wobbe index of the investigated mixture of natural gas with hydrogen effects the heat input and efficiency of a large burner and semi rapid burner of the gas hob.

When analysing the heat input results for the investigated gas hob burners, it can be noticed that a reduction in Wobbe index of natural gas, after hydrogen has been added, causes a decrease in both the heat input and thermal efficiency. The thermal efficiency decreases because after hydrogen has been added to natural gas, the length of the burning gas flame becomes shorter. This is an effect of much faster combustion of hydrogen than methane. Because of this, in the case of uncovered burners such as those of the investigated gas hob, their thermal efficiency decreases.

Addition of hydrogen to natural gas causes a greater amount of steam in relation to the exhaust gases when combusting natural gas only. Because of its higher heat capacity the steam accumulates more thermal energy, thus a greater amount of steam in the exhaust gases should considerably increase the thermal efficiency. This can be noticed in appliances equipped with a heat exchanger, such as a gas-fired air heater or gas fireplace (Fig. 8 and 9). In uncovered burners it is not possible to exploit this phenomenon because of lack of a closed space such as combustion chamber in a gas-fired air heater or gas-fired fireplace and an extended heat exchanger makes it impossible to compensate the smaller amount of thermal energy resulting from heat input reduction by collecting the heat from steam. Nevertheless, it should be noticed that in case of both semi rapid and large burners of the investigated gas hob the heat input was not reduced below the permissible minimum level of 52%. The value of heat input load for auxiliary and large burners did not drop below the permissible value for any of the gas mixtures with hydrogen. For a semi rapid burner the heat input value was reduced below the standard permissible for mixture marked as GH23, i.e. containing 23% of hydrogen.

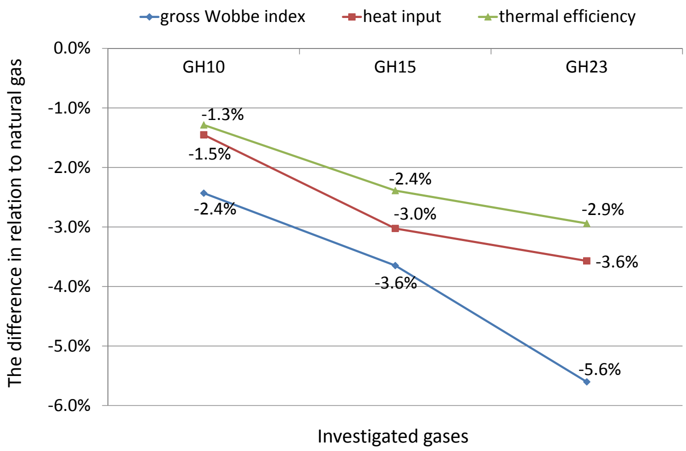

Fig. 1. The difference of gross Wobbe index, heat input and thermal efficiency of investigated mixtures with hydrogen in relation to natural gas of a large gas hob's burner

Rys. 1. Różnica górnej liczby Wobbego, obciążenia cieplnego i sprawności badanych mieszanek z wodorem w stosunku do gazu ziemnego 2E palnika bardzo dużego płyty gazowej

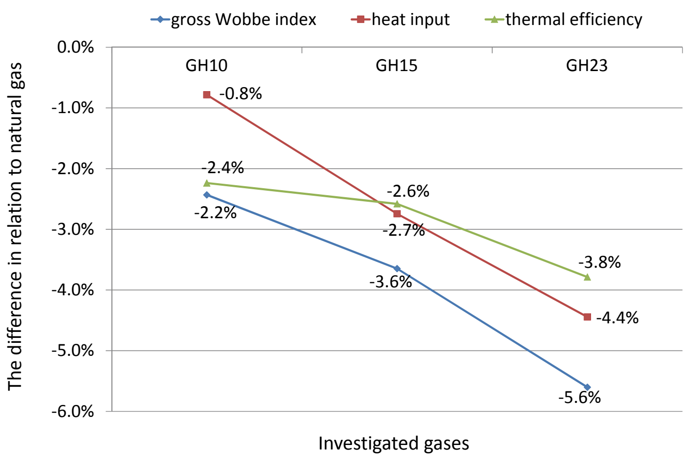

Fig. 2. The difference of gross Wobbe index, heat input and thermal efficiency of investigated mixtures with hydrogen in relation to natural gas of a semi rapid gas hob's burner

Rys. 2. Różnica górnej liczby Wobbego, obciążenia cieplnego i sprawności badanych mieszanek z wodorem w stosunku do gazu ziemnego 2E palnika średniego płyty gazowej

Despite a similar construction of a burner on a gas stock pot range to those on a gas hob, its energy parameters (heat input and thermal efficiency) for all the natural gas with hydrogen mixtures decreased below the minimum permitted by the appropriate standard. The heat input is reduced more than 5% in relation to the value declared by the producer for natural gas (the value is 14 000 W) and efficiency drops below 52%. This situation results most of all from the fact that already for the natural gas without any addition the heat input value approaches the lower limit defined according to the standard's requirements (permissible deviation from the value declared in the standard (PN-EN 203-1:2014) is ±5%)). The result of heat input reduction obtained for natural gas is 13 352 W, and the permissible minimum value after including 5% deviation is 13 300 (calculated in relation to that declared by the producer, i.e. 14 000 W). An addition of hydrogen to natural gas allows to obtain mixtures of lower calorific value what in turn reduces the heat input for GH10, GH15 i GH23. An efficiency decrease of a burner of a gas stock pot range for mixtures with hydrogen addition is caused by the same phenomenon as in the case of gas hob burners. Still the efficiency never drops below the permissible value of 52%. In the case of a gas stock pot range's burner the decrease in efficiency is connected with the fact that even if the appliance operates with natural gas only, its efficiency approaches the lower limit permitted by the standard (thermal efficiency value for natural gas is 52,1%, Fig. 3).

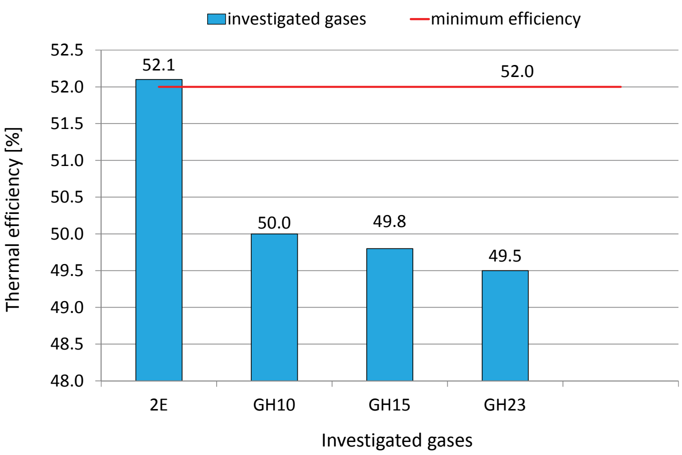

Fig. 3. Results of thermal efficiency for the burner of a gas stock pot range

Rys. 3. Wyniki sprawności cieplnej dla palnika taboretu

Decrease in gas calorific value and shortening of the burner's flames by adding some hydrogen and keeping the same distance of the burner from both the bottom of the pot and the same surface of the pot bottom allow to obtain thermal efficiency values for GH10, GH15 and GH23 below 52%.

The results of investigation for a balanced flue type heater presented on figure 11 clearly show that together with decrease

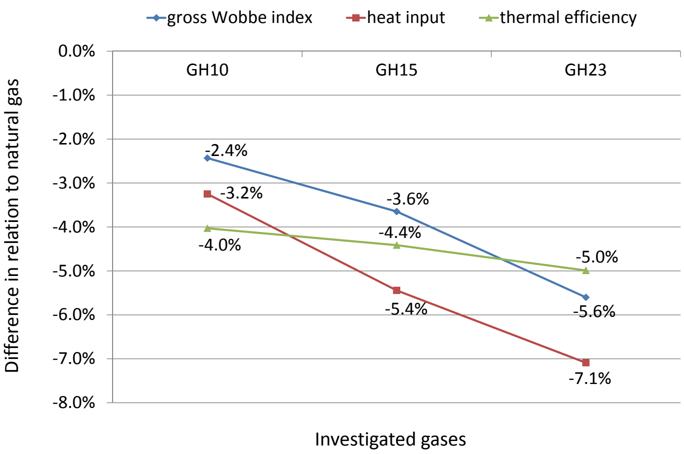

Fig. 4. Difference of gross Wobbe index, heat input and thermal efficiency of the investigated mixtures with hydrogen content in relation to natural gas 2E for a burner of a gas stock pot range

Rys. 4. Różnica górnej liczby Wobbego, obciążenia cieplnego i sprawności badanych mieszanek z wodorem w stosunku do gazu ziemnego 2E dla palnika taboretu gazowego

in Wobbe index, hydrogen addition causes also the heat input decrease in relation to values obtained for natural gas only. That decrease, depending on the amount of hydrogen in the mixture with natural gas, is from 3.3% for GH10 to 7.0% for GH23. However, it should be noticed that only in case of GH23 heat input decreased below the permissible standard (Fig. 5).

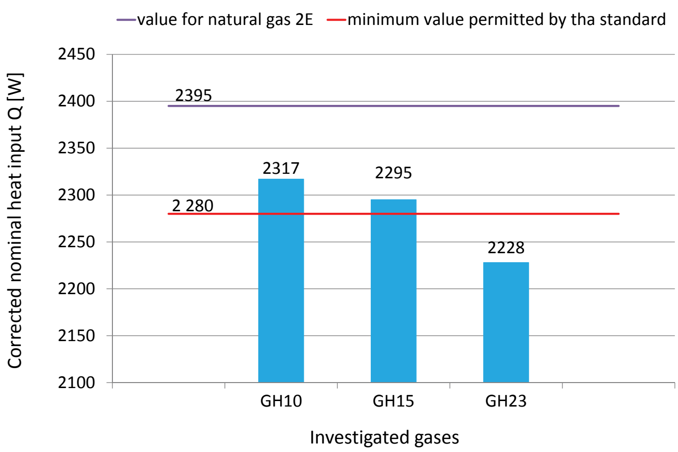

Fig. 5. Corrected nominal heat inputs for a balanced flue type air heater for space heating

Rys. 5. Skorygowane znamionowe obciążenia cieplne dla ogrzewacza pomieszczeń typu *balanced flue*

When analysing efficiency results for this appliance it can be seen that its thermal efficiency decreases with the increase of the amount of hydrogen added to natural gas. Although the decrease of that parameter for GH10 mixture is minimum in relation to natural gas (0.2%) and thermal efficiency does not drop below the permissible level (80%, Fig. 6), efficiency values for GH15 and GH23 mixtures decrease below 80%.

Still, it should be noticed that efficiency decrease for GH15 gas is also slight and equal to 1.5% in relation to natural gas 2E. Although the appliance is equipped with a closed combustion chamber, there is no an expanded heat exchanger. Thus there is no possibility to compensate the heat input decrease for the mixtures with hydrogen by collecting thermal energy accumulated in the steam contained in exhaust gases as it is in the case of a gas fireplace or gas-fired air heater.

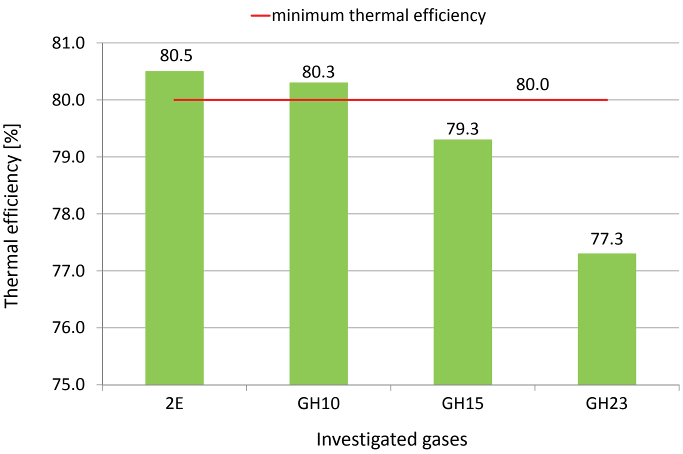

Fig. 6. Results of thermal efficiency for a balanced flue type air heater for space heating

Rys. 6. Wyniki sprawności cieplnej dla ogrzewacza pomieszczeń typu balance flue

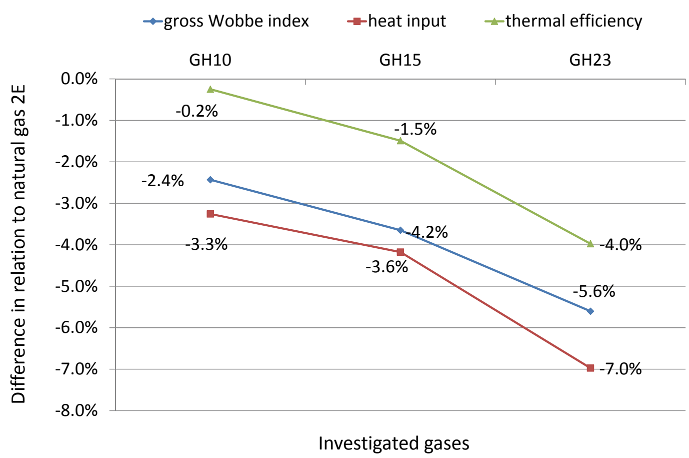

Fig. 7. Difference of gross Wobbe index, heat input and thermal efficiency values of investigated mixtures with hydrogen addition in relation to natural gas for a balanced flue type heater

Rys. 7. Różnica górnej liczby Wobbego, obciążenia cieplnego i sprawności badanych mieszanek z wodorem w stosunku do gazu ziemnego 2E dla ogrzewacza balanced flue

When analysing the following diagrams (Fig. 8 and 9) referring to the investigated gas fireplace and gas-fired air heater, it can be clearly seen that together with a decrease of Wobbe index, because of hydrogen addition to natural gas, also heat inputs decrease in relation to the values obtained for natural gas. That decrease, depending on the appliance and the amount of hydrogen in the mixture with natural gas ranges from 2.3% to even 9.6% for a gas-fired air heater. Nevertheless, in regard to both the appliances decrease in nominal heat input load below permissible values (PN-EN 613:2002 and PN-EN 1020:2010) occurs only in the case of GH23, i.e. containing 23% H_2

When considering the percentage difference in efficiency of natural gas and its mixtures with hydrogen one can observe, that it is slight despite the decrease in heat input of burners of the investigated appliances, i.e. the use of a smaller amount of energy provided in gas. In the case of a gas fireplace as well as a gas-fired air heater efficiency most decreased for the mixture GH23, 1% and 0.2% respectively, despite a few percent reduction of the heat input of the burners. It is surely

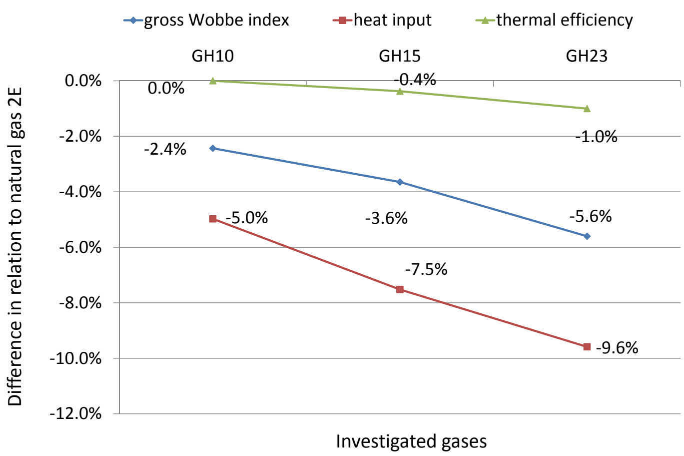

Fig. 8. Difference of gross Wobbe index, heat input and thermal efficiency values of investigated mixtures with hydrogen addition in comparison to natural gas for a gas fireplace

Rys. 8. Różnica górnej liczby Wobbego, obciążenia cieplnego i sprawności badanych mieszanek z wodorem w stosunku do gazu ziemnego 2E kominka gazowego

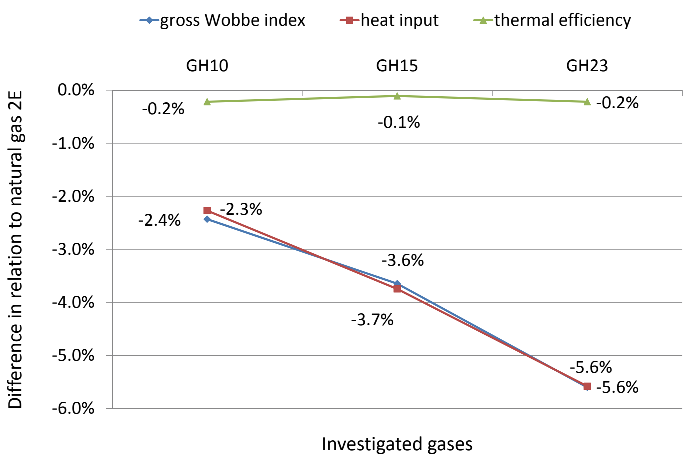

Fig. 9. Difference of gross Wobbe index, heat input and thermal efficiency valuesof investigated mixtures with hydrogen in comparison to natural gas for a gas-fired air heater

Rys. 9. Różnica górnej liczby Wobbego, obciążenia cieplnego i sprawności badanych mieszanek z wodorem w stosunku do gazu ziemnego 2E dla nagrzewnicy gazowej connected with the fact that addition of hydrogen to natural gas causes a greater amount of steam in relation to the amount of exhaust gases emitted, than when using natural gas only. Because of its greater thermal capacity steam can yield more heat in a heat exchanger (that concerns the gas-fired air heater) and is also favourable to heat transfer through radiation (gas fireplace with a combustion chamber surrounded by a glass pane from three sides) thus increasing the heat exchange efficiency. That is why the addition of hydrogen to natural gas in such appliances may increase the efficiency of gas energy exploitation and, at the same time lower the gas cost. The last remark is the more justified because in Poland the system of payment for gas by basing on the amount of provided energy is already functioning. Because of the above, in case when addition of hydrogen decreases the gas calorific value, the final recipient will pay less without noticing lower thermal performance of the appliance.

Since an apparatus to measure the thermal efficiency of gas-fired overhead luminous radiant heaters is not at INiG – PIB disposal, that parameter has not been measured. However, in this appliance similarly as in the other investigated within this work, some decrease in heat input for mixtures containing an addition of hydrogen was stated. Still, in no case reduction below the permissible standard value was registered, as shown on Figure 10.

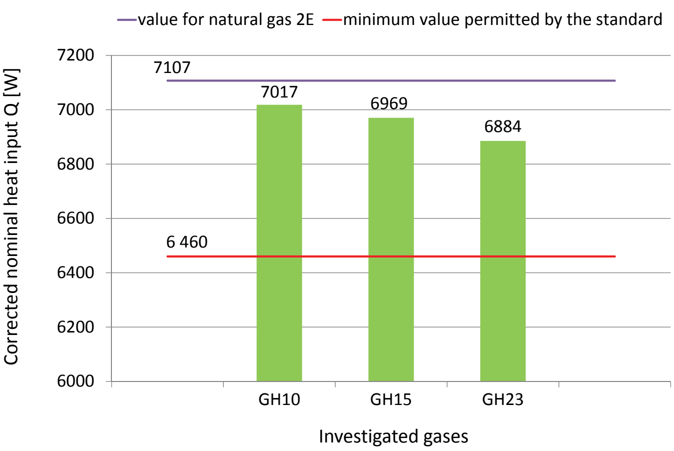

Fig. 10. Corrected nominal heat input for a gas-fired overhead luminous radiant heater

Rys. 10. Skorygowane znamionowe obciążenia cieplne dla promiennika gazowego

Conclusions

Summing up the results of investigation of the effect of hydrogen addition to natural gas on the work of domestic gas-fired appliances for cooking (gas hob with burners equipped with an adjustable air combustion aperture) and air heating for space heating (gas-fired air heater, balanced flue type air heater and gas fireplace) as well as those for commercial use (gas stock pot range and gas-fired overhead luminous radiant heater), it can be stated that an addition of even 23% of hydrogen to natural gas should not worsen their work safety (increase of the content of carbon oxide, nitrogen oxides or hydrocarbon in exhaust gases or unstable work of the burners).

Whereas decrease in the heat input of the burners and, what follows, reduction of thermal efficiency, especially in appliances for cooking (gas hob and gas stock pot range) may cause some concern. Although in the case of the gas hob's burners their thermal efficiency did not drop below the permissible minimum value for any of the investigated mixtures with hydrogen addition, in the case of the gas stock pot range that parameter was lower than 52% (minimum efficiency according to the relevant standard) for all the investigated mixtures. It is connected with the construction of the gas stock pot range itself. The gas burner installed in this appliance was originally designed for the heat input of 10 kW (stated by basing on the analysis of heat inputs of gastronomic appliances investigated by INiG – PIB during several years). The company producing the gas stock pot range investigated within this work, increased its heat input to 14 kW, to satisfy their clients' requirements. To fulfil the requirements in regard to emission of exhaust gases, the burner was lowered in relation to the upper edge of the grate. It is exactly this distance that makes the thermal efficiency for natural gas only remain on the standard-permitted level. In case of an addition of hydrogen which because of its combustion features makes the flame length shorten, for the natural gas mixtures with hydrogen lower efficiencies were obtained. Still, it should be noticed that maximum decrease of thermal efficiency for the burners of a gas hob as well as that of a gas stock pot range in the case of mixtures of natural gas with hydrogen, in relation to that efficiency if only natural gas is used, is 5%. From the user's view such decrease should not be noticeable. Neither it should influence the gas bill because in Poland the system of payment for gas fuel by basing on the amount of energy provided is already functioning. Because of the above, when after adding hydrogen, gas caloric value decreases, the final recipient will pay less.

Similar problem concerning the thermal efficiency decrease appeared in the case of the balanced flue type air heater. The greatest efficiency decrease occurred for GH23 mixture, since it was 4% in relation to natural gas 2E efficiency. Whereas in case of GH15 that decrease is only 1.5%, and 0.2% for GH10. Thus, especially for the mixtures GH10 and GH15 the user should not notify any efficiency decrease in regular use of the appliances. That can be supported by the fact that in investigations of compliance with relevant standard, the thermal efficiency of gas appliances, is determined with the use of a gas of a particular family or group of gases. In the case of natural gas, the reference gas is G20 (100% methane, gross calorific value H_s = 37.78 MJ/m^3). In reality, in the place the appliances are used, natural gas of different composition and calorific value may be used. It should have all the required by law energy parameters (according to the decision of the minister 2010 the gross calorific value in this case should not be lower than 34.0 MJ/m^3, and gross Wobbe index must be within the range of 45.0–56.9 MJ/m^3). In connection with the above, the heating appliance fired by natural gas without hydrogen addition can obtain different efficiency, often lower than those determined in the investigation of compliance with relevant standard.

The problem of efficiency decreasing regards less the gas fireplace and gas-fired air heater where natural gas mixtures with hydrogen are applied because in case of these appliances the decrease is compensated by the increase of efficiency of exhaust heat transfer to the exchanger and by an increase of heat transfer by convection thanks to a higher amount of steam in exhaust gases.

By basing on the conducted investigations it can be stated that a safe amount of hydrogen that can be added to natural gas to ensure safe and effective combustion of the mixture in domestic and commercial gas appliances, without need of alteration in their construction, is 15%.

This paper was written on the basis of the statutory work entitled: *An analysis of the effects of hydrogen addition to natural gas on the work of gas appliances* – the work of the Oil and Gas Institute – National Research Institute was commissioned by the Ministry of Science and Higher Education; order number: 0061/GU/18, archive number: DK-4100-61/18.

Literature

Ciechanowska M., 2014. Polityka energetyczna Polski do 2050 roku. *Nafta-Gaz*, 11: 839–842.

Łach M., 2016. Dokładność wyznaczania współczynnika ściśliwości gazu z podwyższoną zawartością wodoru – porównanie metod obliczeniowych. *Nafta-Gaz*, 5: 329–338. DOI: 10.18668/NG.2016.05.04.

Piskowska-Wasiak J., 2017. Doświadczenia i perspektywy procesu *Power to Gas*. *Nafta-Gaz*, 8: 597–604. DOI: 10.18668/NG.2017.08.07.

INiG – PIB's own data.

Legal and normative acts

PN-EN 30-1-1 + A3:2013 Domestic cooking appliances burning gas – Part 1-1: Safety – General.

PN-EN 30-2-1:2015 Domestic cooking appliances burning gas – Part 2-1: Rational use of energy– General.

PN-EN 203-1:2014 Gas heated catering equipment – Part 1: General safety rules.

PN-EN 203-2-1:2015 Gas heated catering equipment – Part 2-1: Specific requirements – Open burners and wok burners.

PN-EN 613:2002 Independent gas-fired convection heaters.

PN-EN 1020:2010 Non-domestic forced convection gas-fired air heaters for space heating not exceeding a net heat input of 300 kW incorporating a fan to assist transportation of combustion air or combustion products.

PN-EN 419-1:2012 Non-domestic gas-fired overhead luminous radiant heaters – Part 1: Safety.

PN-EN 437 + A1:2012 Test gases – Test pressures – Appliance categories.

The decree of the Minister of Economy of July 2, 2010 on the detailed conditions of the gas system operation (Journal of Laws of 2010, No 133 item 891, single text).

Robert WOJTOWICZ M.Sc. Eng.
Head of the Fuels Usage Department
Oil and Gas Institute – National Research Institute
25 A Lubicz St.
31-503 Krakow
E-mail: *robert.wojtowicz@inig.pl*