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QUALITY EVALUATION OF BIOGAS AND SELECTED METHODS OF ITS ANALYSIS

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Abstract: There were presented technological and ecological aspects of biogas quality evaluation and introduced an overview of the limits of its selected parameters. There were characterized analytical methods for determining the basic composition of biogas, hydrogen sulfide, ammonia, condensation, dust, oils, siloxanes, and aggregated content of sulfur, chlorine and fluorine. The result of comparative analysis and literature studies are proposes of the most adequate to the studies of biogas - analytical methodologies.

Keywords: biogas composition, risks, requirements, analysis

The expected rapid development of renewable power engineering, including biogas-bases (closely related, *inter alia*, to the growing danger of greenhouse effect), requires progress in the standardization of method to assess its quality. Reliable analysis of biogas is a necessary condition for proper control of its border parameters and required - due to technical and environmental aspects - conditioning level.

Biogas is a mixture of gases generating during anaerobic digestion of organic substances, with the participation of methane bacteria, known as the methane fermentation. This term means a group of anaerobic biochemical processes in which macromolecular organic substances (carbohydrates, proteins and fats) are decomposed into alcohols and lower organic acids, and then to methane, carbon dioxide and water [1].

To the primary anthropogenic sources of production possible for the utilization of gas belong: municipal landfills, sewage plants and more specifically - the process of anaerobic stabilization of sewage sludge, and farm biogas plants, fed by animal manure and waste from the agri-food industry.

Dry biogas comprises primarily methane (52÷85%) and carbon dioxide (14÷48%) as well as nitrogen, hydrogen, oxygen, hydrogen sulfide, ammonia and hydrocarbons

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(C_2-C_7) [2]. There may be present in it also traces of organic compounds of sulfur, chlorine, fluorine and silicon as well as aerosol pollution [3, 4]. The composition of the specific biogas depends heavily on the substratum used and parameters of technological process.

Among the organic sulfur compounds in biogas there are detected: mercaptans, thioethers, thiophene and thiophene derivatives, sulphide and carbon oxysulphide, carbon disulfide, dimethyl sulfide, methylamine, trimethylamine, et al. The primary source of their origin is the decomposition of vegetable substances. However, a representative of inorganic sulfur compounds present in the biogas is hydrogen sulfide, which is mainly formed in the process of biochemical, anaerobic decomposition of proteins.

The source of halogen compounds in the biogas may be contaminants in the wastewater (eg chemicals used for water treatment and effluent treatment) and solid wastes (PCV, some types of biomass). Examples of compounds of chlorine and fluorine detected in the biogas are: chloroethane, dichlorofluoromethane, trichlorofluoromethane, chlorotrifluoromethane, trichloroethane, tetrachloroethane, trichloroethane, dichloromethane, dichloroethane, dichloroethene, dichloropropan, carbon tetrachloride et al [4].

Sources of siloxanes may be detergents, personal hygiene agents, antifoaming agents et al. Used or wasted siloxanes go to sewage farm and landfills, where as a result of higher temperature and decomposition of organic matter, on which they were absorbed, they are released into biogas [5].

Technological and ecological premises for assessing the quality of biogas

Technological risks

The most technologically troublesome components of biogas are compounds of: sulfur, chlorine and fluorine. Combustion products of these compounds (SO_2, SO_3, HCl, HF) have an aggressive effect on equipment and fittings. Corrosive effect is also shown by hydrogen sulfide. In addition, it can - as the result of reaction with iron, leading to formation of self-igniting iron sulfide - increase the risk of fire and explosion. Combustion of biogas, containing compounds of sulfur and chlorine in gas engines, reduces the quality of motor oils and catalytic activity. Serious risk to the engines are also the siloxanes and their derivatives. These are highly volatile substances, sparingly soluble in water, of linear or cyclic structure, containing Si-O bonding as well as methyl or ethyl groups. During combustion, they are converted into hard, colmatating, abrasive material (SiO_2) forming deposits on the inner walls of the gas motors, boilers and catalytic converters, what is more - they aggravate lubricating properties of motor oils [5]. The effect of these interactions is decrease of availability of equipment and increase of their maintenance costs.

Difficulties in the operation of installation of transmission and utilization of biogas can also be caused by: condensate (both - aqueous and hydrocarbon), dust, oils and foam entrained from the septic tank. Excessive presence of these substances can cause blocking of gas pipelines, pressure pulses in the system, burners clogging, et al.

Technological risks must also include the problem of explosion of biogas. The risk of autoignition and explosion concerns mainly the poorly insulated and poorly operated municipal waste landfills, which can claim to dilute the biogas by oxygen infiltrating from the air. In a properly sealed and outgassed landfills the methane concentration is usually significantly above the explosive limit. In addition to methane, a potential risk in this respect is also posed by other gases present in the biogas (Table 1). In the case of the underground migration of biogas, the risk of explosion can also occur in the surrounding buildings.

Table 1

Explosive properties of selected components of biogas [6]

Component of biogas	**Lower threshold of explosion [% vol.]**	**Upper threshold of explosion [% vol.]**	**Autoignition temperature [K]**
Methane	4.9	15.4	810
Acetone	2.1	13.0	808
Ammonia	15.0	28.0	903
Hydrogen sulfide	4.3	45.5	563
Carbon monoxide	12.5	75.0	1078
Hydrogen	4.0	75.0	833

Environmental risks

Uncontrolled emission of biogas, in addition to breathing problems caused by its two main components - methane and carbon dioxide (which do not show toxic effects, but can displace oxygen), can cause serious health problems of local residents. Among the tracers detected in the biogas, the most dangerous in terms of toxicology include cyclic hydrocarbons and their derivatives, especially chlorinated hydrocarbons, which are among substances well-absorbed by air passages. Some of them are attached by a carcinogenic effect. Toxic effects are also manifested by some aliphatic hydrocarbons (eg acetone). Among the inorganic substances, the greatest danger is posed by: hydrogen sulfide, carbon monoxide and ammonia.

As a result of combustion of biogas, elements released into atmosphere include, *inter alia*: sulfur oxides, nitrogen and carbon, hydrogen chloride, hydrogen fluoride and hydrocarbons. Combustion of biogas containing chlorine, under adverse conditions, can also cause the emission of dioxins and furans [7].

Biogas is also disruptive to the environment due to its reek-acting character. The main odorants present in the biogas, in addition to ammonia, hydrogen sulfide, mercaptans and other organic sulfur connections include hydrocarbons (including: ethylene, toluene, benzene, xylene, napthalene), organochlorine compounds (methylene chloride, chloroethans, chloroethylenes, vinyl chloride, chlorobenzene, chlorotoluene), phenols, et al. The smell of biogas is the most onerous in the early stages of decomposition of organic compounds. An effective method of eliminating odor is burning biogas. Odor can be also eliminated by chemical methods. In order to full oxidation of odors the process should be conducted at the temperature of above 1000^{o}C (also because of potential risk of generating dioxins).

The quality of biogas - requirements

In connection with the above-mentioned risks, biogas needs to be cleaned, especially from the elements such as: S, Cl and F. Their content is limited by the equipment manufacturers for the utilization of biogas and sometimes also by government regulations and standards. The requirements and recommendations in this regard are different in various countries. For example, according to German requirement the content of hydrogen suliide in inflammable gases is 5 mg/m^3, while according to Polish and Hungarian regulations it is 20 mg/m^3 [8]. In the case of biogas the manufacturers of equipment such as: gas engines for power generators, boilers, catalyst container, heat exchangers, usually recommend higher values of H_2S as a border. For example, a manufacturer of generators [9] recommends to not exceed the level of 200 mg H_2S/m^3 before activated carbon adsorber and at the inlet to the engine generator it proposes total allowable content of total sulfur for level of 700 mg H_2S/10 kWh (200 mg H_2S/10 kWh for system equipped with a catalytic converter). According to Polish requirements, total sulfur in combustible gases should not exceed 40 mg/m^3, in accordance to Hungarian standards - 100 mg/m^3 and German - 120 mg/m^3 [8]. In turn, Heinze et al [10] recommend that the aggregate limit of sulfur content in the biogas was 2200 mg CH_4/m^3. The same source shows the limits values of halides in biogas at the level, respectively: compounds of Cl - 100 mg CH_4/m^3, compounds of F - 50 mg CH_4/m^3, halides in total (CI+F) - 100 mg CH_4/m^3. However, Chvatal [8] sets limit concentration of halides (as the sum of Cl in total and doubled sum of F in total) at the level of 100 mg/m^3 before absorber and at the inlet of the engine - 100 mg/10 kWh (20 mg/10 kWh for the system equipped with a catalytic converter).

Evaluation of the total content of organic silicon compounds in the biogas is made mostly on the basis of an analysis of set of components shown in Table 2.

Table 2

Organic silicon compounds potentially present in the biogas, and their physical properties [9, 11-17]

Organic silicon compound	**Abbrevia-tion**	**Aggregate formula**	**Vapour pressure at 25°C [kPa]**	**Boiling temperature [°C]**	**Water solubility at 25°C [mg/dm^3]**
Hexamethyldisiloxane	L2	$C_6H_{18}Si_2O$	4.12÷5.62	100÷107	0.93
Heksamethylocyklotrisiloksan	D3	$C_6H_{18}O_3Si_3$	1.14÷1.83	134÷135	1.56
Octamethylotrisiloxane	L3	$C_8H_{24}Si_3O_2$	0.52	153	0.035
Octamethylcyclotetrasiloxane	D4	$C_8H_{24}O_4Si_4$	0.13÷0.17	176	0.056
Decamethyltetrasiloxane	L4	$C_{10}H_{30}Si_4O_3$	0.073	194	0.0067
Decamethylcyklopentasiloxane	D5	$C_{10}H_{30}O_5Si_5$	0.02÷0.05	211	0.017
Dodecaetylopentasiloxane	L5	$C_{12}H_{36}Si_5O_4$	0.009	230÷232	0.0003
Dodekamethylcykloheksasiloxane	D6	$C_{12}H_{36}O_6Si_6$	0.003÷0.004	245	0.005
Trimethylsilanol	MOH	$(CH_3)_3SiOH$	2.13	70÷99	35000÷42600
Tetramethylosilan	TMS	$Si(CH_3)_4$	95.06	26÷28	20

Data about the limit content of siloxanes in the literature are divergent. For example, manufacturers of gas engines, for supply of biogas, recommend limiting content of siloxanes at the level of 10÷50 mg/m^3 [16, 18]. In turn, Deublein and Sterinhauser [19] recommend the limit concentration of siloxanes at the level of 0.2 mg/m^3 in the biogas designed for heating and energy systems. Chvatala [9], due to the lack of standardized procedures of determining siloxanes in the biogas, suggests their indirect control by periodic measurements of silicon compounds in motor oil.

Other restrictions on selected indicators of biogas were collected in Table 3.

Table 3

Selected indicators of quality of biogas used for the combustion in gas motors of generators [9, 18]

Parameter	Unit	Value
Maximum temperature	[K]	313÷333
Maximum relative humidity • at the inlet of the engine • at the inlet of the activated carbon adsorber	[%]	80 50
Dust • maximum granulation • maximum concentration	[μm] [mg/m^3]	0.3÷10 10÷50
Condensate	-	0
Maximum content ammonia	[mg/10kWh] [a)] [mg/m^3] [mg CH$_4$/m^3]	50 105 55
Maximum content of oil	[mg CH$_4$/m^3]	5÷45

a) the concentration based on the amount of energy contained in the gas:

$$S[\mathrm{mg/10kWh}] = \frac{10 \cdot 3600 \cdot S[\mathrm{mg/m^3}]}{W_d[\mathrm{kJ/m^3}]}$$

where: S - concentration, W_d - calorific value of biogas. Concentration in $\mathrm{mg/m_n^3}$ concern at standard conditions, ie 273 K, 101.3 kPa and dry gas.

The method of sampling and analytical methods used in assessing the quality of biogas

Basic parameters of the biogas used to assess its quality

The most important trade parameter of biogas as fuel is the content of methane and the associated energy parameters, ie calorific value, combustion heat, and Wobbe index. From a technical point of view the important thing is the content of corrosive components (oxygen, water, carbon dioxide, hydrogen sulfide and other sulfur compounds as well as chlorine and fluorine compounds) and substances that can cause operational difficulties (ie condensate, dust, oils, siloxanes). Energy parameters of biogas can be determined according to standards developed for natural gas PN-EN ISO 13686 from 2005 and PN-EN ISO 6976 from 2008.

Collection of sample from gas pipeline to biogas transport

Collection of the sample must ensure its representativeness, ie cannot cause change in the properties or its composition (eg due to condensation of the components of biogas or dilution as a result of leakage of the measurement system). Collection point should guarantee the complete mixing and stability of the biogas in terms of temperature and pressure. It may not be near so-called dead spaces in pipeworks or in areas of condensate collection. In order to avoid the parietal effects, intake of condensate and blocking of spouts, samples should be charged by probe from the interior of pipework, on its vertical segment. The representativeness of the sample is also affected by the way of collection. Elements of measurement system for the collection should be blew through initially by charged gas and keep warm to a temperature higher than the dew point of biogas. In the case of pulsating flow, the pressure in the system for the collection should equalize and stabilize these pulses (eg by using buffer tanks). Apparatus connected to the pipeworks must withstand the prevailing pressure (usually 1÷15 kPa). In order to reduce the pressure we can use for example - regulated vents.

The aforementioned factors cause the fact that the correct input has often critical importance for meaningful results of later analysis. The most serious difficulties are associated with high relative humidity of gas (close to 100%) and its chemical composition. Some components of biogas, such as H_2S, NH_3, can react with each other as well as with other components of biogas and dissolve in the condensate. They require, therefore, the analysis as soon as possible, preferably "*in situ*".

To the insulating charge, depending on type of substance to be determined, there is used a previously calibrated glass receivers (pipettes), poly or Teflonbags of Tedlar type, containers of acid-proof steel. For the "*in situ*" measurement there are used absorbent canisters with properly chosen sorbent or absorption scrubbers filled with the absorbing liquid or there is performed a direct determination using portable analyzers.

Determination of the basic composition of biogas

The composition of CH_4, CO_2, O_2, H_2, N_2 and hydrocarbons can be designed by chromatography in accordance with PN-EN ISO 6974, 2006 or using portable gas analyzers.

Gas chromatography, using a measuring system consisting of at least two columns, is one of the most accurate and specific method for designing the composition of biogas. One of the column is used to stop the higher hydrocarbons from *n*-pentane, washed out as a composite peak of C_{6+}. Second, in turn is applied to the determination of: nitrogen, carbon dioxide, methane and lower hydrocarbons to *n*-pentane. This technique is useful for determination of helium, hydrogen and oxygen. This is one of the few analytical methods to ensure the implementation of qualitative and quantitative analysis in a single process for complex substances in the form of gases or vapors. This method is often used in combination with mass spectrometry, which further increases the accuracy of the identification of components of the examined mixtures. It is suitable for testing of gases containing components, whose mole fractions are within the ranges given in Table 4.

Table 4

Ranges of mole fractions at which you can use a method (PN-EN ISO 6974 from 2006)

Component of the analyzed gas	Mole fraction range [%]
nitrogen	0.001÷15.0
carbon dioxide	0.001÷35.0
methane	40.0÷100.0
ethane	0.001÷10.0
propane	0.001÷3.0
iso-butane (2-methylopropane)	0.001÷1.0
n-butane	0.001÷1.0
neo-pentane (2,2-dimetylopropane)	0.001÷0.5
iso-pentane (2-metylobutane)	0.001÷0.5
n-pentane	0.001÷0.5
hexane isomers + sum of all C_6 and higher hydrocarbons	0.001÷0.2

In the mole fractions ranges we can achieve the following precision of measuring results - repeatability (0.001%) and reproducibility (0.002%). The method can also be used when there is not found to be one or few components of the sample. The method is not applicable to the analysis of gases containing hydrocarbon condensate.

The obtained results of determinations are used to calculate the calorific value, relative density and Wobbe index. The method is applicable to the determinations made using the process or laboratory chromatographs. The components of biogas (carbon dioxide, methane, propane, butane and pentane isomers) are marked with the use of *Thermo-Conductive detector* (TCD), while the determination of sum of hydrocarbons from C6 to C8 additionally requires the presence of the *Flame-Ionization detector* (FID).

Comparison of conditions for gas composition analysis by gas chromatography method according to the PN-EN ISO 6974, 2006 is summarized in Table 5.

Table 5

Conditions for gas analysis according to PN-EN ISO 6974 from 2006

Designed component of gas	**PN-EN ISO 6974-3**	**PN-EN ISO 6974-4**	**PN-EN ISO 6974-5**	**PN-EN ISO 6974-6**
helium; hydrogen; oxygen	×			×
nitrogen; carbon dioxide	×	×	×	×
methane; propane, butane and pentane isomers	×	×	×	×
hexane isomers and higher alkanes		×	×	
sum of C6, C7, C8	×			×
Conditions of chromatographic analysis				
Number of columns	2 (packed columns)	2	3	3 (capillary columns)
Temperature of column	a) 35÷200ºC at 15ºC/min b) 30÷250ºC at 30ºC/min	isothermal conditions	isothermal conditions	a) 30÷120ºC at 12ºC/min b) 35÷240ºC at 8ºC/min
Carrier gas	a) helium b) argon	helium	helium	a) argon b) nitrogen
Detectors	a) TCD and FID b) TCD	TCD	TCD	a) TCD and FID b) FID
Columns switching	no	yes	no	yes
Duration of analysis phase	a) 44 minutes b) 24 minutes	≤ 20 minutes	7÷12 minutes	a) 43 minutes b) 40 minutes
Duration of analytical cycle	60 minutes	≤ 20 minutes	7÷12 minutes	55 minutes

Determinations a) and b) given in the Table 5 refer to the separate stages of the analytical method. The way of performing the determinations includes an analysis of the working reference gas mixture (modules) and sample of tested gas. Subsequently, we directly determine: nitrogen, carbon dioxide, methane, ethane, propane, butane and pentane isomers, using appointed chromatograms.

In addition to the laboratory or process measuring systems (stationary or mobile) there are also available portable analyzers for the determination of the gaseous components by method of absorption in the infrared (NDIR - *non-dispersive infrared absorbance*) - for example CH_4 and CO_2, galvanic cells (O_2) and electrochemical sensors (H_2S). The analyzers can be equipped with FID detector, enabling measurement of VOCs (volatile organic compounds).

Determination of the condensate, dust and oils

From the operational point of view, an important parameter for biogas is water vapor content and the associated water dew point temperature. One of the method used for determining the water content in field conditions is the Karl Fischer method according to PN-EN ISO 10101 from 1997. Another methodology in this area is proposed by published in Poland in 2004, PN-EN ISO 11541 - “Natural Gas. Determination of water under high pressure”. A useful rule may also be PN-EN ISO 18453 “Natural gas. Correlation between water content and water dew point temperature” of 2007.

Measurement of the amount of hydrocarbon liquid, which may condensate from gas at specified conditions of temperature and pressure, can be made according to PN-EN ISO 6570 from 2006 - “Natural gas. Determination of potential hydrocarbon liquid. Gravimetric methods”.

The concentration of dust may be determined by particular gravimetric method, maintaining isocinetictivity of sample collection and its fraction composition - by the microscopic method, after sampling, as above on filters of Synpor type, limpidity using cyclohexanone and calculating the number of grains in the various fractions under the microscope.

For the determination of concentrations of oil there may be applied the gravimetric method using Soxhlet extraction.

Determination of hydrogen sulfide and ammonia

For the determination of H_2S and NH_3 there can be used well-known, highly specified manual spectrophotometric and coulometric methods as well as portable gas analyzers, enabling their fast and accurate analysis. Offered analyzers operate on the basis of different technological solutions. The contents of H_2S and NH_3 are usually measured by electrochemical cells. Commercially available - multi-channel analyzers - allow the simultaneous measurement of other gases, such as: O_2, CO and HCN. Electrochemical sensor H_2S allows to use it to measure across a wide range of concentrations (0÷9999 ppm). The disadvantage of this type of sensors for measuring the composition of gas mixtures is the possibility of interferences of measuring as a result of so-called - cross-dependencies. From this perspective, it is preferable to make a use of NDIR sensors.

Determination of organic sulfur compounds, chlorine and fluorine

Organic compounds of sulfur, chlorine and fluorine can be determined in biogas using gas chromatography or sorption-titration methods. In the case of chromatography there are use the following types of detection: alkali-flame-ionization, flame-photometric and electrochemical. However, in the case of application of sorption liquid there are used methods with precipitation titration (potentiometric, conductometric and coulometric), calorimetric, iodometric, polarographic and other methods.

During combustion of biogas, the above-mentioned compounds are oxidized, hence more important than knowledge of the individual components (whose designation made due to the quantity and variety is not practically possible) is the information on the content of their sum.

For determination of total sulfur in the biogas we can use the methods of hydrogenation or catalytic reduction of sulfur compounds and the determination of resulting H_2S as well as the method of oxidation of sulfur compounds and determination of resulting SO_2. For determination of sulfur dioxide we can use the turbidimetric, nephelometric, conductometric, coulometric, colorimetric methods as well as method of absorption spectrophotometry method.

The total content of chlorine and fluorine in the biogas can be determined by their oxidation and the resultant determination of hydrogen chlorine and hydrogen fluoride. For the determination of HCl and HF, the products of combustion of biogas can be absorbed in deionized water and then can be analyzed due to the content of Cl^- and F^- ions, using the ion chromatograph with conductometric detector and anion column [1].

Determination of siloxanes

Both, the collection of samples and analysis of siloxanes in biogas mixture face many problems primarily related to the chemical instability of these compounds (in particular D3 and TMS [11]), diversification of their physical properties, small concentration and high humidity of biogas. Since now, there has not been developed widely accepted, standardized methodology for measuring their concentrations [9, 11, 12].

Previous attempts of collecting samples for siloxanes determination was based on the use of containers made of acid-proof steel, flexible plastic bags (including coated on the insight with a layer of aluminum) and adsorbents (activated carbon, silica gel, molecular sieves, porous polymers, ion exchange resins) or organic absorbents (methanol, *n*-hexane, dodecane, hydrocarbon oils, et al). Review and analysis of methods of collection of siloxanes are shown in [3, 11, 12, 14, 20].

It seems that the method having a minimum of defects is the use of silica gel (also dries biogas), molecular sieves and polymer sorbents. The disadvantage of activated carbon as adsorbent of siloxanes and their derivatives is their hindered desorption from this material (use for the purification of biogas, it is not subjected to regeneration). Its use is also problematic because of the high humidity of biogas. In all cases there is a risk of loss due to adsorption and condensation on the walls of the equipment used for collection (especially glass) and the possibility of incomplete adsorption or absorption in the case of sorbents.

Identification and quantification of individual siloxanes is carried out by *gas chromatography* method (GC) with FID and FPD detectors. There is also used the method of GC-MS (*gas chromatography with mass spectrometry*) [20]. However, the aggregate content of siloxane absorbed in organic liquids is determined by *atomic absorption spectroscopy* (AAS).

Summary

Among the presented analytical methods for evaluating the quality of biogas, the one that deserves special attention is the gas chromatography, which enables fast and accurate analysis of complex substances present in the form of gases or vapours. For periodic measurements, with which we deal mostly in case of biogas installation, especially useful are portable devices, currently present on the market, for example: portable gas chromatograph with dual detectors (PID - *photo-ionizing* as well as ECD - *electron capture*) ensuring fast and accurate "*in-situ*" analysis of volatile organic substances contained in the biogas. An interesting and practical solution is also using portable analyzers for the measurement of CH_4, CO_2, H_2S, O_2 and NH_3, especially those whose principle of determination is based on the phenomenon of absorption of infrared radiation.

For the determination of sulfur, chlorine and fluorine in biogas, the most advantageous seems to be method including the sum content of these compounds, based on flameless combustion of biogas in the air and then on spectrophotometric and chromatographical analysis of combustion products [21]. It has no disadvantages typical for well-known methods of Lingener and Wickbold, based on combustion and is selective in relation to other compounds present in biogas. The authors [21] introduced the installation based on this method, which is characterized, among others, by: no need to use hydrogen and oxygen (which appeared in Wickbold method), thus providing a safer operating conditions. Moreover, the control of the process is also easier, thanks to automatically controlled combustion temperature.

In the case of condensates, dust and oils as well as physical parameters (eg moisture content, density and energy parameters) we can use a standard, normalized methodologies for natural gases or for waste gases.

The greatest difficulty is the determination of organic silicon compounds, so-called siloxanes. In particular, hitherto used methods of collecting samples in this area require further research.

In the era of the fight against climate warming and the rapid development of renewable energy sources, which include biogas, methods for assessing its quality require further progress and comprehensive standardization.

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OCENA JAKOŚCI BIOGAZU ORAZ WYBRANE METODY JEGO ANALIZY

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Abstrakt: Przedstawiono technologiczne i ekologiczne aspekty oceny jakości biogazu oraz zaprezentowano przegląd granicznych wartości jego wybranych parametrów. Scharakteryzowano metody analityczne oznaczania składu podstawowego biogazu, siarkowodoru, amoniaku, kondensatu, pyłów, olejów, siloksanów oraz sumarycznych zawartości związków siarki, chloru i fluoru. Efektem przeprowadzonych analiz porównawczych i badań literaturowych są propozycje metodyk analitycznych najbardziej adekwatnych do badań biogazu.

Słowa kluczowe: skład biogazu, zagrożenia, wymagania, oznaczanie