ARCHIVES OF ENVIRONMENTAL PROTECTION

vol. 39 no. 4 pp. 71 - 80 2013

VERSITA

PL ISSN 2083-4772
DOI: 10.2478/aep-2013-0031

ENVIRONEMENTAL IMPACT OF STRAW BASED FUEL COMBUSTION

MONIKA CZOP*, MAŁGORZATA KAJDA-SZCZEŚNIAK

Technical University of Silesia
Faculty of Energy and Environmental Engineering
Department of Technology and Installations for Waste Management
Konarskiego 18, 44-100 Gliwice
*Corresponding author's e-mail: monika.czop@polsl.pl

Keywords: Formed fuel, biomass, thermal processes, emission of gas pollutions, ashes, heavy metals.

Abstract: Biomass is commonly considered as a renewable fuel, which taking into account emission of CO_2 does not contribute to the emission of the greenhouse gases.

In the research, combustion tests of two types of fuel formed on the basis of straw with addition of polyethylene were performed in the laboratory. The article presents results of measurements of gas pollution coming from the combustion of the formed fuel. Obtained results were compared with similar literature data for the combustion of coal. The research covers also testing of chemical content, content of heavy metals and selected physical properties of ashes generated during the process of burning fuel based on straw.

INTRODUCTION

One of the basic features of the energetic development of each country is the best possible use of the sources of energy. Nowadays, in industrialized countries the energy is respected and used in a rational way with the wide help of renewable sources of energy. A principle in energetic policy of member countries of the European Union is limiting emission of greenhouse gases. One of the highly promoted solutions in the European Union is gradual replacement of fossil fuels with biomass [4, 5, 6, 7, 15, 18].

All the methods of transforming fuels into energy have advantages and disadvantages, both in respect of influence on the health and safety of people and effect on the environment. One may say that certainly at the moment there is no method of energy production that would not carry any risks whatsoever [16, 21, 22].

The most common and the simplest method of acquiring energy from the biomass is its burning or combustion with coal. Each process of fuel burning, including biomass, is a basic source of atmospheric contamination with gas and solid combustion products. Most of the components of combustion gases can be considered as contaminative to natural environment [4, 5, 6, 10, 15, 21].

It is assumed nowadays that adding biomass, such as for example straw to the coal would decrease emission of sulfur dioxide and nitrogen oxide, which are responsible for the phenomenon of the so called acid rains, and for organic pollutants including polycyclic aromatic hydrocarbons. Moreover, calcium compounds found in the biomass can become a natural sorbent for the sulfur dioxide emitted during coal combustion [4, 5, 24].

Straw is a by-product of agricultural production. In the past couple of years in Poland its production has amounted to average 29 millions of Mg. An advantage of straw over the coal is a zero emission of CO_2. During straw combustion the amount of CO_2 emitted to the atmosphere equals its assimilation by plants in the following year of vegetation [4, 5, 6, 21, 22].

Combustion of fuels gives solid products such as ash or slag, called combustion wastes. The amount of these wastes depends on the amount of fuel used, its quality (content of ashes), type and construction of furnace as well as efficiency of the dedusting system [18, 23].

From the energetic point of view, chemical content of ash from the biomass is of big importance, since a high content of strong alkali and aggressive chorine may cause corrosion to the energetic devices and fouling on heating surfaces [1, 2, 4, 5].

The performed tests allowed to preliminarily determine probable contaminations which could possibly be created during combustion of fuel made of straw with additive of low density polyethylene.

TESTING METHODOLOGY

The tests focused on the energetic use of fuels covered two types of the formed fuels [9]:

- Fuel based on oat straw with shredded polyethylene (PE-LD) (both components reduced to the size of maximum 15 mm – Fig. 1A),
- Fuel based on oat straw with plain polyethylene (PE-LD) (only oat straw reduced to the size of maximum 15 mm, polyethylene formed an external envelope around the straw in the form of briquette – Fig. 1B).

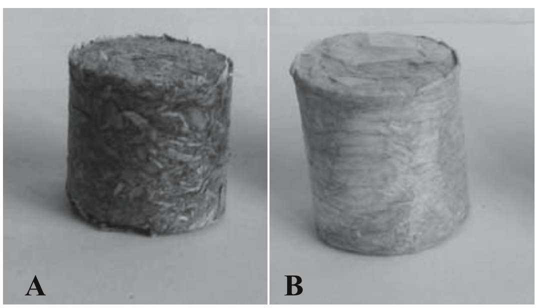

Fig. 1. Fuel based on oat straw with polyethylene: A – shredded, B – plain (photograph by M. Kajda-Szcześniak)

The fuel prepared in laboratory conditions is produced from dry, crushed straw by compression under pressure with low density polyethylene added as a binder. Low density polyethylene was selected due to the fact that this is a waste from the polyolefin group most often found in the stream of municipal wastes.

Another argument for the preparation of installations to process this type of waste can be based on the fact that according to the order of the Minister of Economy and Labour dated 7 September 2005 on criteria and procedures for allowing storage of wastes on landfills of a given type (Journal of Laws no. 186 item 1553 with amendments) starting from 1 January 2013 it will not be possible to dispose of municipal wastes which exceed: total organic carbon (TOC) over 5%, loss at ignition over 8%, heat of combustion over 6MJ/kg.

Percentage participation of polyethylene in fuel has been selected on the basis of experiment. Addition of 5% guarantees acquisition of durable form and shape of fuel.

Thermal transformation was tested in the laboratory post which consisted of electrical chamber furnace with gas retort, temperature register and automatic air supply system to the combustion chamber. The retort is equipped with air supply system and a tray which introduces fuel to the furnace. In order to enable air flow to the fuel, holes were drilled at the bottom of the tray of such diameter as to make pouring of input material difficult [9, 25].

For tests a sample of approximately 22 g was taken. Combustion process took place in the temperature of 800°C with permanent air flow of 15 dm^3/min. Moreover, the test rig was equipped with portable exhaust-gas analyser which enabled testing content of combustion gases (CO, SO_2, NO, CO_2, O_2) with sampling every ten seconds [9].

The diagram showing is presented in Fig. 2.

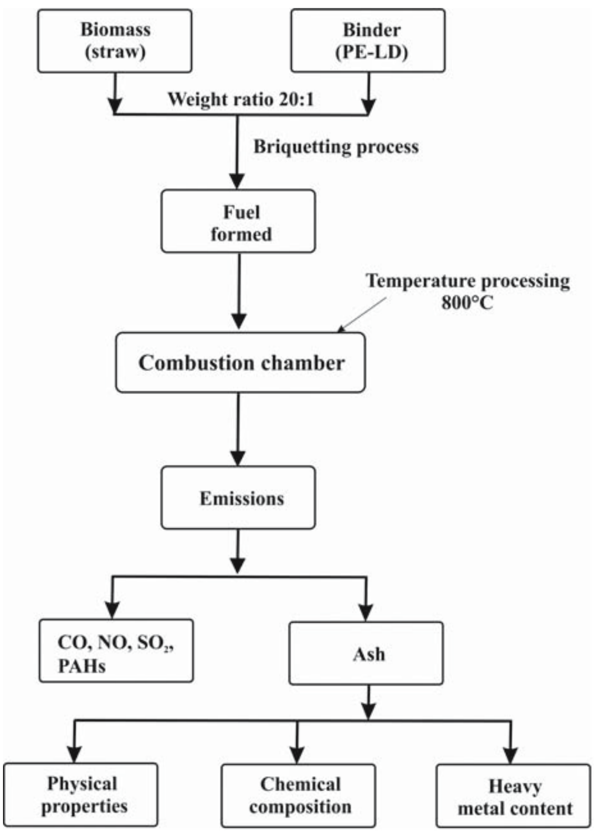

Fig. 2. Diagram of experiment (by M. Czop, M. Kajda-Szcześniak)

As a result of the combustion process, two types of ashes were obtained:

➢ ash 1 (ash from burning fuel based on oat straw with the admixture of shredded polyethylene, Fig. 3),

➢ ash 2 (ash from burning fuel based on oat straw with the admixture of plain polyethylene, Fig. 4).

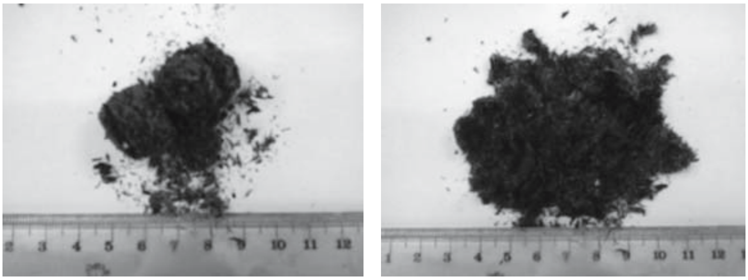

Fig. 3. Ash from burning fuel based on oat straw with the admixture of shredded polyethylene (by M. Czop)

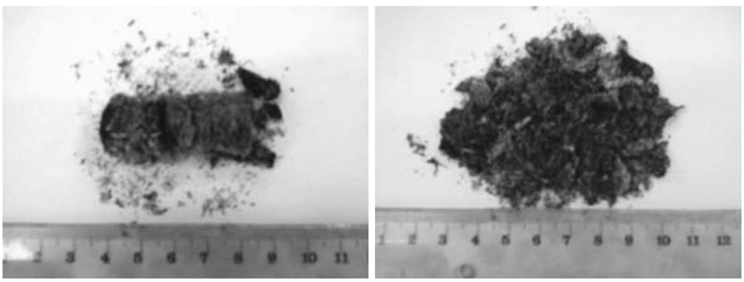

Fig. 4. Ash from burning fuel based on oat straw with the admixture of not shredded polyethylene (by M. Czop)

All the tests were performed in accordance with the valid standards [19, 20].

In the obtained ashes, the following parameters were marked: moisture content, the content of combustible and incombustible particles, analysis of ashes for basic chemical components (Ca, Mg, K, Na, SiO_2, Al) and the content of heavy metals (Zn, Pb, Cd, Cu, Ni, Co, Cr).

EMISSION OF POLLUTANTS

Emission of gas pollutants

Combustion of straw is not detrimental to the environment because, as mentioned before, there is no additional emission of CO_2. During combustion the amount of carbon dioxide emitted equals carbon dioxide assumed by plants during vegetation [26].

Carbon dioxide is a combustion product of all the natural fuels and is directly related to the content of carbon in fuels. Hard coal was selected for comparison due to the fact that the highest efficiency of use of biomass can be obtained in the co-burning technology. According to Energy Regulatory Office, co-burning technology may be effectively realized both in fluidized beds where technical problems boil down to maintaining proper input of bio-fuel to the furnace and in pulverized boilers and grate boilers [13].

The results presented in Table 1 are an arithmetic average of measurements performed with emissions analyzer LANCOM Series II which was connected to the laboratory furnace.

The combustion process was an atmospheric process with two zones: normal burning and afterburning. Total CO_2 and O_2 in normal burning zone for fuel based on straw (A) was approximately 19% and for fuel based on straw (B) was approximately 17% (Table 1).

Table 1. Values of emission of gas combustible products [9, 17]

Properties	Unit	Fuel on the basis of straw (A)	Fuel on the basis of straw (B)	Coal
CO_2	%	4.77	5.37	12.67
O_2	%	13.55	11.48	5.76
SO_2	mg/m^3_n	60.63	30.46	856–8563
NO_x	mg/m^3_n	336.10	370.87	535–1338

Total participation of CO_2 and O_2 in both zones of combustion for fuel based on straw (A) was 20.5% and for fuel based on straw (B) approximately 20%.

Emission of SO_2 results mainly from the presence of sulfur in the fuel. In the majority of cases, fuels contain sulfur in the form of organic and non-organic compounds. During the combustion process most of the sulfur content is formed as SO_2.

Nitrogen oxides are emitted mainly during combustion of fuels as nitrogen oxide (NO), nitrogen dioxide (NO_2) and dinitrogen monoxide (N_2O). The first two form a mixture known as NO_x.

Table 1 shows the results of the emission of gas pollutants created during combustion of fuels formed on the basis of oat straw with the admixture of polyethylene crushed (fuel A) and non crushed (fuel B). For comparison, emission during combustion of coal is presented.

Compared to coal, fuel obtained on the basis of straw is characterized by lower emission of SO_2, which amounts to (for fuel A) – 60.63 mg/m^3_n, and (for fuel B) – 30.46 mg/m^3_n respectively. Difference in emission of SO_2 between produced fuels may be caused by a form of introduction of low density polyethylene to the fuel.

The formed fuel in both cases shows lower emission of NO_x which amounts to less than 380 mg/m^3_n.

The emission of CO_2 during combustion of straw equals CO_2 assumed by the plant from the environment during its growth. An addition of a few percent of low density polyethylene does not have a major impact on the emission of carbon dioxide. The emission of CO_2 during combustion of the formed fuel is 2.5 times lower than the relevant emission during carbon combustion.

In respect of the values concerning emission of gas pollutions quoted in Table 1 it is suggested to implement combustion with biomass as a method of limiting emission of SO_2 and NO_x from combustion of coal [8, 11, 14, 26].

The analysis shows that the combustion of straw with the addition of polyethylene is advantageous from the ecological point of view because it limits the emission of CO, NO_x and SO_2.

Characteristics of ashes from burning formed fuel

Ashes created from burning fuel on the basis of straw with polyethylene added had light grey colour.

Tested ashes have moisture content from 0.89% for ashes from burning fuel based on oat straw with shredded polyethylene to 0.78% for ashes from burning fuel based on oat straw with added not shredded polyethylene (Table 2).

Table 2. Physicochemical properties of ashes from the combustion of biomass

Properties	Unit	Ash 1	Ash 2
Moisture content	%	0.89	0.78
Content of combustible elements [9]	%	12.55	12.68
Content of ash in an air-dry sample	%	87.45	87.32
Content of ash in dry sample	%	86.67	86.64
Loss at ignitron 500°C (LOI)	%	13.70	15.40

The content of combustible components in the ashes depends on the conditions of burning process and on the type of the furnace. In the ashes created as a result of burning in the laboratory furnace combustible components noted were on the same level, i.e. 12.55% for ash from the combustion of fuel based on straw with shredded PE_LD and 12.68% for the ash from burning fuel based on straw with the whole PE-LD.

High content of the loss at ignition (not combusted coal) of 15% in the analyzed ashes may cause higher request for water, which is a disadvantageous effect in case such ashes are used for the production of cement or concrete. To compare, loss at ignition in Polish fly ashes from the combustion of coal oscillate between 1 and 5%.

Within the framework of tests of the obtained ashes, an analysis of heavy metal content has been carried out. The content of heavy metals was determined in the Institute of Polish Academy of Sciences in Zabrze. The emission of heavy metals in the ashes arises from its presence in fuels. Most of the metals (As, Cd, Cu, Hg, Ni, Pb, Se, V, Zn) are emitted in the form of compounds such as oxides or chlorides, together with dust particles.

Analyses of heavy metals content showed relatively small differences between tested ashes.

The content of particular metals in the ash is distributed in the following series of values:

- ➢ for ashes from combustion of fuel on the basis of oat straw with an addition of shredded polyethylene Zn>Pb>Cu>Cr>Ni>Co>Cd,

➢ for ashes from combustion of fuel on the basis of oat straw with an addition of not shredded polyethylene Zn>Pb>Cr>Cu>Ni>Co>Cd (Table 3).

Table 3. Content of heavy metals in the ashes resulting from burning biomass and PE-LD [3]

	Zn	Pb	Cd	Cr	Cu	Ni	Co
	mg/kg						
Ash 1	454,0	71,0	2,5	63,0	67,0	43,0	9,0
Ash 2	570,0	308,0	2,1	75,0	46,0	11,0	5,0

In the analyzed ashes the mostly represented metal was zinc (from 570 to 454 mg/kg), and the least was cadmium (from 2.1 to 2.5 mg/kg).

The ash from the combustion of fuel on the basis of straw with added solid polyethylene had over four times more lead content (308 mg/kg s.m.) than the ash from the combustion of fuel on the basis of straw with added shredded polyethylene. Such a big difference in lead content in tested ashes could result from of low density polyethylene in the fuel. In the first case (ash 2) polyethylene was wrapped around briquettes which might have caused other reactions in the process of combustion. Differences in lean content in ashes should be tested depending on the method of introducing binder (PE-LD) to the fuel.

In the case of nickel the contingency was reversed. The ash from the combustion of fuel on the basis of straw with added shredded polyethylene contained four times more nickel (43 mg/kg s.m.) than the ash from the combustion of fuel on the basis of straw with the whole polyethylene.

Cadmium in the analyzed ashes was maintained at low level and did not exceed 2.5 mg/kg. Chromium in the tested ashes reached the values of approximately 75 mg/kg. However, the amount of copper in the ash from burning fuel based on the straw with decomposed polyethylene was 1.5 times higher than the copper in the ash from fuel with the whole polyethylene. The content of cobalt in the ash from fuel based on straw with shredded polyethyne was low and did not exceed 9 mg/kg, but it was about 2 times higher than cobalt in ashes from fuel with the polyethylene without size reduction.

The order of the Minister of Agriculture and Rural Development dated 21 December 2009 on realization of some provision Acts on manures and fertilizing process (Journal of Laws of 2009 no. 224 item 1804) specifies exactly what are the limits for the content of arsenic, cadmium, lead and mercury in mineral manures.

Out of the analyzed ashes, the ash from the combustion of fuel on the basis of straw with not shredded polyethylene shall be excluded from the use for manuring due to excessive amount of lead. However, the ash from the combustion of fuel based on the straw with the admixture of shredded polyethylene can be provisionally used for manuring, as the amount of cadmium and lead does not exceed the limits specified in the order.

Proportions between alkaline components (Fe_2O_3, CaO, MgO, Na_2O, K_2O i P_2O_5) and acid components (SiO_2, Al_2O_3 i TiO_2) included in the ash from the biomass indicate that the ash tends to form sediments (Table 4). Analyses of test results reveal minor differences in the composition of chemical elements of ashes.

Table 4. Composition of chemical elements in the obtained ashes

Properties	Unit	Ash 1	Ash 2	Coal ash [1, 2, 12, 14]
CaO	%	6.54	4.40	2.66
MgO	%	1.25	1.06	2.76
K_2O	%	19.60	10.30	2.98
Na_2O	%	0.14	0.12	0.7–3.8
SiO_2	%	38.80	54.10	50.82
Al_2O_3	%	0.96	0.94	28.64
Fe_2O_3, SO_3, TiO_2, P_2O_5 and other	%	32,71	29,08	–

Percentage of SiO_2 and Al_2O_3, i.e. oxides which limit unfavourable properties of forming sediments on heating devices amounts to 39.76% for burning fuel formed on the basis of oat straw with shredded polyethylene and 55.04% for burning fuel formed on the basis of oat straw with not shredded polyethylene, respectively.

On the other hand, the content of alkaline oxides in the ashes from biomass with addition of polyethylene amounts to 4.40–6.54% CaO, and 10.30–19.60% K_2O. Difference in the content of K_2O and SiO_2 between tested ashes may result from the form of polyethylene in the fuel. Ash from combustion of fuel where low density polyethylene was not decomposed showed two times lower content of K_2O and 1.5 times higher content of SiO_2 than the ash from combustion of fuel with not decomposed polyethylene. Such a difference may be the effect of complexity of chemical process of fuel combustion.

In the ashes from combustion carbon mainly compounds of SiO_2, and Al_2O_3 [1, 2, 12] are present.

High content of low melting oxides of alkaline metals in ashes from fuel based on straw and polyethylene may decreases melting temperature. Low melting temperature of ash in the burning process may unfortunately result in contamination of heating surface, grill in the furnace and forming excessive amounts of slag. These factors may lead to the creation of slags in the boiler.

SUMMARY

On the basis of the presented results the following conclusions can be formulated:

- use in the process of fuel production components of plants and plastic wastes from the polyolefin group has a great impact on the reduction of the stream of generated municipal and agricultural wastes,
- fuel formed on the basis of oat straw and low density polyethylene is characterized by significantly lower emission of SO_2 and NO_x than hard coal,
- ashes created from burning fuels based on straw and low density polyethylene do not contain detrimental substances, which would make their further economic reuse impossible, for example in civil engineer, road construction or mining,

- ➢ ashes from the combustion of fuel based on straw and shredded PE-LD may be used for manuring,
- ➢ ash from combustion of fuel based on oat straw and decomposed PE-LD may be preliminarily qualified for use as manure. However, further tests should be performed to confirm this.

REFERENCES

[1] Białowiec, A., Janczukowicz, W., & Krzemieniewski, M. (2009). Możliwości zagospodarowania popiołów po termicznym unieszkodliwianiu osadów ściekowych w aspekcie regulacji prawnych (Possibilities to use ashes after thermal neutralization of sediments in the light of legal regulations) *Środkowo-Pomorskie Towarzystwo Naukowe Ochrony Środowiska*, 11, 959–971.

[2] Borowski, G., & Miłczak, M. (2010). Badanie przydatności brykietów z popiołów paleniskowych jako podbudowy drogowe. (Testing suitability of briquettes from furnace ashes for the construction of road subbase), *Postępy nauki i techniki*, 4, 136–143.

[3] Czop, M., & Kajda-Szcześniak, M. (2010). Content of heavy metals in ashes after burning biomass briquette, *Archives of Waste Management and Environmental Protection*, 12, 1, 67–76.

[4] Dąbrowski, J., & Piecuch, T. (2011). Mathematical Description of Combustion Process of Selected Groups of Waste *Annual Set The Environment Protection* (*Rocznik Ochrona Środowiska*), 13, 253–268.

[5] Dąbrowski, J., Dąbrowski, T., & Piecuch, T. (2013). Laboratory Studies on the Effectiveness of NO_x Reduction by Selective Catalytic Reduction SCR Method, *Annual Set The Environment Protection* (*Rocznik Ochrona Środowiska*), 15, 301–313.

[6] Denisiuk, W. (2006). Produkcja roślinna jako źródło surowców energetycznych (Production of plants as energy sources), *Inżynieria Rolnicza*, 5, 123–131.

[7] Domańska, D., & Zacharz, T. (2008). Odpady biomasowe jako źródło energii alternatywnej (Biomass wastes as source of alternative energy), *Archives of Environmental Protection*, 34 (spec.), s. 39–54.

[8] Golec, T. (2004). Współspalanie biomasy w kotłach energetycznych. (Combustion of biomass in energetic boilers), *Energetyka*, 7/8, 437–445.

[9] Kajda-Szcześniak, M. (2008). Analiza możliwości wykorzystania wybranej biomasy w procesie formowania paliw (Analysis of possibilities of using selected biomass in the process of fuel forming) Doctoral thesis, Silesian University of Technology, Gliwice 2008.

[10] Kaltschmitt, M., & Hartmann, H. (2001). Energie aus Biomasse. Grundlagen, Techniken und Verfahren. Springer, Berlin 2001.

[11] Kotowicz, J., & Bartela, Ł. (2007). Energetyczne wykorzystanie biomasy drzewnej – przegląd technologii. (Energetic use of timber biomass – review of technologies), *Rynek Energii*, 6, 22–28.

[12] Kowalczyk-Juśko, A. (2009). Popiół z różnych roślin energetycznych. (Ashes from various energetic plants), *Proceedings of ECOpole*, 3 (1), 159–164.

[13] Krawczyński, M. (2005). Współspalanie paliw – szanse i zagrożenia, (Co-combustion of fuels – opportunities and threats), http://www.ure.gov.pl/wai/pl/429/1190/Wspolspalanie_paliw_8211_szanse_i_zagrozenia.html (25.09.2012).

[14] Kubica, K., Ściążko, M., & Raińczak, J. Współspalanie biomasy z węglem (Combustion of biomass and coal), conbiot.ichpw.zabrze.pl/21_Co-combustion_of_coal_and_biomass.pdf (11.06.2012).

[15] Ljung, A., & Nordin, A. (1997). Theoretical Feasibility for Ecological Biomass Ash Recirculation: Chemical Equilibrium Behavior of Nutrient Elements and Heavy Metals during Combustion, *Environmental Science & Technology*, 31 (9), 2499–2503.

[16] Łebkowska, M., & Załęska-Radziwiłł, M. (2011). Produkty użyteczne ze ścieków i odpadów stałych (Usable products from sewage and solid waste). *Archives of Environmental Protection*, 37, 3, 15–19.

[17] Nadziakiewicz, J., Wacławiak, K., & Stelmach, S. (2007). Procesy termiczne utylizacji odpadów (Thermal processes for the utilization of wastes), Editorial of Silesian University of Technology, Gliwice 2007.

[18] Niedziółka, I., & Zuchniarz, A. (2006). Analiza energetyczna wybranych rodzajów biomasy pochodzenia roślinnego (Energetic analysis of selected types of vegetal biomass), *MOTROL*, 8A, 232–237.

[19] PN-Z-15008-02:1993. Odpady komunalne stałe. Badania właściwości paliwowych. Oznaczanie wilgotności całkowitej. (Municipal solid wastes. Tests of fueling properties. Determination moisture content).

[20] PN-Z-15008-03:1993. Odpady komunalne stałe. Badania właściwości paliwowych. Oznaczanie zawartości części palnych i niepalnych. (Solid municipal wastes. Tests of fueling properting. Determination of combustible and incombustible elements).
[21] Rosik-Dulewska, Cz. (1998). Zagrożenia środowiska w zasięgu oddziaływania wtórnego pylenia z transportowanych pyłów energetycznych (Threats to environments within the secondary dusting from transported energetic dust). *Archives of Environmental Protection*, 24, 3, 129–145.
[22] Solway, A. (2009). Renewable Energy Sources. Heinemann/Raintree, 2009.
[23] Strzelczyk, F., & Wawszczak, A. (2008). Efektywność biomasy jako paliwa energetycznego (Effectiveness of biomass as energetic fuel), *Rynek Energii*, 5, 51–57.
[24] Sztyma-Horwat, M., & Styszko, L. (2011). Nitrogen Oxides NO_x Emissions from Combustion of Willow Biomass, *Annual Set The Environment Protection* (*Rocznik Ochrona Środowiska*), 13, 787–800.
[25] Wandrasz, J.W., & Wandrasz, A.J. (2006). Paliwa formowane. Biopaliwa i paliwa z odpadów w procesach termicznych. (Formed fuels. Bio-fuels and fuels from wastes in thermal process), Wyd. Seidel-Przywecki Sp. z o.o., Warszawa 2006.
[26] Werther, J., Saenger, M., Hartge, E.U., Ogada, T., & Siagi, Z. (2000). Combustion of agricultural residues, *Progress in Energy and Combustion Science*, 26, 1–27.

SKUTKI SPALANIA PALIWA NA BAZIE SŁOMY DLA ŚRODOWISKA PRZYRODNICZEGO

Biomasa jest powszechnie uważana za paliwo odnawialne, które w rozliczeniach emisji CO_2 traktowana jest jako paliwo nie wnoszące emisji gazów cieplarnianych.

W pracy wykonano badania spalania dwóch rodzajów paliw formowych, na bazie słomy z dodatkiem polietylenu, w skali laboratoryjnej. W artykule przedstawiono własne wyniki pomiarów zanieczyszczeń gazowych powstających ze spalania paliwa formowanego. Uzyskane wyniki porównano z analogicznymi danymi literaturowymi dla spalania węgla. W ramach pracy zbadano również skład chemiczny, zawartość metali ciężkich i wybrane właściwości fizyczne popiołów powstałych w procesie spalania paliwa na bazie słomy.