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COMPARISON OF POLLUTANT EMISSION INDICATORS DURING VIRGINIA MALLOW PELLETS AND WOOD PELLETS COMBUSTION – A CASE STUDY[1]

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ABSTRACT

Ecological aspects and environmental threats indicate that wood pallets should be used mainly in low-power furnaces for heating households. Because burners and fuel feeding systems were adjusted to wood pellets, pellets from other types of biomass, including the waste biomass in systems which enable a controlled process, should be considered. Taking into consideration the possibility of use of Virginia mallow pellets for supply of low-power furnaces as alternative fuel to wood pellets, the objective of the research was to determine and compare indicators of emission of CO, NO_X, SO_2, 16 WWA including B(a)P, TOC and dust during combustion of these two biofuels. Emission indicators were referred to the mass of combusted biofuel and the amount of the obtained energy. Installation used in the research was a typical installation used for heating of one-family houses and designed for combustion of pellets. CO and dust emission indicators for Virginia mallow pellets were considerably higher in comparison to the indicators for wood pellets. Emission indicators of the remaining pollutions (SO_2, NO_X, TOC, dust, WWA, B(a)P) were similar to both tested biofuels.

Introduction

The growing interest in combustion of various types of biomass requires undertaking the issue of emission of exhaust fumes toxic elements from low-power furnaces because their participation in the global energy consumption scale is considered to be significant (Jabłoński and Wnuk, 2009; Niedziółka and Szpryngiel, 2014). Ecological aspects and environmental threats indicate that wood pallets should be used mainly in low-power furnaces for heating households. However, shortage of cheap, good quality wood pellets, which are presently used in Poland are applied in professional power industry, incite interest in agricultural biomass pellets as fuel for heating low-power furnaces (Juszczak, 2012). The balance of biomass supply on the power industry market may be supplemented by

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obtaining it from plantations of perennial domestic plants and those introduced in Poland (Stolarski et al., 2014; Niedziółka et al., 2015). Virginia mallow (*Sida hermaphrodia* R.) is a plant which has a satisfactory potential of yield and advantageous characteristic of energy parameters (Szyszlak-Bargłowicz et al., 2012). Research on the compaction process of biomass are undertaken (Niedziółka and Szpryngiel, 2011; Zając, 2015). However, there is a shortage of literature concerning the use of obtained biofuels by direct combustion in heating low-power furnaces. In low-power installations, pellets are combusted the most often in automatic furnaces. Usually, burners and fuel feeding systems of these furnaces are adjusted to wood pellets. However, combustion of pellets from other types of biomass should be considered so the combustion process can be controlled (Olsson and Kjällstrand, 2004; Polák et al., 2007; Carvalho et al., 2013; Czop and Kajda-Szcześniak, 2013; Qiu, 2013).

Combustion process organization including the physico-chemical properties of fuel has a decisive impact on the carbon dioxide emission, organic pollutants and nitric oxide. The amounts of emitted organic pollutants are mutually dependent. The higher is the CO emission index, the higher is the load of emitted organic pollutants. This relation results from the oxidization degree of volatile products of fuel degassing in the homogeneous combustion zone. The amount of the emitted SO_2 depends on the content of sulphur in fuel. The higher it is the higher is SO_2 load introduced to environment (Ściążko et al., 2003).

However, there is a considerable uncertainty concerning the assessment of the impact of emission of pollution which accompanies the biomass combustion on the quality of air in the local scale (Pastorello et al., 2011) It results not only from the lack of data on the amount of combusted biomass but also from the lack of emission indicators, which would describe combustion during exploitation. The emission size of toxic elements of exhaust gases during biomass combustion depends greatly on the quality of a combustion device, type and quality of fuel and working conditions (Johansson et al., 2004; Win et al., 2012; Nielsen, 2013; Orasche et al., 2013).

Taking into consideration the possibility of use of Virginia mallow pellets for supply of low-power furnaces as alternative fuel to wood pellets, the objective of the research was to determine and compare indicators of emission of CO, NO_X, SO_2, 16 WWA including B(a)P, TOC and dust during combustion of these two biofuels. Emission indicators were referred to the mass of combusted biofuel and the amount of the obtained energy. Installation used in the research was a typical installation used for heating one-family houses and designed for combustion of pellets. During the combustion tests its rating settings were not disturbed. The results obtained during the research are not strict data, but only examples noted for one time indicating the level of emission of particular compounds.

Methodology of research

Emission tests of Virginia mallow pellets combustion and wood pellets were carried out in cooperation with the Institute of Chemical Processing of Carbon in Zabrze and they were carried out according to the procedures developed in the Institute for fuel and furnaces testing purposes:

– Q/ZS/01/A:2010 procedure "Combustion efficiency determination",
– Q/ZS/02/A:2010 procedure "Determination of emission indicators of pollutions emitted during solid fuels and biomass combustion",

- Q/LG/07/A:2011 procedure "Determination of the gas components content in gas"
- Q/LG/04/A:2011 procedure "Determination of WWA content including B(a)P in exhaust gases",
- Q/LG/03/A:2011 procedure "Determination of organic pollution content in exhaust gases",
- Q/LG/02/A:2011 procedure "Determination of the dust content in exhaust gases emitted in the combustion process".

For combustion tests of Virginia mallow pellets and wood pellets a furnace with automatic fuel batching with 32 kW power adjusted for wood pellets combustion was used. This furnace is equipped with a retort burner, to which fuel is fed from the container with a screw feeder. Air for combustion is led by a fan to the nozzles system in a burner. The furnace operation is controlled with an electronic controller. The combustion tests were carried out in the set conditions of the furnace operation at the rating settings; the tests lasted 6 hours.

Ultimate and proximate analysis of the fuel used in the test were presented in table 1.

Table 1
Ultimate and proximate analysis of Virginia mallow and wood pellets

Parameter	Symbol	Unit	Virginia mallow pellets	Wood pellets
Moisture content	W_t^r	(%)	7.7	5.7
Ash	A^a	(%)	2.9	0.3
Volatile matter	V^{daf}	(%)	82.68	84.45
Carbon	C^a	(%)	48.1	49.5
Hydrogen	H^a	(%)	5.79	6.06
Sulphur	S^a_A	(%)	0.07	0.02
Nitrogen	N^a	(%)	0.42	0.17
Gross calorific value (HHV)	Q_s^a	(kJ·kg^{-1})	19,084	19,953
Net calorific value (LHV)	Q_i^r	(kJ·kg^{-1})	16,804	17,893

The composition of exhaust fumes from the furnace was measured with the use of the system of SIEMENS analysers. The system comprised ULTRAMAT 23 analysers which enable CO measurement within 0-5% and 0-50%, CO_2 within 0-50%, SO_2 within 0-2500 ppm, including one which cooperates with a converter of NO_2 into NO. These measurements were carried out with the use of the IR referential method. Measurement of O_2 concentration in gas was taken with OXYMAT 5 analyser, which operates based on the referential method which uses the phenomenon of paramagnetism. This analyser is equipped with the range of 0-25% O_2. Exhaust fumes were being sampled constantly with the use of the system comprising a probe with a ceramic filter, a heated hose and the gas conditioning system. The collection of the exhaust fumes and organic pollutants samples was carried out with the use of the system which consists of a probe connected with the heater dust separator, pipe with XAD2 and active carbon and gas aspirator. Fumes samples for determination of hydrocarbon were collected to tedlar type bags and then analysed with gas chromatograph.

Based on the obtained results of emission tests during combustion of Virginia mallow pellets and wood pellets, pollutant emission indicators for these fuels were determined. Volume of air and fumes from 1 kg of fuel in stoichiometric conditions was calculated based on formulas 1 and 2 (Kruczek, 2001) depending on the net calorific value and in real conditions also in relation to the air excess coefficient (3):

$$V_{ps}^{t} = 0.99 \times \frac{Q_i^r}{4186.8} + 0.126 \qquad (m_n^3 \cdot kg^{-1}) \qquad (1)$$

$$V_{s}^{t} = 0.99 \times \frac{Q_i^r}{4186.8} + 1.126 \qquad (m_n^3 \cdot kg^{-1}) \qquad (2)$$

$$V_{s} = V_s^t + (\lambda - 1) \times V_{ps}^t \qquad (m_n^3 \cdot kg^{-1}) \qquad (3)$$

where:

Q_i^r – net calorific value of fuel, ($kJ \cdot kg^{-1}$)
V_s^t – volume of fumes in stoichiometric conditions (λ=1) from 1 kg of fuel, ($m_n^3 \cdot kg^{-1}$)
V_{ps}^t – volume of air in stoichiometric conditions (λ=1) from 1 kg of fuel, ($m_n^3 \cdot kg^{-1}$)
V_s – volume of fumes in stoichiometric conditions (λ=1) from 1 kg of fuel, ($m_n^3 \cdot kg^{-1}$)
λ – coefficient of air excess

Emission from 1 kg was calculated as a product of fumes volume from 1 kg of fuel and average concentration value in regular conditions at real concentration of oxygen.

Research results and discussion

Great differences in the amount of the fuel consumed in the test were reported. During combustion of Virginia mallow pellets, the mass of the consumed fuel was 28.9 kg and in case of wood pellets it was 44.8 kg resulting respectively in the fuel mass stream of 4.8 and 7.4 $kg \cdot h^{-1}$. Taking into consideration the calorific value of fuel, energy put in case of Virginia mallow pellets was 23.65 kW and in case of wood pellets it was 37.06 kW. The obtained thermal power during the test of combustion of Virginia mallow pellets was 20.2 kW at the 90% thermal capacity of a furnace and during the test of wood pellets combustion thermal power of 33.5 kW was obtained at the 91.1% thermal capacity of the furnace. Moreover, differences in the value of the coefficient of air excess λ were observed. In case of combustion of Virginia mallow pellets it was 1.8 and during combustion of wood pellets it was 1.5. This difference may be justified by the difficulty in adjusting the furnace control to the conditions of combustion.

The determined pollution emission indicators during Virginia mallow and wood pellets combustion – were presented in table 2. Higher values of emission indicators were reported during combustion of pellets from Virginia mallow, particularly in case of CO and dust emission.

Table 2
Pollution emission indicators for the combusted wood pellets and Virginia mallow pellets referred to the combusted fuel mass and the amount of the obtained energy

Parameter	Unit	Virginia mallow pellets	Wood pellets
CO	$(g \cdot kg^{-1})$	20.4	0.4
SO_2	$(g \cdot kg^{-1})$	0.0	0.0
NOx	$(g \cdot kg^{-1})$	3.5	3.4
TOC	$(g \cdot kg^{-1})$	0.7	0.5
Dust	$(g \cdot kg^{-1})$	3.5	0.4
WWA	$(mg \cdot kg^{-1})$	2.9	2.7
B(a)P	$(mg \cdot kg^{-1})$	0.03	0.04
CO	$(g \cdot GJ^{-1})$	1213.9	22.4
SO_2	$(g \cdot GJ^{-1})$	0.4	0.0
NOx	$(g \cdot GJ^{-1})$	206	192.0
TOC	$(g \cdot GJ^{-1})$	41.1	27.7
Dust	$(g \cdot GJ^{-1})$	206.0	23.8
WWA	$(mg \cdot GJ^{-1})$	170	154.0
B(a)P	$(mg \cdot GJ^{-1})$	1.8	2.3

High CO and dust emission during combustion of Virginia mallow pellets resulted from incomplete combustion and bad organization of the combustion process which was associated with the physical and chemical properties of this biofuel and its bad quality. Reduction of temperature in the combustion chamber caused by difficulties in feeding fuel and a little higher moisture affected higher CO concentration. A high content of dust in fuel impeded movement of pellets in feeder containers; moreover, a rough surface of Virginia mallow pellets caused their blocking in containers (despite of the use of moving elements) which resulted in a momentary shortage of supply of a desired amount of pellets to the burner. In case of wood pellets no such obstacles were met.

The indicated NO_X emission indicators for both investigated biofuels and CO and dust indicators for Virginia mallow pellets were higher than the range of emission indicators for wood pellets presented in articles (Johansson et al., 2004; Paulrud et al., 2010; Boman et al., 2011; Win et al., 2012). The TOC and WWA emission indicators were within the range presented in these publications. Emission indicators during wood pellets combustion determined by Win et al. (2012) for six different devices including also the start up and stop stage of furnaces, were: 192-547 $g \cdot GJ^{-1}$ for CO; 61-95 $g \cdot GJ^{-1}$ for NO; 6-45 $g \cdot GJ^{-1}$ for TOC, 31-116 $g \cdot GJ^{-1}$ for dust. During the start up and stop of the furnace, emissions of CO (63-95%) and TOC (48-93) were higher. NO and dust emissions prevailed during exploitation of furnaces in stabilized conditions.

Pollution emission indicators higher than the ones determined in tests were found by Juszczak (Juszczak, 2012) combusting pellets from sunflower husks. They were for CO 5315.0 $g \cdot GJ^{-1}$; for NO_X 469 $g \cdot GJ^{-1}$; for dust 30 $g \cdot GJ^{-1}$.

Carvalho et al. (2013) indicated pollutant emission indicators for pellets of various types of agricultural biomass and wood pellets. These indicators were also decisively higher during combustion of wood pellets. The highest values of CO emission indicators were reported during combustion of pellets of hay (280 $g \cdot GJ^{-1}$), wheat bran (224 $g \cdot GJ^{-1}$) and straw (223 $g \cdot GJ^{-1}$), which were from eleven to fourteen times higher in comparison to the indicators of emission during combustion of wood pellets. CO emission indicators registered during combustion of pellets from maize straw, waste from vineyard cuttings and sorgo were quite low (two to five times higher than the CO emission indicators for wood pellets). NO_X, SO_2 and dust emissions were also high when feeding the furnace with agricultural biomass pellets.

Moreover, higher pollutant emission indicators from low-power furnaces fed with wood and wood pellets were registered in case of manual batch furnaces in comparison to automatic furnaces (Ozgen et al., 2014). For manual batch furnaces CO, NO_X and B(a)P emission indicators were respectively: 5858 $g\cdot GJ^{-1}$; 122 $g\cdot GJ^{-1}$ and 77 $mg\cdot GJ^{-1}$, and for automatic furnaces they were considerably higher and were: 219 $g\cdot GJ^{-1}$; 66 $g\cdot GJ^{-1}$ and 0.8 $mg\cdot GJ^{-1}$.

Wielgosiński (2009) by determination of CO, NO and TOC emission indicators for common osier chips, rapeseed straw briquettes, pellets from wood waste and oak bark chips found out that among biofuels, the highest CO emission indicator for straw and the lowest for willow tree. The highest NO emission indicator was determined during straw combustion and the lowest one during willow tree combustion. In case of the total organic compounds the highest values of the emission indicator were found out for the rapeseed straw and wood pellets and the lowest one for willow tree and oak bark. The size of emission during biomass combustion was comparable to the emission during hard coal combustion and in case of hydrocarbon emission it was higher.

Summary and conclusions

On account of the growing combustion of various types of biomass to a small scale, carrying out tests on the emission of pollutions which accompany this process is indispensable from the point of view of assessment of health and environmental issues. Determination of pollution emission indicators from heating devices is a significant element of analysis of the material circulation of solid biofuels. It allows precise indication of the impact of particular factors (fuel type, device type, combustion cycle) on the environment.

The following conclusions were formulated based on the research studies that were carried out:

1. CO and dust emission indicators for Virginia mallow pellets were considerably higher in comparison to the indicators for wood pellets.
2. Higher CO and dust emission during combustion of Virginia mallow pellets resulted from incomplete combustion and bad organization of the process as a result of a great non-uniformity of Virginia mallow pellets and lack of adjustment of the control system to the applied fuel.
3. Emission indicators of the remaining pollutions (SO_2, NO_X, TOC, dust, WWA, B(a)P were similar to both tested biofuels.
4. Combustion of pellets from various types of agricultural biomass in low-power furnaces designed for combustion of wood pellets may be related to higher toxic emission of fumes elements in comparison to the basic fuel, namely wood pellets.
5. The obtained results indicate the necessity of research over optimization of the parameters of the combustion process of pellets from various types of biomass in order to enable the change of algorithm of furnace control.

References

Boman, C., Pettersson, E., Westerholm, R., Boström, D., Nordin, A. (2011). Stove performance and emission characteristics in residential wood log and pellet combustion, part 1: pellet stoves. *Energy Fuels, 25*(1), 307-314.

Carvalho, L., Wopienka, E., Pointner, C., Lundgren, J., Verma, V. K., Haslinger, W., Schmidl, C. (2013). Performance of a pellet boiler fired with agricultural fuels. *Applied Energy, 104*, 286-296.

Czop, M., Kajda-Szcześniak, M. (2013). Environmental impact of straw based fuel combustion. *Archives of Environmental Protection, 39*(4), 71-80.

Jabłoński, W., Wnuk, J. (2009). *Zarządzanie odnawialnymi źródłami energii: aspekty ekonomiczno-techniczne*. Oficyna Wydawnicza "Humanitas" ISBN 978-83-89275-40-0.

Johansson, L. S., Leckner, B., Gustavsson, L., Cooper, D., Tullin, C., Potter, A. (2004). Emission characteristics of modern and old-type residential boilers fired with wood logs and wood pellets. *Atmospheric Environment, 38*(25), 4183-4195.

Juszczak, M. (2012). Pollutant concentrations from a 15 kW heating boiler supplied with sunflower husk pellets. *Environment Protection Engineering, 38*(1), 35-43.

Kruczek, S. (2001). *Kotły: konstrukcje i obliczenia*. Oficyna Wydaw. Politechniki Wrocławskiej. ISBN 83-7085-600-4.

Niedziółka, I., Szpryngiel, M., Kachel-Jakubowska, M., Kraszkiewicz, A., Zawiślak, K., Sobczak, P., Nadulski, R. (2015). Assessment of the energetic and mechanical properties of pellets produced from agricultural biomass. *Renewable Energy, 76*, 312-317.

Niedziółka, I., Szpryngiel, M. (2011). Ocena energetyczna procesu zagęszczania wybranych surowców roślinnych w brykieciarce ślimakowej. *Inżynieria Rolnicza, 9*(134), 153-159.

Niedziółka, I., Szpryngiel, M. (2014). Possibilities of using biomass for energy purposes. *Agricultural Engineering, 1*(149), 155-164.

Nielsen, O.K. (2013). *EMEP/EEA air pollutant emission inventory guidebook 2013*. Technical guidance to prepare national emission inventories.

Olsson, M., Kjällstrand, J. (2004). Emissions from burning of softwood pellets. *Biomass Bioenergy, 27*(6), 607-611.

Orasche, J., Schnelle-Kreis, J., Schön, C., Hartmann, H., Ruppert, H., Arteaga-Salas, J. M., Zimmermann, R. (2013). Comparison of emissions from wood combustion. Part 2: impact of combustion conditions on emission factors and characteristics of particle-bound organic species and Polycyclic Aromatic Hydrocarbon (PAH)-related toxicological potential. *Energy Fuels, 27*(3), 1482-1491.

Ozgen, S., Caserini, S., Galante, S., Giugliano, M., Angelino, E., Marongiu, A., Hugony, F., Migliavacca, G., Morreale, C. (2014). Emission factors from small scale appliances burning wood and pellets. *Atmospheric Environment, 94*(0), 144-153.

Pastorello, C., Caserini, S., Galante, S., Dilara, P., Galletti, F. (2011). Importance of activity data for improving the residential wood combustion emission inventory at regional level. *Atmospheric Environment, 45*(17), 2869-2876.

Paulrud, S., Kindbom, K., Gustafsson, T. (2010). *Emission factors and emissions from residential biomass combustion in Sweden*; 34; Swedish Meteorological and Hydrological Institute: Norrköping, 2010.

Polák, M., Neuberger, P., Rutkowski, K. (2007). Wpływ recyrkulacji spalin na proces spalania biomasy. *Inżynieria Rolnicza, 11*, 169-176.

Qiu, G. (2013). Testing of flue gas emissions of a biomass pellet boiler and abatement of particle emissions. *Renewable Energy, 50*(0), 94-102.

Ściążko, M., Zieliński, H., Chmielniak, T. (2003). *Termochemiczne przetwórstwo węgla i biomasy*. ICPW. ISBN 83-913434-1-3.

Stolarski, M. J., Krzyżaniak, M., Śnieg, M., Słomińska, E., Piórkowski, M., Filipkowski, R. (2014). Thermophysical and chemical properties of perennial energy crops depending on harvest period. *Internatiomal Agrophysics, 28*(2), 201-211.

Szyszlak-Bargłowicz, J., Zając, G., Piekarski, W. (2012). Energy biomass characteristics of chosen plants. *Internatiomal Agrophysics,* 26(2), 175-179.
Wielgosiński, G. (2009). Czy *biomasa jest paliwem ekologicznym*. III Ogólnopolski Kongres Inżynierii Środowiska, Lublin. Pozyskano z: http://wis. pol. lublin. pl/kongres3/tom1/38. pdf
Win, K. M., Persson, T., Bales, C. (2012). Particles and gaseous emissions from realistic operation of residential wood pellet heating systems. *Atmospheric Environment, 59*, 320-327.
Zając, G. (2015). Impact of diameter of pressing channels and moisture on parameters of pelleting process of virginia mallow biomass. *Agricultural Engineering, 1(153)*, 141-150.

PORÓWNANIE WSKAŹNIKÓW EMISJI ZANIECZYSZCZEŃ PODCZAS SPALANIA PELETÓW ZE ŚLAZOWCA PENSYLWAŃSKIEGO I PELETÓW DRZEWNYCH – STUDIUM PRZYPADKU

Streszczenie. Aspekty ekologiczne i zagrożenia zanieczyszczeniem środowiska wskazują, że pelety drzewne powinny być wykorzystywane przede wszystkim w kotłach małej mocy do ogrzewania gospodarstw domowych. Ze względu na dostosowanie palników i układów podających paliwo do peletów drzewnych, należy rozważyć spalanie peletów z innych rodzajów biomasy, w tym odpadowej w systemach umożliwiających prowadzenie tego procesu w sposób kontrolowany. Mając na uwadze możliwość wykorzystywania peletów ze ślazowca pensylwańskiego do zasilania kotłów grzewczych małej mocy, jako paliwa alternatywnego w stosunku do peletów drzewnych, za cel badań postawiono wyznaczenie i porównanie wskaźników emisji CO, NO_X, SO_2, 16 WWA w tym B(a)P, TOC i pyłu podczas spalania tych dwóch biopaliw. Wskaźniki emisji odniesiono do masy spalanego paliwa i ilości uzyskanej energii. Instalacja zastosowana w badaniach była typową instalacją wykorzystywaną do ogrzewania domów jednorodzinnych przeznaczoną do spalania peletów. Wskaźniki emisji CO i pyłu dla peletów ze ślazowca pensylwańskiego były znacznie wyższe w porównaniu do wskaźników dla peletów drzewnych. Wskaźniki emisji pozostałych zanieczyszczeń (SO_2, NO_X, TOC, pył, WWA, B(a)P były zbliżone dla obu badanych biopaliw.

Słowa kluczowe: biomasa, pelety, spalanie, wskaźniki emisji