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PRODUCTION OF EMISSIONS DURING COMBUSTION OF VARIOUS BIOFUELS

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***Abstract*:** Biomass, or more precisely biofuel, nowadays increasingly substitutes for fossil fuels in the process of heating. It is used for heating of the drying medium as well. The paper is focused on the evaluation of the heat source during combustion of various kinds of solid biofuels. The heat source in question is the boiler VIGAS 25 with controller AK 2000 for home heating. The device TESTO 330-2LL was used for the measurement of gaseous emissions. Tested biofuels included bark briquettes and hardwood briquettes. The results of experimental measurements of gaseous emissions production for two fuels are processed in tabular and graphic form in dependence on the boiler output and the combustion time. Monitoring of surface temperature of the boiler was carried out by the means of the thermal imaging camera Flir.

Key words: *heat source, solid biofuel, emissions, briquette, firewood*

INTRODUCTION

Considering its wide application, biomass is the most significant alternative to fossil fuels. Its energy can be converted by direct combustion into thermal energy, by means of

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which it is possible to heat houses and flats, or it can be further converted into electrical energy. As regards industry, all types of biomass can be utilized. In Slovakia it is primarily used in solid form for heating in the urban heating plants. Similarly, the operation of crop dryers considerably relies on agricultural waste, which is an easily available and affordable source of energy [1], [2] and [3].

On the other hand, combustion of biomass also has its drawbacks. In recent years, so-called clean fuels have become quite preferred, mainly in the form of pellets and briquettes. However, the price of these biomass-based fuels, calculated with regard to calorific value, nowadays approaches the cost of natural gas. Apart from energetic and economic points of view, the role of environmental aspects in the characterization and evaluation of biofuels gains considerable importance. Numerous analyses and measurements of emissions arising from the combustion of biofuels indicate that flue gas contains, apart from the main products of the oxidation of carbon and hydrogen - CO_2 and H_2O, also other aliphatic and aromatic hydrocarbons, CO and nitrogen oxides [4], [5]. For this reason, the idea of so-called ecological harmlessness of heat production from wood and wood waste should be abandoned, while further attention shall be paid to the development and improvement of technological procedures of biofuel combustion in the furnaces of heat generators [6], [7].

The article introduces the results of measurements of concentration of gaseous emissions performed on the heat source for home heating which combusts wood biomass.

MATERIAL AND METHODS

Production of flue-gas emissions was observed on the hot water gasification boiler VIGAS 25 with controller AK 2000, which is designed particularly for firewood combustion and is used for home heating [8].

Boiler parameters are as follows: manufacturer VIMAR, nominal output 25 kW, output range 5 - 31 kW, efficiency 85,49 %, max. operational pressure 0,3 MPa, chimney draft 15 - 20 Pa, firebox capacity 120 dm^3, max. electrical input 70 W, noise level 45,5 dB [9]. This boiler is made for combustion of firewood with appropriate moisture content up to 20 %. The manufacturer recommends the following alternative fuels: wood briquettes, woodchips, sawdust and wood shavings, provided that they are burned together with larger pieces of wood (logs).

The fuel is dried and gasified in the firebox, from which the produced wood gas flows through a refractory concrete nozzle to the combustion chamber. There it burns with the help of the secondary air. Flue gas is intensively cooled in the exchanger. Unburned residue is swept out of the combustion chamber. In order to start up the boiler, the lighting up valve controlled by a draw-bar in the front part of the boiler is used. To meet the requirements of simple operation, the device contains the control unit AK 2000 placed in the upper part of the boiler. This control system enables very efficient combustion of various types of biofuels. In case of long-term power outage or automatic regulation failure it is possible to heat by opening the flue baffle and leaving the lower door ajar. This method of heating requires more frequent checks of the water outlet temperature and smaller amounts of fuel to refill, because loading the firebox to the maximum may cause overheating of the boiler [8].

For the purpose of the experiment, two types of biofuels were used- bark briquettes and hardwood briquettes. These fuels were selected in order to provide comparison of the emissions arising from the combustion of fuel which the boiler is designed for (i.e. firewood) in contrast to alternative fuels or the ones which were not recommended by the manufacturer.

The device Testo 330-2 LL was used for the measurement of emissions. It is a flue gas analyser, which can measure various quantities and save the obtained values to the memory.

During the experiment, the following quantities were observed: O_2 %, CO ppm, CO_2 %, T_s (flue gas temperature) °C, T_v (ambient air temperature) °C, *qA* (chimney loss) %, η (efficiency) %, λ (air surplus) -, NO ppm, NO_x ppm, chimney draft Pa.

In order to start the measurement of the emission production, it is necessary to choose the option *Flue gas measurement* on the device and confirm the choice. In case the type of the fuel was not selected yet, it has to be submitted in the settings prior to the measurement.

During the experiment, the flue gas probe of the device was placed approximately 900 mm from the flue outlet of the boiler. At the same time, to ensure the most accurate results possible, the end of the probe was set approximately in the middle part of the flue.

Moisture content of selected biofuels was determined by the means of the laboratory oven Memmert UFE 400 and calculated as an average of several measurements. Weight of the samples was measured by the scales KERN EG 420 with 0,001 g resolution. The samples were dried at the temperature of 105°C to a constant weight.

Moisture content from the obtained weight of the samples was calculated according to the following relation:

$$w = \frac{m_1 - m_2}{m_1} 100 \tag{1}$$

Where:
w [%] - moisture content,
m_1 [g] - initial weight,
m_2 [g] - dry matter weight.

This relation was used to determine carbon monoxide content in the emissions:

$$CO_e = \frac{21\% - O_{2ref}}{21\% - O_2} 1{,}25\, CO \tag{2}$$

Where:

CO_e	[mg·m^{-3}]	- carbon monoxide content in the emissions,
21	[%]	- concentration of oxygen in the air (*const.*),
O_2	[%]	- measured concentration of oxygen,
O_{2ref}	[%]	- reference oxygen content (depending on the fuel),
$1{,}25$	[mg·m^{-3}·ppm^{-1}]	- conversion factor (ppm → mg·m^{-3}),
CO	[ppm]	- measured concentration of carbon monoxide content.

This relation was used to calculate nitrogen oxides content in the emissions:

$$NO_{xe} = \frac{21\% - O_{2ref}}{21\% - O_2} 2{,}05\, NO_x \tag{3}$$

Where:
NO_{xe} [mg·m^{-3}] - nitrogen oxides content in the emissions,
2,05 [mg·m^{-3}·ppm^{-1}] - conversion factor (ppm → mg·m^{-3}),
NO_x [ppm] - measured concentration of nitrogen oxides content.

Surface temperature of the boiler was monitored by the thermal imaging camera Flir T-335.

RESULTS AND DISCUSSION

The first measurement of selected emissions and other quantities for given fuel was carried out approximately 30 minutes after loading of the boiler. Following measurements were performed in 30-minute intervals in order to point out the differences at varying output of the boiler. Measured values for bark briquettes and hardwood briquettes are presented in Tab. 1 and Tab. 2, respectively. Corresponding values of boiler output for each measurement are provided. At 100% of the boiler output, chimney draft was also measured. It reached the value of -18 Pa at maximum flue gas temperature of 80,9°C.

Table 1. Results of measurements of emissions during combustion of bark briquettes

	O_2	CO_2	CO		T_S	T_V	qA	η	Λ
	[%]	[%]	[ppm]	[mg·m^{-3}]	[°C]	[°C]	[%]	[%]	[-]
1.	15,4	7,06	1284	2866,1	76,55	26,0	3,8	96,2	2,23
2.	19,1	1,84	1378	9065,8	33,20	26,2	3,3	96,7	11,10
3.	17,9	3,00	550	2217,7	58,30	27,0	6,2	93,8	6,96
4.	19,8	1,16	777	8093,7	45,50	26,3	11,6	88,4	18,00
5.	17,4	3,43	1165	4045,1	62,40	25,8	8,7	91,3	5,97
6.	14,4	6,38	585	1108,0	104,00	25,6	9,7	90,3	3,34
7.	17,5	3,39	780	2785,7	67,40	25,7	7,9	92,9	6,08
8.	16,8	5,42	1111	3306,5	72,90	25,7	8,2	91,8	4,83

	NO		NO_x		Boiler output
	[ppm]	[mg·m^{-3}]	[ppm]	[mg·m^{-3}]	[%]
1.	100	366,1	105	384,4	100
2.	12	129,5	12	129,5	0
3.	94	621,6	98	648,1	30
4.	16	273,3	16	273,3	10
5.	98	558,1	103	586,5	70
6.	101	313,7	106	329,2	100
7.	54	316,3	57	333,9	40
8.	95	463,7	101	493,0	70

Three six-piece (6 kg) packs of block-shaped briquettes made from tree bark were used in the experiment. Their size was 15 x 7 x 10 cm (*w* x *h* x *l*) and average moisture content reached 4,7 %. Briquettes were put into the firebox with embers for easier start up. After loading and closing of the firebox door, control measurement of carbon monoxide concentration around the boiler was performed. The results indicated slightly increased concentration, reaching 286 ppm. The next measurement after 20 minutes showed significant decrease to 56 ppm. During the following measurement after 30 minutes, no considerable change in CO concentration was observed. From the short-term point of view it remained within the safe limits.

Fig. 1 shows the dependence of oxygen, carbon dioxide and carbon monoxide levels in the flue gas on the boiler output and chimney loss at given output during the combustion of bark briquettes.

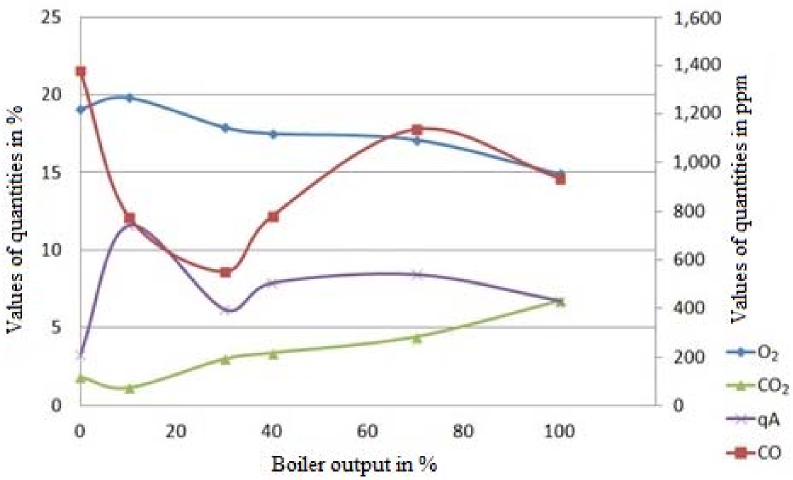


Figure 1. Dependence of oxygen, carbon dioxide, carbon monoxide levels in the flue gas on the boiler output and chimney loss at given output

Fig. 2 demonstrates the dependence of nitrogen oxides and nitric oxide emission levels in the flue gas on the boiler output, the dependence of flue gas temperature on the boiler output as well as course of ambient air temperature during the measurement. The graph depicts average values of two measurements which were performed at 100% and 70% of the boiler output.

The graph in the Fig. 1 shows decrease in carbon monoxide emissions at boiler output in the range 10-40% with a minimum reached at 30% of the boiler output. On the other hand, Fig. 2 indicates rise in nitrogen oxides emission level at 30% of the boiler output. This growth may be explained by the fact that bark briquettes are primarily intended to keep the embers burning once the boiler is turned off, rather than to be used for heating.

Fig. 3 presents dependence of efficiency and air surplus on the boiler output. From the graph we can see that efficiency significantly dropped at 10% of the output. This decline may be similarly attributed to the purpose of bark briquettes.

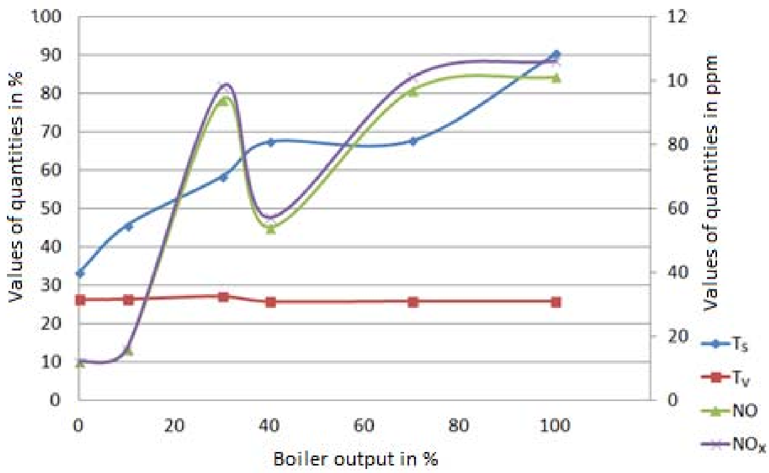


Figure 2. Dependence of nitrogen oxides and nitric oxide emission levels in the flue gas on the boiler output, dependence of flue gas temperature on the boiler output, and course of ambient air temperature during the measurement

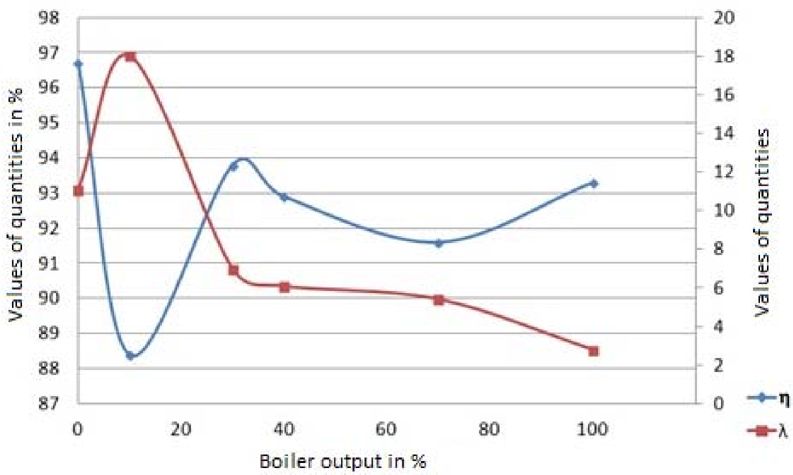


Figure 3. Dependence of efficiency and air surplus on the boiler output

In the following experiment, three five-piece (10 kg) packs of cylinder-shaped hardwood briquettes were used. Their length was 26 cm, diameter 9,5 cm and average moisture content reached 6,0 %. In order to ensure easier start up, embers from firewood were set up prior to loading of the firebox with briquettes.

The first measurement was performed approximately 30 minutes after loading of the boiler with the new fuel. Emissions and other quantities were measured in 30-minute intervals with respect to the boiler output. Results are shown in Tab. 2 with corresponding values of boiler output at which they were obtained. Similarly to the previous measurements, chimney draft was measured at full boiler output. It reached the value of -12 Pa at maximum flue gas temperature of 76,7 °C.

With respect to the scope of the article, graphic dependences are not provided. Nevertheless, significant decrease in carbon monoxide emissions at 30-70% of the boiler output was observed. This decline may be attributed to the appropriate combustion parameters for this kind of fuel in the given boiler output range. During combustion of hardwood briquettes (and firewood as well), production of nitrogen oxides emissions depends on the fuel gas temperature.

Table 2. Results of measurements of emissions during combustion of hardwood briquettes

	O_2	CO_2	CO		T_S	T_V	qA	η	Λ
	[%]	[%]	[ppm]	[mg·m^{-3}]	[°C]	[°C]	[%]	[%]	[-]
1.	15,7	5,15	1590	3750,0	87,6	25,7	11,6	88,4	4,88
2.	13,8	7,01	1256	2180,6	99,9	25,5	9,8	90,2	2,90
3.	16,8	4,06	321	955,4	73,9	25,6	12,2	87,8	6,47
4.	17,0	3,86	170	531,3	85,4	26,3	31,6	68,4	6,25
5.	17,3	4,64	155	523,6	71,9	25,3	7,9	92,1	6,84
6.	15,1	5,41	1358	2877,1	103,4	25,8	10,7	91,2	4,13
7.	19,6	1,40	1200	10714	33,3	27,0	3,8	96,2	17,50
8.	19,3	1,65	741	5448,5	45,8	27,4	4,7	95,3	16,20

	NO		NO_x		Boiler output
	[ppm]	[mg·m^{-3}]	[ppm]	[mg·m^{-3}]	[%]
1.	60	232,1	63	243,7	100
2.	44	125,3	46	131,0	90
3.	53	258,7	56	273,3	70
4.	42	215,3	44	225,5	50
5.	41	227,2	43	238,2	30
6.	57	198,1	60	208,5	100
7.	14	205,0	15	219,6	0
8.	16	192,9	17	205,0	10

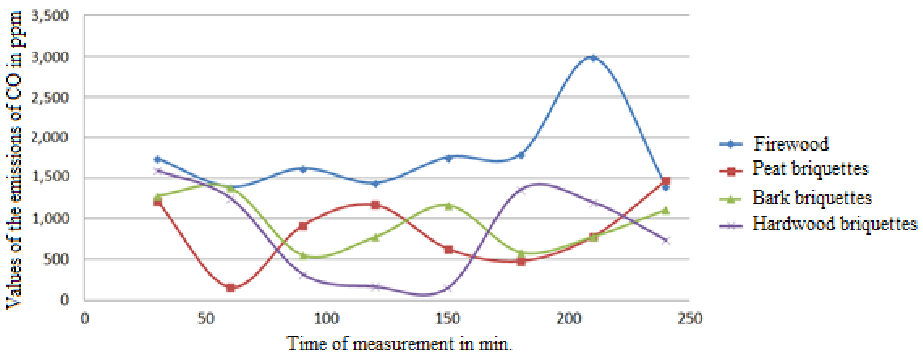
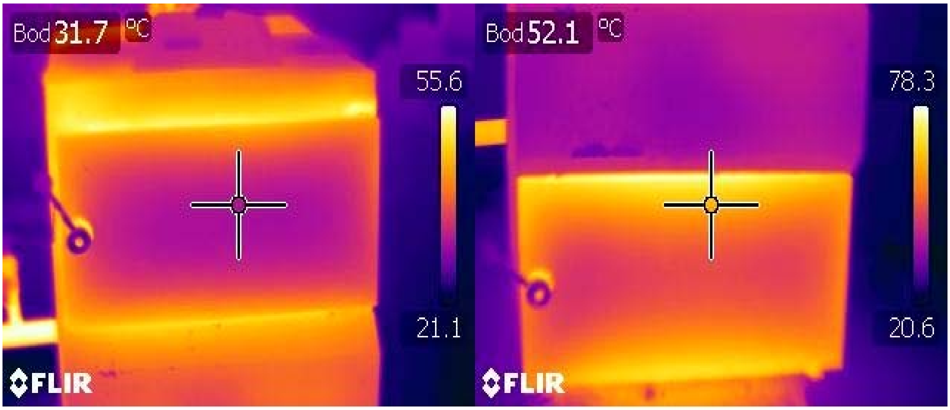


Figure 4. Dependence of production of carbon monoxide emissions on the time of measurement

In order to provide comparison of the tested biofuels, Fig. 4 shows the dependence of carbon monoxide emissions level on the time of measurement. It is apparent that the emissions reached a peak during combustion of firewood. However, the course of the emissions remained stable, except the measurement at 80% of the boiler output. Other kinds of fuel were characteristic of considerable variability in production of carbon monoxide emissions, as regards dependence on the time of measurement and on boiler output as well.

Fig. 5 shows the boiler monitored by the means of the thermal imaging camera. Thermograms depict upper part with the firebox door and lower part with the combustion chamber door. Increased temperature on the outer edges indicates so-called thermal bridge, when the heat conduction in the door frame causes warming of the surface panels. The boiler is not suitably designed in this part.



a. *b.*

Figure 5. Thermogram of the boiler surface
a. firebox door, b. combustion chamber door

According to [10], combustion of biomass, as far as carbon dioxide (CO_2) emissions are concerned, may be considered as neutral. Various authors [11], [12] and [5], [7], hold the same views and present biomass as a neutral source of energy. This article is in line with this theory, although the results of the measurements indicate relatively high levels of emissions, especially when using a biofuel the tested heat source was not designed for. Differences in flue gas temperature were also observed. The analysis of the course of boiler wall temperature is dealt with in the following paper [13].

According to [1], measurements at the heat source for a housing estate showed that combustion of biomass produces considerably higher amount of air pollutant emissions than combustion of natural gas. For example, approximately 19 times more emissions of particulate matter arise. Despite the fact that the device has a whirl separator, CO emissions are nearly 13 times higher and NO_x emissions are 9 times higher than comparable heat production from natural gas generates. This situation implies higher fees for air pollution. However, some advantages may be also pointed out, such as economic profitability and regional employment support.

The operating staff may have negative impact on the production of emissions by using of the inappropriate type of fuel for the given device, using of the fuel with higher moisture content and by the amount and frequency of loading of the device with fresh fuel.

CONCLUSIONS

The results have shown that firewood is the most suitable fuel for this type of boiler. During the combustion of firewood, the lowest levels of emissions (except CO emissions) and the highest combustion efficiency (η = 91,9÷94,6%) were measured. Other kinds of biofuels were characteristic of higher amounts of air pollutants. Variability in the emission levels was observed in bark briquettes, as regards dependence on the time of measurement and on boiler output as well. Combustion of bark briquettes also generated the highest amounts of NO_x emissions (106 ppm) and NO emissions (101 ppm).

The data supported the recommendation of the manufacturer to use firewood as a primary biofuel and wood briquettes as an alternative fuel for this boiler type. As regards long-term operation, it is not possible to draw any conclusions for another fuel from this experiment. Thermogram of the boiler surface from the front indicated increased temperature on the outer edge of the firebox door and combustion chamber door. This problem should be addressed by the manufacturer.

BIBLIOGRAPHY

[1] Vitázek, I., Vitázková, B., Ploth, J. 2012. Produkcia plynných emisií zdroja tepla na biomasu. In *Sborník příspěvku 31. mezinárodní konference „Setkání kateder mechaniky tekutin a termomechaniky“*. Brno: VUT, 2012, s. 245-248. ISBN 978-80-214-4529-1.

[2] Magó, L. 2010. Survey of solid biomass potentials of Hungarian agriculture. *Agricultural Engineering*, Vol. XXXV, No. 4. p.p. 27-33.

[3] Magó, L., Topisirovic, G., Oljača, S., Oljača, V.M. 2010. Solid biomass potential from agriculture in Hungary and Serbia. *Agricultural Engineering*, Vol. XXXV, No. 4. p.p. 35-45.

[4] Vitázek, I., Chrastina, J., Vitázková, B. 2011. Plynné emisie na vybranom zdroji tepla. In *Zborník vedeckých prác z medzinárodnej vedeckej konferencie „Technika v technológiách agrosektora 2011“*. Nitra: SPU, 2011, s.139-144. ISBN 978-80-552-0684-4.

[5] Petrović, M., Petrović, P., Mačvanin, N., Prokeš, B. 2010. Biomasa iz poljoprivrede kao potencijalni izvor alternativnih goriva pogonskih agregata. *Agricultural Engineering*, Vol. XXXV, No. 4. p.p. 47-62

[6] Dzurenda, L. 2004. Produkcia oxidov dusíka z procesu spaľovania vlhkého dreva niektorých ihličnatých a listnatých drevín. In *Acta Mechanica Slovaca,* roč. 8, 2004 č. 3-A, s. 87-92. ISSN 1335-2393.

[7] Gligorijević, R., Jevtić, J., Borak, Đ. 2010: Biomass from agriculture as an alternative fuel source potencional engines. *Agricultural Engineering*, Vol. XXXV, No. 4. p.p 63-69.

[8] Pinter, T. 2013. *Posúdenie zdroja tepla pre spaľovanie biopaliva*. (Diplomová práca). Nitra: SPU, 2013, 80s.

[9] Firemné materiály *VIMAR - Teplovodný kotol Vigas 25*. [online]. [cit. 2013-2-27]. Available through: http://www.vimar.sk/?u1=kotlyvodne&u2=vigas025&jazyk=sk. [Access date : 30.06.2014.]

[10] Jandačka, J., Mikulík, M. 2008. *Ekologické aspekty spaľovania biomasy a fosílnych palív*. [online]. 1. vydanie. Žilina: Juraj Štefuň - GEORG, 2008. 116s. ISBN 978-80969161-7-7 [cit. 2012-09-05]. Available through: http://www.biomasainfo.sk/docs/PriruckaAspekty.pdf. [Access date : 30.06.2014.]

[11] Jandačka, J. 2007. Druhy biomasy. In *Možnosti lokálneho vykurovania a výroba elektrickej energie z biomasy* [online]. [cit. 2012-07-15]. Available through: http://www.biomasa-info.sk/docs/05jandacka_s.pdf. [Access date : 30.06.2014.]

[12] Pepich, Š. 2009. Poľnohospodárska biomasa z pohľadu regionálnej bioenergetiky. In *Agrobioenergia - časopis Združenia pre poľnohospodársku biomasu*, roč. 4, 2009, č. 1, p.p. 21-24.

[13] Trávníček, P., Kukla, R., Vítěz, T., Mareček, J. 2011. Experimental Determination of Temperatures of the Inner Wall of a Boiler Combustion Chamber for the Purpose of Verification of a CFD Model. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis,* Vol.59, No. 1, p.p. 235-242. ISSN 1211-8516.

EMISIJE GASOVA TOKOM SAGOREVANJA RAZLIČITIH BIOGORIVA

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***Sažetak*: ** Biomasa, ili tačnije rečeno biogorivo, danas sve više zamenjuje fosilna goriva za grejanje. Takođe, koristi se i za zagrevanje fluida pri sušenju. Ovaj rad je usmeren na ocenu izvora toplote tokom sagorevanja različitih vrsta čvrstih biogoriva. Izvor toplote koji je ispitivan je bojler VIGAS 25 sa kontrolerom AK 2000 za kućno grejanje. Za merenje gasovitih emisija je korišćen uređaj TESTO 330-2LL. Testirana biogoriva bili su briketi od kore drveta i briketi od tvrdog drveta. Rezultati eksperimentalnih merenja produkcije gasova ova dva goriva su predstavljeni u tabelarnoj i grafičkoj formi, u zavisnosti od izlaznih parametara bojlera i vremena sagorevanja. Površinska temperatura bojlera je praćena termovizijskom kamerom Flir.

Ključne reči: *izvor toplote, čvrsto biogorivo, emisije, briketi, ogrevno drvo*

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