Reduction in Difficulties of Phytomass Combustion by Co-Combustion of Wood Biomass

Michal HOLUBCIK, Jozef JANDACKA, Jozef MICIETA

Department of Power Engineering, Faculty of Mechanical Engineering, University of Zilina, Univerzitna 8215/1, 010 26 Zilina, Slovak Republic

michal.holubcik@fstroj.uniza.sk, jozef.jandacka@fstroj.uniza.sk, jozef.micieta@fstroj.uniza.sk

DOI: 10.15598/aeee.v14i1.1386

Abstract. *Wood biomass and phytomass play very important role in the reducing of fossil fuel consumption. Nowadays, the most used biofuel in Slovak republic is log wood, namely spruce and beech wood. Alternatively, there are also biofuels based on vegetal biomass (phytomass) like wheat straw or grass. The advantage of these biofuels is lower cost price because they are usually considered as waste product. The major disadvantage of these vegetal biofuels is their problematic combustion. It is mainly due to the low ash melting temperature because of chemical composition of ash from phytomass. The low ash melting temperature causes slagging and sintering, which reduce the efficiency of the combustion process. This disadvantage causes very difficult and problematic combustion of phytomass. The article deals the way of trouble reduction during combustion of pellets made from phytomass (specific hay) through the wood pellet co-combustion in a standard automatic boiler for combustion of wood pellets. During the experiments, the mixing ratio of hay pellets and wood pellets is varied and subsequently, there is determined its impact on the combustion process, namely on heat output of the boiler, and there is also evaluated the effect of the mixing ratio on the production of carbon monoxide (CO), nitrogen oxides (NO_x), sulphur dioxide (SO_2), organic hydrocarbons (OGC) and particulate matters (PM10, PM2.5).*

Keywords

Ash melting temperature, biomass, combustion difficulties, co-combustion, emission, pellet.

1. Introduction

Biomass is nowadays becoming more and more popular energy source. This is due to decreasing reserves of fossil fuels and their rise in prices [1]. The great advantage of biofuel is renewability, especially in the planned cultivation of fast growing plants and low production of carbon dioxide (CO_2) emissions from combustion, since the amount of released CO_2 was consumed by plants during their growth. Currently, the chemical energy from biofuels is released mainly from the combustion [2]. Biomass covers approximately 15 % of total world energy consumption, especially in the Third World, where it is used mainly for cooking and heating. Relatively high proportion of energy sources cover biofuels in Sweden and Finland (17 % and 19 %), and also in other developed countries of the European Union (EU), [3].

Biomass use for energetic purposes is becoming more and more actual and supported practically all over the world. Till the current time, the most important biomass source as fuel for heating was wood in various forms [4]. It is given by wood use for household heating in area of the EU, because it is accessible easily. Current trend is use all part of trees and plants. Thus, there are used waste parts of trees like branches and limbs, which are cut to wood chip [5] and [6]. It can be automatic, respectively automatic operation fired directly in boiler plant of various heat output. Also, there are used waste from wood treatment in the wood-processing industry, mainly in form of wood sawdust. From sawdust are made high-quality fuels like wood pellets and briquettes. These forms of biofuel satisfy besides energetic, ecologic and environmental requirements, also comfort and safety attributes of combustion [7]. One of major advantages of wood pellets is possibility of household applications, where they can replace prevailing automatic boilers. In our region there are clearly prevalent automatic boilers for combustion of natural gas [3]. Currently, a disadvantage of wood pellets is their relatively high price, which is above the value of 200 €/t. The higher cost of wood-based fuel comes comparably, the more effort to seek other fuel sources for heating there is. We can say that there is a depletion of cheaper sources of wood fuel, thus it is natural to they begin use other resources such as straw, hay, various energetic plants and other fuels from vegetable or animal origin.

The most scientific works were realised in area of co-combustion of coal with various types of biomass. Biomass co-combustion also represents a low cost, sustainable, and renewable energy option that ensures reduction in net CO_2, SO_x and often NO_x emissions and also in the anaerobic release of CH_4, NH_3, H_2S, amides, volatile organic acids, mercaptants, esters, and other chemicals [8], [9].

Similar tendency of search for cheaper wood-based fuels also affects owners of pellet boilers. Many owners of pellet boilers, which are designed only for wood pellet try to use various alternative biofuels, including pellets made from plants, waste materials or various plant seeds like cereal corn, sunflower, maize and others. The owners of these boilers can't often realize that these boilers are designed for combustion of wood pellets, and therefore the use of alternative biofuels leads to several difficulties. A typical combustion trouble of alternative fuels are slagging and creating agglomerates and sintered figures from ash into the combustion chamber and the burner, due to the low ash melting temperature of certain phytomass like wheat straw. These agglomerates of ash can reduce the effectiveness of the boiler, because they accumulate on the surfaces of heat exchanger, can create local overheating of the material, support corrosion and contribute to other troubles. Second main trouble of phytomass combustion is several times higher ash content than wood pellets. So, there is need to take away higher amount of ash, but boiler system is not designed for it.

This article deals with one of the methods how to reduce troubles during combustion of cheaper and inferior quality biofuels made from phytomass, which are an alternative to wood biofuels. The article describes the impact of low-quality pellets made of hay with low-quality wood pellets on the combustion process in ordinary automatic boiler for heating with wood pellets.

2. Method of Experiment

The essence of the experiment is to determine the feasibility of co-combustion of low-quality pellets from hay in addition to low-quality wood pellets, in order to ensure suitable condition for combustion into the automatic boiler designed only for wood pellet combustion, since the combustion of hay pellets alone there are not allowed in such boiler type. During the experiments are determined the heat output of the boiler, and production of gaseous emissions, particularly carbon monoxide (CO), nitrogen oxides (NO_x), organic hydrocarbons (OGC), sulfur dioxide (SO_x) and particulate matters (PM10, PM2.5).

Fig. 1: Pellets made from hay (left), wood pellets with bark content (right).

2.1. Used Biofuels

The following pellets, made from biomass, are co-fired in various ratio, during the experiment (Fig. 1):

- Alternative pellets: hay pellets, namely hay from meadow grass. Measured parameters of reference sample have the values: the relative moisture is 7.5 % (according to STN EN 14774-1 [10]), the calorific value is 16.5 $MJ \cdot kg^{-1}$(according to STN EN 14918 [11]) and the ash content is around 6.7 % (according to STN EN 14775 [12]). The ash melting temperature – deformation temperature of pellets is approximately 760 °C. Dry sample contains 45.53 % of carbon, 5.72 % of hydrogen and 0.43 % of nitrogen.

- Wood pellets: low-quality pellets made from various sort of wood with dominance of spruce wood also with bark contain. Measured parameters of reference sample have the values: the relative moisture of pellets is 7.5 % (according to STN EN 14774-1 [10]), the calorific value is 17.7 $MJ \cdot kg^{-1}$ (according to STN EN 14918 [11]) and the ash content is around 0.8 % (according to STN EN 14775 [12]). The ash melting temperature – deformation temperature of pellets is approximately 1090 °C. Dry sample contains 49.84 % of carbon, 6.03 % of hydrogen and 0.13 % of nitrogen.

Alternative pellets (A) and wood pellets (D) are co-fired in ratios showed in Tab. 1.

Tab. 1: Tested mixtures of alternative and wood pellets.

Sample	Mixing ratio of pellets
A0/D100	0 % Alternative, 100 % Wood
A20/D80	20 % Alternative, 80 % Wood
A40/D60	40 % Alternative, 60 % Wood
A60/D40	60 % Alternative, 40 % Wood
A80/D20	80 % Alternative, 20 % Wood

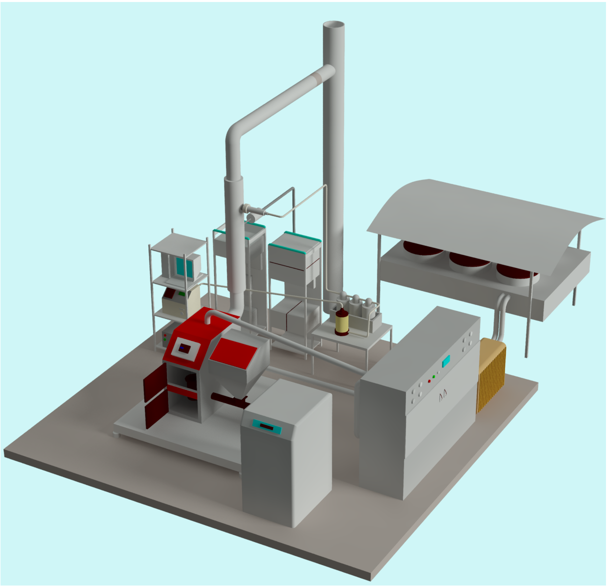

Fig. 2: The experimental device for testing of various boiler.

2.2. Measurement of Thermal-Technic Parameters of Boiler

Co-combustion of alternative pellets, namely pellets made from grass mixes with low-quality wood pellets is implemented on an experimental device for testing boilers. The device is built from the experimental boiler, the device for heat consumption (i.e. device for regulation of heat produced by boiler), the gaseous emission analyzer, the particulate matter analyzer, measuring apparatus, to which are connected all the measuring equipment and the computer for processing of the measured data (Fig. 2). The various parameters are recorded every 20 seconds. During the measurements is ensured constant chimney draft 12±2 Pa via a flue fan, which speed is controlled by the frequency regulator.

The experimental boiler is the automatic hot-water boiler designed to combustion of wood pellets with a nominal performance 18 kW and with the installed retort burner (Fig. 3). All samples of pellets with various mixing ratio of alternative and wood pellets are burned at the same operating settings of the boiler – fuel feeding time of spiral conveyor is 18 s, idle time of conveyor is 25 s, the combustion air is set to constant air access.

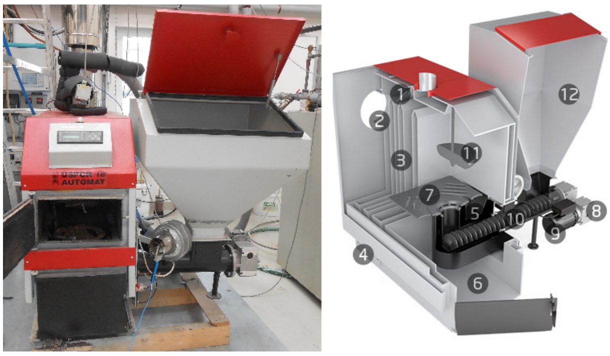

Fig. 3: The experimental boiler (1 – Firing flap, 2 – Flue ducting, 3 – Heat exchanger, 4 – Cleaning lid, 5 – Air inlet, 6 – Ash pan, 7 – Furnace, 8 – Gearbox, 9 – Motor, 10 – Feed screw, 11 – Flue gas rectifier, 12 – Fuel hopper).

The thermal power of experimental boiler was measured by calorimetric method where the flow of the heat transfer medium (water) was measured by magnetic flowmeter YOKOGAWA ADMAG AXF with measurement accuracy ±0.35 % and the temperature difference of the heat transfer medium (water) was measured by two paired resistance thermometers PT100 with measurement accuracy ±0.4 %.

The production of CO, NO_x, SO_2 and OGC (organic hydrocarbons) are measured by the flue gas analyzer ABB AO 2020, which records the value of emissions in units ppm (parts per million). These values are converted to $mg \cdot m^{-3}$ according to the equation:

$$Y = X \cdot \frac{M}{22.41} \cdot \frac{p}{101325}, \tag{1}$$

where Y represents a calculated production for the one of emissions in $mg \cdot m^{-3}$, X is the measured emission in ppm unit, M represents the molecular weight of the components in $g \cdot mol^{-1}$, the value 22.41 represents the standard molar volume in $dm^3 \cdot mol^{-1}$ and p represents the pressure in Pa. As the normalized concentration of oxygen in the flue gas from a boiler O_{2n} is considered 10 %. Therefore, the measured values of each emission are recalculated according to the formula:

$$Y_{10\,\%\,O_2} = Y \cdot \frac{21 - O_{2n}}{21 - O_{2avg}}, \tag{2}$$

where $Y_{10\,\%\,O_2}$ is the normalized emission concentration in $mg \cdot m^{-3}$, Y represents emission, which is calculated by a previous Eq. (1) in $mg \cdot m^{-3}$, O_{2n} represents the normalized concentration of oxygen in the flue gas in % and O_{2avg} represents the mean value of the oxygen concentration in the flue gas in %. This measurement device is regularly calibrated by authorized person from the external company.

The production of particulate matters is measured by gravimetric method, which consists of multiple sampling by use of the complex sampling apparatus under

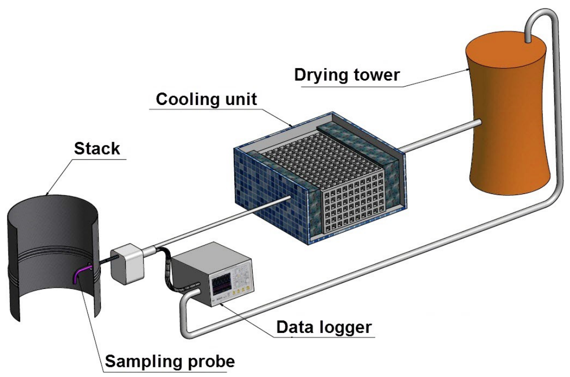

Fig. 4: The measurement scheme for a flue gas analysis by gravimetric method.

Fig. 5: The combustion chamber of the boiler during alternative pellet combustion.

isokinetic conditions with subsequent gravimetric evaluation. It is important that the gas sample is taken away isokinetic, i.e. velocity of gas in the nozzle of the sampling probe have to be the same as the velocity of gas in the flue-gas ducting. The samples of solids are collected on the so-called flat filters.

For the measurement of the particulate matter production are used the analyzer Tecora (Fig. 4) and the three-stage separation impactor ISOSTACK for the automatic isokinetic measurement of low, medium and high concentrations of particulate matters according to norm EN 13284-1 [13] and STN ISO 9096 [14]. The use of mentioned impactor enables to determine the particle size distribution: above 10 μm, until 10 μm (PM10) and until 2.5 μm (PM2.5). The regulation of isokinetic condition for flue gas sampling, is secured on the basis of flue gas velocity in the flue way. The flue gas velocity is measured by the Pitot (i.e. airspeed) tube. This measurement device is regularly calibrated by authorized person from the external company.

All thermal-technical tests of the boiler are performed according to the norm STN EN 303-5 [15]. The experiments were realized 3 times for each tested biofuel sample.

3. An Influence of Co-Combustion of Alternative Pellets and Wood Pellets on Combustion Process

During the experiments are confirmed the assumptions that the combustion of alternative pellets alone in the boiler for combustion of wood pellets is complicated. The difficulties are the creating of agglomerates, clinkers, sintered matters and ash deposits. The essence of the named problems is caused by the low ash melting temperature of alternative pellets, namely by the low ash softening temperature. This caused clogging of the under fed burner (Fig. 5). It was needed to remove the ash deposits at regular time intervals (approximately 10 minutes). Otherwise, ash deposits could extinguish the flame and cause other troubles like clogging the burner. The experiments of co-combustion are realized so that the first is only wood pellets in combustion process. The combustion of wood pellets alone is without troubles on cue. Sequentially, there are fired mixtures of alternative and wood pellets at the ratio from 20 %/80 % (A20/D80) until 80 %/20 % (A80/D20). This is limit ratio, which has slag formation so large that combustion is not continuous, and the sintered ash is necessary to remove manually.

The Fig. 6 shows the average heat output of the experimental boiler during the co-combustion of alternative and wood pellets in various mixing ratio. The increasing proportion of alternative pellets causes declining in the heat output of tested boiler, due to lower calorific value of alternative pellets by comparison with wood pellets and the influence of sintering ash, and also removing of unburned fuel together with sintered ash into the ash pan.

The Fig. 7 shows the average values of CO and NO_x production during the co-combustion of alternative and wood pellets in various mixing ratio. With increasing proportion of alternative pellets, there is increased production of CO, due to reduced access of oxygen to the flame core because of agglomerates and clinkers. This fact caused that the higher proportion of alternative pellets there is, the more incomplete the combustion process becomes. The CO production is significantly affected also by burning fixed carbon out in the ash pan of the boiler. The measured CO concentrations do not exceed 3000 $mg \cdot m^{-3}$, which is the emission limit for class 3 of automatic boilers for solid biofuels according to EN 303-5 [15]. Tested automatic boiler for combustion of wood pellets quality parameters achieves class

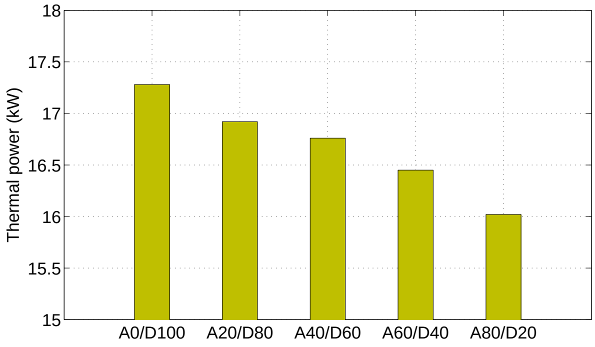

Fig. 6: The average heat output of the experimental heat source during co-combustion of alternative and wood pellets in the dependence on their various ratio.

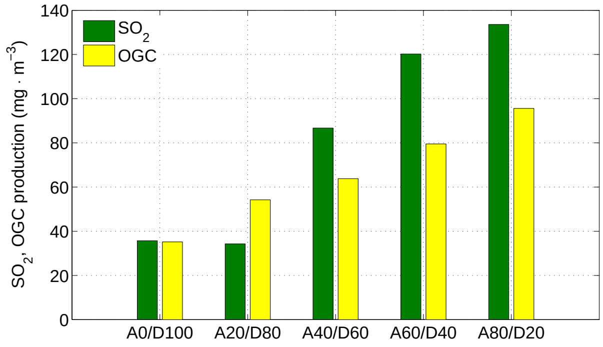

Fig. 8: The average SO_2 and OGC production during co-combustion of alternative and wood pellets in the dependence on their various mixing ratio.

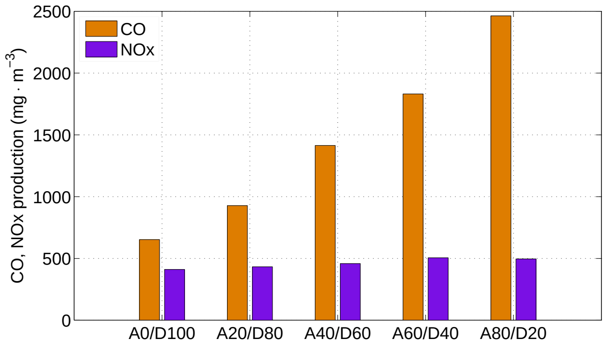

Fig. 7: The average CO a NO_x production during co-combustion of alternative and wood pellets in the dependence on their various ratio.

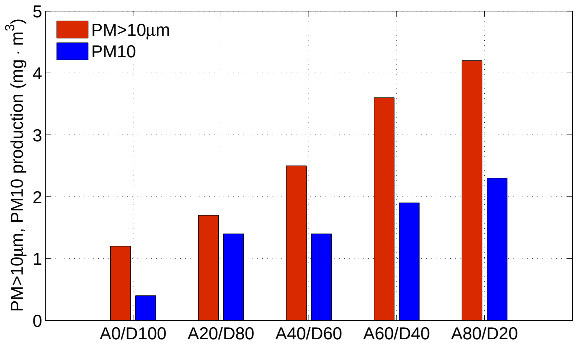

Fig. 9: The average production PM>10 µm a PM10 during co-combustion of alternative and wood pellets in various ratio.

5 according to EN 303-5 [15], i.e. total CO production is less than 500 mg·m^{-3}. NO_x production is increased with raising ratio of alternative pellets and wood pellets, due to the higher content of nitrogen in hay.

The Fig. 8 shows the average value of the SO_2 and OGC production during the co-combustion of alternative and wood pellets in various mixing ratio. SO_2 production is increased with increasing proportion of alternative pellets, due to higher sulfur content in hay, compared with wood pellets. The increasing proportion of alternative pellets increases OGC production, e.g. in case of 80 % ratio of the alternative pellets to wood pellets, there is triple OGC production compared the combustion of wood pellets alone. The measured OGC concentrations do not exceed the 100 mg·m^{-3}, which is the emission limit for class 3 of automatic boilers for solid biofuels according to EN 303-5 [15]. Tested automatic boiler by combustion of high-quality wood pellets achieves the emission parameters class 5 according to EN 303-5 [15]. In this case, total OGC production is less than 20 mg·m^{-3}.

The Fig. 9 shows the average value of the particulate matter production PM>10 µm, PM10 and PM2.5 during co-combustion of alternative and wood pellets in various mixing ratio. Production of PM>10 µm and PM10 increases with increasing proportion of alternative pellets, due to differences in the chemical composition of fuels, higher ash content of the alternative pellets and partially incomplete combustion.

The average production of PM2.5 i.e. the smallest particle size until 2.5 µm is manifold higher than the production of particles with a size above 2.5 µm (PM>10 µm + PM10). PM2.5 particles are the most dangerous in view of human healthy, because they can accumulate in the lungs and penetrate deeply into the blood circulation, in which they can cause a cancer. The average PM2.5 production is not increased by increasing proportion of alternative pellets, except the mixing ratio A80/D20, in which is the PM2.5 production higher by 56 mg·m^{-3}, compared to the PM2.5 production during the combustion of wood pellets alone.

The measured total concentrations reach, even exceed the value 150 mg·m^{-3}, which is the emission limit for class 3 of automatic boilers for solid biofuels according to EN 303-5 [15]. Tested automatic boiler during combustion of high-quality wood pellets achieves the

Tab. 2: Maximal deviations of measured values during experiments.

Sample/Parameter	A0/D100	A20/D80	A40/D60	A60/D40	A80/D20
Thermal Power (kW)	±0.458	±0.526	±0.397	±0.431	±0.284
CO (mg·m^{-3})	±29.1	±24.5	±87.4	±112.5	±109.7
NO$_x$(mg·m^{-3})	±4.4	±3.2	±6.1	±3.9	±11.8
SO$_2$ (mg·m^{-3})	±0.86	±0.74	±3.12	±1.94	±4.52
OGC (mg·m^{-3})	±1.17	±2.79	±1.98	±4.01	±2.87
PM>10 μm (mg·m^{-3})	±0.2	±0.2	±0.2	±0.2	±0.2
PM10 (mg·m^{-3})	±0.2	±0.2	±0.2	±0.2	±0.2
PM2.5 (mg·m^{-3})	±9.1	±6.3	±7.4	±11.2	±20.8

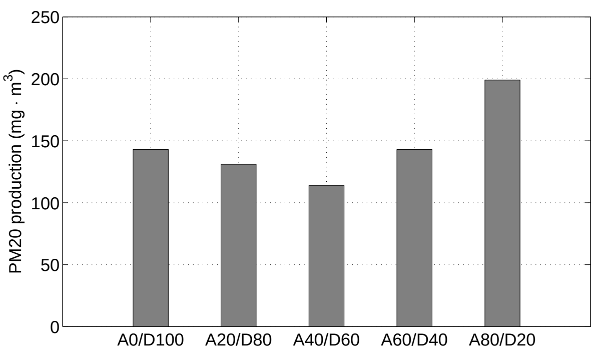

Fig. 10: The average PM2.5 production during co-combustion of alternative and wood pellets in the dependence on their various ratio.

emission parameters for class 5 according to EN 303-5 [15]. Concretely in this case, the total PM production is less than 40 mg·m^{-3}.

All presented values are values obtained from the difference of real measured values during experiments and measured values during blind measurement (without combustion). Maximal deviations of measured values during experiments for all tested parameters are shown in the Tab. 2. Maximal deviation did not exceed 10 % except PM2.5 measurement of A80/D20 sample.

4. Conclusion

The co-combustion of alternative pellets from hay with low-quality wood pellets is not suitable in the boiler with a conventional retort burner, which is designed for combustion of usual wood pellets. There is required a frequent operator intervention – mainly removing of slag formations, ash deposits on the burner parts and much more frequently removing ash from the ash pan. An increasing proportion of alternative pellets influences the heat output of the boiler negatively, as well as it has a negative impact on the production of all monitored emissions. Based on the knowledge obtained during the experiments, we can conclude that the co-combustion of alternative pellets and wood pellets reduces the combustion troubles of biofuels from phytomass, which has the low ash melting temperature, insufficiently in the ordinary boilers with a retort burner for usual wood pellets. For the purpose of successful co-combustion of problematic biofuels together with others in usual boiler is the further possibility to test fuel with different properties, especially fuel with higher amount of ash content. Since, we assume that mixed ash, which is produced from biomass with low and higher ash melting temperature, would be help solve this trouble. Another alternative, how to achieve satisfactory combustion of problematic biofuels in conventional boilers may be use of additives or modification of the combustion chamber design.

Acknowledgment

his article has been prepared within the framework of the project VEGA 1/0548/15 The impact of bark content and additives on mechanical, energy and environmental characteristics of wood pellets.

References

[1] HORBAJ, P. and N. JASMINSKA. Analysis of Economical Efficiency of Low-Temperature Heating Utilization and HW Supply in Combination with Solar Collectors in Housing and Municipal Sphere. *Acta Mechanica Slovaca*. 2010, vol. 14, iss. 1, pp. 76–79. ISSN 1335-2393. DOI: 10.2478/v10147-011-0010-3.

[2] HORBAJ, P., P. LUKAC, M. LAZAR and M. LAZAROVA. Preparation and Utilization of Biogas Produced from Wastes in Slovakia. *Acta Mechanica Slovaca*. 2014, vol. 18, iss. 2, pp. 64–69. ISSN 1335-2393.

[3] HORBAJ, P., T. ROMAN and P. TAUS. Doterajsie skusenosti zo spalovania drevnej stiepky a slamy za ucelom vykurovania budov. *Acta Mechanica Slovaca*. 2007, vol. 11, iss. 4, pp. 417–421. ISSN 1335-2393.

[4] LABAJ, J., A. KAPJOR and S. PAPUCIK. *Alternativne paliva pre energetiku a dopravu*. Zilina:

Juraj Stefun–GEORG, 2011. ISBN 978-80-89401-15-4.

[5] LABAJ, J., M. PATSCH and D. BARTA. Combustion of alternative fuels. In: *TRANSCOM 2009*. Zilina: University of Zilina, 2009, pp. 67–76. ISBN 978-80-554-0031-0.

[6] VITAZEK, I. and J. TIROL. Emisie pri spalovani biomasy. In: *Technika v technologiach agrosektora 2009*. Nitra: Slovak University of Agriculture in Nitra, 2009, pp. 73–79. ISBN 978-80-552-0287-7.

[7] DZURENDA, L. and N. DELIISKI. Drying of beech timber in chamber drying kilns by regimes preserving the original colour of wood. *Acta Facultatis Xylologiae*. 2013, vol. 55, no. 2, pp. 31–42. ISSN 1336-3824.

[8] SAHUA, S. G., N. CHAKRABORTYB and P. SARKARA. Coal-biomass co-combustion: An overview. *Renewable and Sustainable Energy Reviews*. 2014, vol. 39, iss. 1, pp. 575–586. ISSN 1364-0321. DOI: 10.1016/j.rser.2014.07.106.

[9] TILLMAN, D. A. Cofiring benefits for coal and biomass. *Biomass and Bioenergy*. 2000, vol. 19, iss. 6, pp. 363–364. ISSN 0961-9534. DOI: 10.1016/S0961-9534(00)00048-9.

[10] STN EN 14774-1:2010. *Solid biofuels – Determination of moisture content – Oven dry method – Part 1: Total moisture – Reference method*. Bratislava: STN, 2010.

[11] STN EN 14918:2010. *Solid biofuels – Determination of calorific value*. Bratislava: STN, 2010.

[12] STN EN 14775:2010. *Solid biofuels – Determination of ash content*. Bratislava: STN, 2010.

[13] STN EN 13284-1:2003. *Air quality – Stationary source emissions – Determination of low range mass concentration of dust – Part 1: Manual gravimetric method*. Bratislava: STN, 2003.

[14] STN ISO 9096:2004. *Air quality – Stationary source emissions – Manual determination of mass concentration of particulate matter*. Bratislava: STN, 2004.

[15] STN EN 303-5:2012. *Heating boilers – Part 5: Heating boilers for solid fuels, manually and automatically stoked, nominal heat output of up to 500 kW – Terminology, requirements, testing and marking*. Bratislava: STN, 2012.

About Authors

Michal HOLUBCIK received the doctoral degree Ph.D. in field of study Energy machines and equipment in year 2013 at Department of energy technics and equipment at University of Zilina. He defended the thesis: Possibilities of increasing of ash melting temperature from biomass. Currently, he works as a research worker and he solves issues with use of alternative energy sources, especially improving energy and mechanic parameters of biofuels, improving combustion process of biofuels, energetic use of waste and micro-cogeneration.

Jozef JANDACKA received the professor degree in field of study Energy machines and equipment in year 2010 at University of Zilina. Currently, he works as a vice-rector for development at University of Zilina. He deals with theoretic and experimental issues in branch of thermal technics and heat energy, heat and energy mechanisms and use of renewable energy sources.

Jozef MICIETA received master degree M.Sc. from Energy machines and equipment in 2012 at University of Zilina. Currently, he is a postgraduate student at University of Zilina. His research interests include CFD simulation of combustion and small-scale boilers for biomass.