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Chosen properties of the forest and agricultural biomass

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Abstract: *Chosen properties of the forest and agricultural biomass*. The objective of the study is to determine the following characteristics of the forest and agricultural biomass: combustion heat, calorific value, and the content of moisture, ash, sulfur, and carbon. The following kinds of biomass were taken into account: sunflower husk pellets, wood pellets, straw and hay briquettes, and forest chips. The investigated biomass properties (their average values) change: for combustion heat between 20.0 (wood pellets) and 14.6 MJ/kg (forest chips), for calorific value between 17.7 (sunflower husk pellets) and 12.8 MJ/kg (forest chips), for moisture content between 29.6 (forest chips) and 7.5% (wood pellets), for ash content between 7.2 (hay briquettes) and 1.2% (wood pellets), for carbon content between 52.3 (wood pellets) and 37.4% (forest chips), and for sulfur content between 0.15 (straw briquettes) and 0.02% (forest chips).

Key words: forest biomass, agricultural biomass, combustion heat, calorific value, ash content, elements content

INTRODUCTION

Facing the finiteness of fossil fuels and the environmental problems arising from their consumption, new prospects to cover energy demand are urgently required [Osowski and Fahlenkamp 2006].

Biomass is the one of the most important regenerative energy sources. The advantage of biogenous energy sources is apart from their regeneration and CO_2 – neutrality their availability in the large variety of appearances. Wood, energy crops, as well as agricultural and forest residues, which are the main renewable energy sources, are typical examples of biomass [Osowski and Fahlenkamp 2006, Demirbaş 2011].

Biomass has been used as an energy source for eons. The utilization of biomass for heating and cooking not only dates to precivilized conditions, but it also continues to be used for these purposes to this day in many developed and developing nations. The modern use of biomass is distinguished from the traditional use of biomass energy by its conversion into high-quality energy carriers, like electricity and biomass liquid fuels for transportation [Hoogwijk et al. 2005, Hubbard 2015].

Biomass in Poland has the greatest technical potential of all domestic sources of renewable energy. The use of biomass as a fuel, especially in large combustion plants allows to limit of CO_2 emissions in the national balance sheet [Bloch-Michalik and Gaworski 2015]. Moreover it is important to notice that since 1 January 2013 Poland has been considered financially responsible for the greenhouse gases it emits, with means that the ecological argument becomes also economically credible. The existing infrastructure related to energy production in Poland enables, which minor costs involved, the use of biomass potential, a fuel that is relatively inexpensive and can be used to improve the energy security of Poland [Dzikuć and Piwowar 2016].

Utilization of biomass for energy purposes calls for its prior preparation for subsequent processing and acquiring energy. The type of biomass, its moisture content, combustion heat, calorific value, ash, sulfur and carbon content should be taken, among others characteristics, into consideration. Problems connected with moisture content in the forest chips and their drying were investigated by, among others, Gendek and Głowacki [2009] and Głowacki and Gendek [2011]. The combustion heat and calorific value of selected wood species were determined by, among others, Björn et al. [2012], Reva et al. [2012], So and Eberhardt [2013], Gendek and Zychowicz [2014], Zeng et al. [2014], Gendek [2015] and Lisowski et al. [2015]. The ash content in different parts of trees and straw were investigated by, among others, Olanders and Steenari [1995], Kataki and Konwer [2001], Liu and Li [2010], and Zeng et al. [2014].

The objective of the study was to determine the following characteristics of the forest and agricultural biomass: combustion heat, calorific value, and the content of moisture, ash, sulfur, and carbon. The following kinds of biomass were taken into account: sunflower husk pellets, wood pellets, straw briquettes, hay briquettes, and forest chips.

MATERIAL AND METHODS

The material moisture content was determined according to PN-EN 14774--1.2010 Standard. The samples were dried for 24 h in the temperature of 105 ±2°C, until achieving dry substance.

Measurement of the combustion heat and calculation of the calorific value was performed in accordance with the standard PN-ISO 1928.2002. Combustion was conducted in a calorimetric bomb placed in calorimeter LECO AC 600.

The material ash content was determined using automatic analyzer LECO TGA 701. Measurement of the sulfur content was performed in analyzer LECO SC-144 DR, whereas the material carbon content was determined using automatic analyzer LECO 628 CHN.

Significance of the impact of biomass kind on combustion heat, calorific value, and content of moisture, ash, sulfur, and carbon was determined using analysis of variance (Anova) after accepting the uniformity test of Lavene's variance. Tukey test HSD was applied for division into uniform groups (at the significance level of $p = 0.05$). Calculations were carried out using IBM®SPSS® Statistics 21 application.

RESULTS AND DISCUSSION

Figure 1 presents the exemplary results of the dependence upon moisture content of the following characteristics of hay and straw briquettes: combustion heat, calorific value, content of ash, sulfur and carbon. It can be observed that the energetic values decrease with increasing of moisture content. The same dependence was stated for sunflower husk pellets, wood pellets, and forest chips and in the literature, e.g. Głowacki and Gendek [2011]. The higher the moisture content, the lower the carbon content in hay and

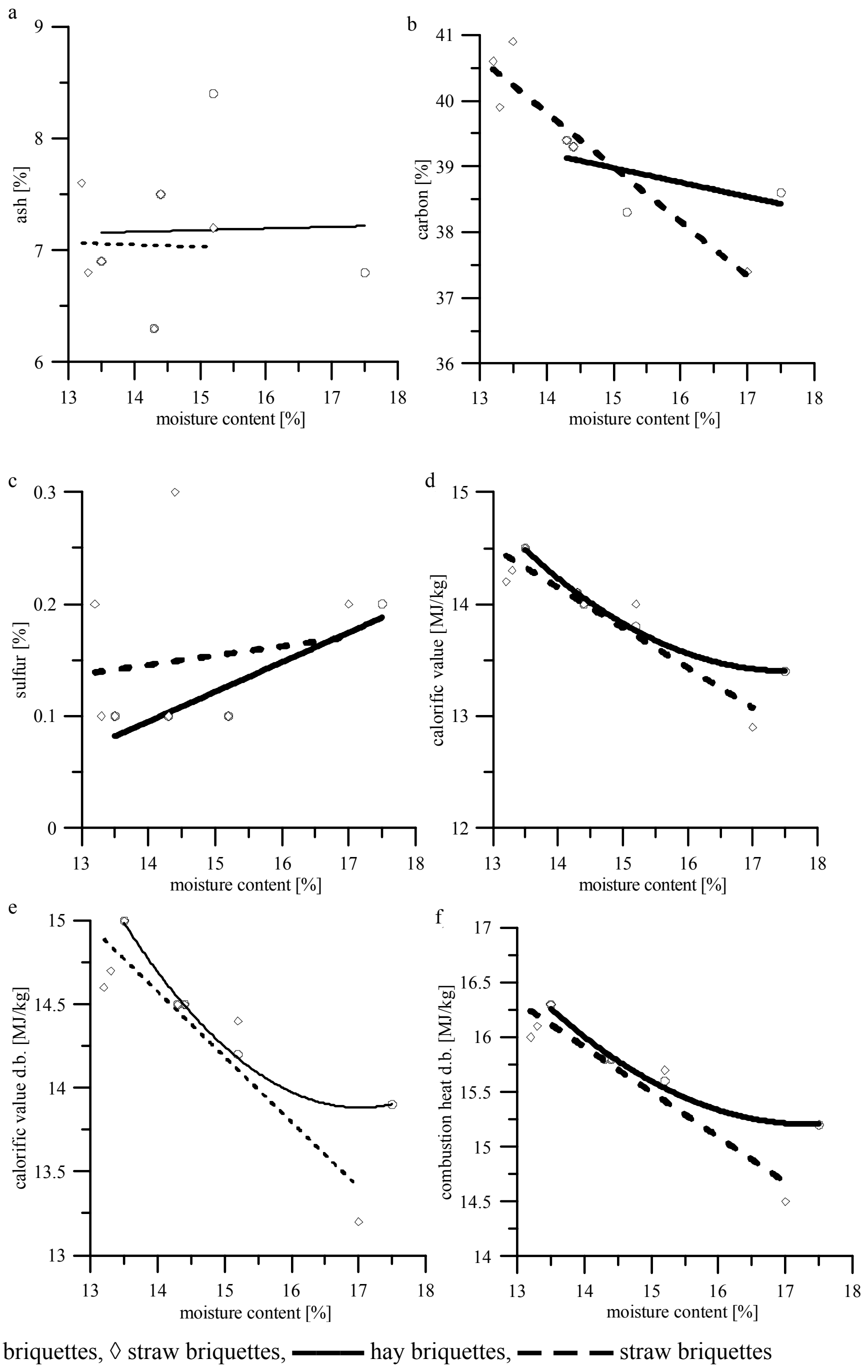

FIGURE 1. The dependence of: (a) ash content; (b) carbon content; (c) sulfur content; (d) calorific value; (e) calorific value on d.b.; (f) combustion heat upon moisture content for hay and straw briquettes

straw briquettes and the same situation was observed for the rest of investigated biomass. It can be stated (Fig. 1) that sulfur content increases with increasing of moisture content. The same dependence was observed for forest chips but for sunflower husk and wood pellets the inverse relationship was stated. It can be assumed that the value of ash content in hay and straw briquettes as well as in forest chips do not depend on the moisture content. Discussed value for sunflower husk and wood pellets increases with increasing of moisture content.

The average values of moisture content, ash content, carbon and sulfur content, and the average values of calorific value and combustion heat and the results of statistical analyses are presented in Figures 2–5.

It can be stated that the average moisture content (Fig. 2) of forest chips is the greatest (29.6%) and discussed value of wood pellets is the lowest (7.5%). The average moisture content of forest chips differs significantly from discussed values of remaining types of biomass. The differences in discussed value between sunflower husk pellets and wood pellets and between hay and straw briquettes are not statistically significant.

Comparing the obtained results of ash content (Fig. 3) one can find that the highest average values contain hay and straw briquettes (7.2 and 7.1%) and the difference is statistically insignificant. The lowest average ash content shows wood pellets (1.2%). The discussed values for sunflower husk pellets, wood pellets, briquettes, and forest chips differ significantly. Obtained values of ash content are slightly different that reported by Zeng et al. [2014] for different parts of Masson pine trees (0.21–3.20%) and showed by Olanders and Steenari [1995] for bark/wood chips and straw pellets (2.17–4.18%).

It can be seen that the average carbon content (Fig. 4a) is the greatest for wood pellets (52.3%) and the lowest for forest

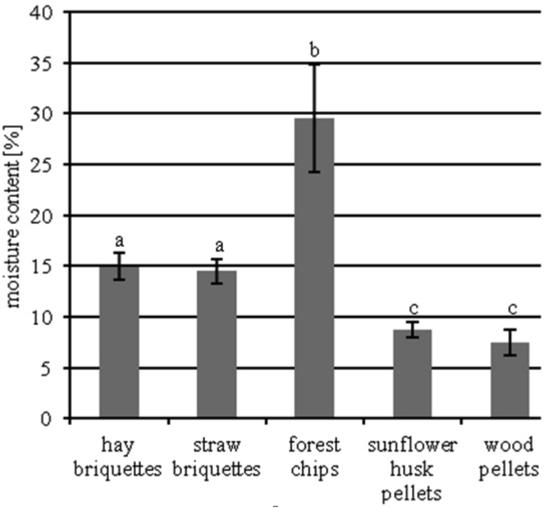

FIGURE 2. Average values of moisture content in different kind of biomass and the results of statistical analyses (a, b, c – the same letters indicated homogenous groups)

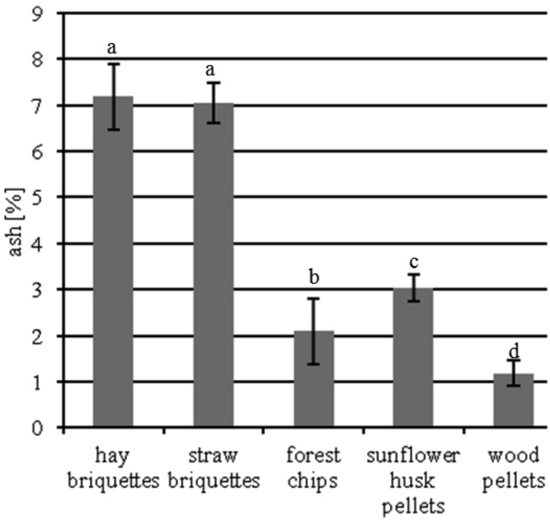

FIGURE 3. Average values of ash content in different kind of biomass and the results of statistical analyses (a, b, c, d – the same letters indicated homogenous groups)

chips (37.4%). Analysis of the effect of the biomass kind on the value of the average carbon content showed that discussed values are significantly different for sunflower husk pellets and wood pellets, and the difference between mentioned kinds of biomass and the rest of investigated ones is statistically significant either. The impact of the hay and straw briquettes and forest chips on the average carbon content is statistically insignificant. Kubica et al. [2003] reported similar values of carbon content for biomass (44–51%). Wandrasz and Wandrasz [2006] gave the following range of carbon content: from 37.4 (bark of leafy trees) to 56.5% (oak tree with bark) and from 37.1 (grass from roadside) to 60.5% (rapeseed seeds).

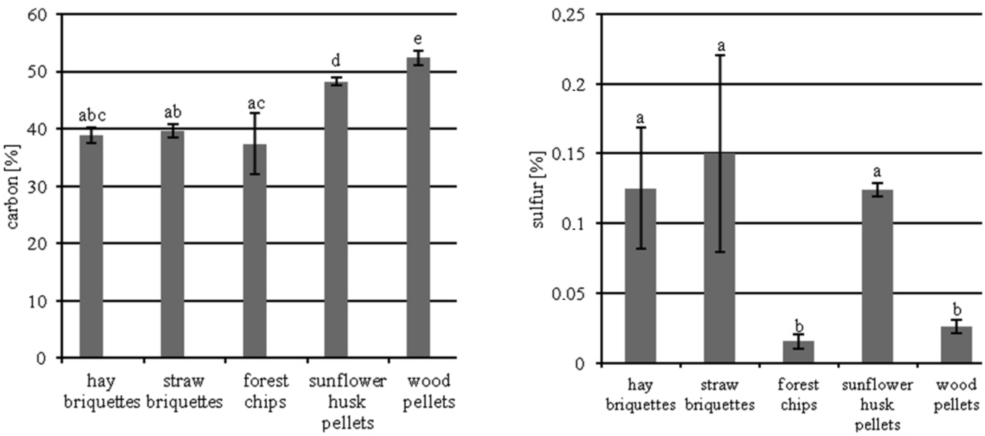

FIGURE 4. Average values of: carbon content (a), sulfur content in different kind of biomass (b) and the results of statistical analyses (a, b, c, d, e – the same letters indicated homogenous groups)

The value of the average sulfur content (Fig. 4b) change between 0.015 for forest chips and 0.15% for straw briquettes. The differences between the discussed value for sunflower husk pellets, hay and straw briquettes are statistically insignificant. The same situation can be observed between wood pellets and forest chips. It can be find in the literature the similar values of sulfur content: 0.08–0.19% for bark/wood chips and straw pellets [Olanders and Steenari 1995] and 0.02–0.3% for different parts of wood, straw, grains and seeds [PN-ISO 1928, 2002].

Figure 5 shows that calorific value for sunflower husk pellets and wood pellets is the greatest (17.7 and 17.6 MJ/kg, respectively, and 18.7 and 18.6 MJ/kg d.b., respectively). The lowest average calorific value shows forest chips (12.8 MJ/kg and 13.5 MJ/kg d.b.). The differences between discussed values are for sunflower husk and wood pellets statistically insignificant. The same situation can be observed between hay and straw briquettes. These briquettes show very similar values of calorific value: 13.96 MJ/kg and 14.42 MJ/kg d.b. for hay briquettes, 14.00 MJ/kg and 14.42 MJ/kg d.b. for straw briquettes. The following values of calorific values of biomass can be found in the literature: 21–23 MJ/kg for different parts of Masson pine tree [Zeng et al. 2014], 19.05–20.00 MJ/kg for coniferous tree and 17.34–20.86 MJ/kg for deciduous tree [Dobrowolska et al. 2010], from 14.64 (spruce bundle) to 19.53 MJ/kg (pine with shrub layer) [Gendek and Zychowicz 2014], from 15.04 (briquettes from apple tree wood) to 15.20 MJ/kg (pellets from apple tree wood) [Lisowski et al. 2015], from 17.98 (pure pine sawdust) to 18.32 MJ/kg (crushed pine cones) [Gendek 2015]. The quality requirements for pellets vary according to different standards. The calorific value should: amount to 17.5–19.5 MJ/kg (German standard DIN 51731), be greater than 18 MJ/kg (ISO 17225-1, Austrian standard Ö-NORM M 7135), be greater than 16.9 MJ/kg (Swedish standard SS 18 71 20) [Lisowski et al. 2015].

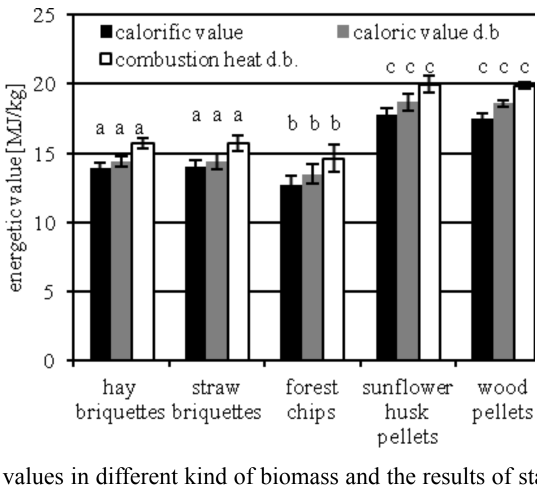

FIGURE 5. Energetic values in different kind of biomass and the results of statistical analyses (a, b, c – the same letters indicated homogenous groups)

Average values of combustion heat (Fig. 5) for sunflower husk pellets and woods pellets are almost the same (20.0 and 19.9 MJ/kg d.b., respectively) and this difference is statistically insignificant. Discussed values for hay and straw briquettes are also very similar (15.7 and 15.8 MJ/kg d.b., respectively) and the difference is statistically insignificant. The average value of combustion heat for forest chips is the lowest (14.6 MJ/kg d.b.). Similar values of combustion heat can be found in the literature. Gendek and Zychowicz [2014] stated that discussed value varies from 16.09 (spruce bundle) to 21.03 MJ/kg (pine with shrub layer), whereas Lisowski et al. [2015] obtained the following values for biomass from apple tree: 16.02 MJ/kg for briquettes and 16.18 MJ/kg for pellets. Wandrasz and Wandrasz [2006] gave the following values for combustion heat: 18.61 MJ/kg for oak bushes, 19.42 MJ/kg for oak bark, 20.05 MJ/kg for spruce, and 20.38 MJ/kg for fir.

CONCLUSIONS

The following conclusions can be drawn from the comparison of investigated forest and agricultural biomass:

1. The calorific value and the combustion heat is the greatest for sunflower husk pellets and wood pellets therefore it can be stated that both kinds of pellets are the best (among five investigated kind of biomass) for energy purposes.
2. The lowest calorific value and combustion heat shows the forest chips. The moisture content of discussed material is the greatest.
3. The lowest values of ash and sulfur content contain wood pellets and forest chips.
4. Hay and straw briquettes show the highest values of ash content. Both mentioned materials and sunflower husk pellets contain high level of sulfur.

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Streszczenie: *Wybrane właściwości leśnej i rolniczej biomasy*. Celem badań jest wyznaczenie następujących właściwości biomasy leśnej i rolniczej: ciepło spalania, wartość opałowa, zawartość wody, popiołu, siarki i węgla. Badano następujące rodzaje biomasy: pelety z łuski słonecznika, pelety drzewne, brykiety z siana, brykiety ze słomy i zrębki leśne. Spalanie przeprowadzano w bombie kalorymetrycznej umieszczonej w kalorymetrze LECO AC 600. Zawartość popiołu oznaczano w analizatorze automatycznym LECO TGA 701, zawartość siarki wyznaczano w analizatorze LECO SC-144 DR, a zawartość węgla w analizatorze automatycznym LECO 628 CHN. Wyznaczone właściwości biomasy (ich średnie wartości) zmieniały się w zakresie: ciepło spalania od 20 (palety drzewne) do 14,6 MJ/kg (zrębki leśne), wartość opałowa od 17,7 (pelety z łuski słonecznika) do 12,8 MJ/kg (zrębki leśne), zawartość wody od 29,6 (zrębki leśne) do 7,5% (pelety drzewne), zawartość popiołu od 7,2 (brykiety z siana) do 1.2% (pelety drzewne), zawartość węgla od 52,3 (pelety drzewne) do 37,4% (zrębki leśne), zawartość siarki od 0,15 (brykiety ze słomy) do 0,02% (zrębki leśne).

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