Influence of chemical properties of biomass plant agricultural origin on outlays energy incurred during the production of pellets

Wpływ właściwości chemicznych biomasy roślinnej pochodzenia rolniczego na nakłady energii ponoszone podczas produkcji peletów

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Abstract

In this study, was analysed made the measurements of the content of water, carbon, hydrogen, nitrogen, sulphur and chlorine in plant biomass of agricultural origin in the context of the impact of these features on the energy expenditures incurred in its pelleting. For the examined raw materials statistical analysis results showed negative linear trend between energy expenditures and: water content, total sulfur and chlorine. Positive linear trend between energy expenditures and: contents of carbon, hydrogen, and nitrogen. Wherein the coefficients of correlation expenditures energy and: carbon, hydrogen and chlorine are significant $p<0.05$.

Keywords: chemical properties of the biomass, compaction energy consumption, plant biomass

Streszczenie

W pracy, analizowano wykonane oznaczenia zawartości wody, węgla, wodoru, azotu, siarki i chloru w biomasie roślinnej pochodzenia rolniczego pod kątem wpływu tych cech na ponoszone nakłady energetyczne jej peletowania. Dla rozpatrywanych surowców analiza statystyczna otrzymanych wyników wykazała ujemne tendencje liniowe między nakładem energii elektrycznej a: zawartością wody, siarki całkowitej i chloru oraz dodatnie między nakładem energii elektrycznej a: zawartością węgla, wodoru i azotu. Przy czym współczynniki korelacji dla nakładu energii elektrycznej i: zawartości węgla, wodoru oraz chloru są istotne z $p<0,05$.

Słowa kluczowe: właściwości chemiczne biomasy, nakłady energii zagęszczania, biomasa roślinna

Streszczenie szczegółowe

Do badań wybrano słomę: pszenną ozimą, pszenżyta ozimego, żytnią, mieszanki zbożowej i gryczaną. Pozyskany materiał rozdrobniono rozdrabniaczem bijakowym wyposażonym w sita o otworach 8 mm. Następnie określono zawartość: wody, węgla, wodoru, azotu, siarki, chloru. Aglomeracja ciśnieniowa surowców przebiegała przy użyciu peleciarki z nieruchomą jednostronną matrycą płaską, a napęd rolek przekazywany był od silnika elektrycznego o mocy 7,5 kW przez zespół przekładni zębatych. Do badań nad energochłonnością procesu zagęszczania wykorzystano miernik parametrów sieci typu Lumel N14, sprzężony z komputerem rejestrującym. Stwierdzono, że w warunkach badań najmniejsze zużycie energii elektrycznej występowało podczas zagęszczania słomy gryczanej dla której oznaczono najmniejszą ilość węgla i wodoru, a największą chloru i siarki. Parametr ten dla pozostałych surowców był o około 45% wyższy. Wzajemne udziały pomiędzy rozpatrywanym składem chemicznym spowodowały, że wśród badanych gatunków słomy, biomasa słomy gryczanej, była surowcem o najbardziej korzystnych właściwościach do aglomeracji ciśnieniowej. Natomiast zawartość w rozpatrywanym materiale badawczym wody, węgla, wodoru, azotu, siarki i chloru jest czynnikiem determinującym jego przydatność na cele energetyczne. Nie mniej jednak, duże zróżnicowanie pierwiastkowe w składzie substancji organicznej, jak również ich wpływ na proces zagęszczania poszczególnych surowców energetycznych pochodzenia rolniczego wskazuje na potrzebę dalszych badań w tym zakresie oraz ich upowszechniania.

Introduction

Plant biomass as a renewable, environmentally friendly energy source has enjoyed constant interest. At the same time, this trend is noted mainly in relation to forest biomass. That is why, for energy purposes, it is recommended to use biomass waste and surpluses of conventional agricultural crops, such as straw cereals and other plants and grasses of permanent grassland and wasteland [Świętochowski, et al., 2011].

These materials, in their original state, unprocessed, are diverse not only in terms of their physical characteristics (humidity, density) but also chemical characteristics [Denisiuk, 2009; Rybak, 2006; Wandrasz and Wandrasz, 2006]. Proportions of individual elements in solid fuels, which include biomass, are different and depend on the type of fuel and its degree of coalification. With increasing metamorphism comes a significant increase in the carbon content, and a decrease in oxygen and a slight decrease in hydrogen content. The proportions of nitrogen and sulphur, in practice, do not depend on the carbon content of the fuel, and the other elements present in the biomass in small amounts form a mineral substance [Kowalczyk-Juśko, 2009; Rybak, 2006; Wandrasz and Wandrasz, 2006]. It should also be noted that the quantitative differences in the chemical composition are present in the biomass of not only different species, but can also occur within a single species. This can be influenced by both the quality of the habitat and the conducted agricultural practices [Świętochowski, et al., 2011]. Hence, plant biomass is a difficult material for energy use in the unprocessed form and it causes difficulties during its compaction. The pressure agglomeration process is complex, and the desired parameters of the agglomerate are influenced by two main groups of factors. The first group consists of material factors such as the degree of comminution of the raw material, its uniformity, the presence of substances facilitating the merging of particles and the physical state at the time of compaction, and the moisture and temperature. The second comprises the construction and operational factors of the compacting machine and the machining of the product obtained [Hejft, 2002; Obidziński and Hejft, 2007].

Information on a range of the listed parameters of the biomass densification process can be obtained from the literature [Denisiuk, 2009; Rybak, 2006; Wandrasz and Wandrasz, 2006]. In reference to the presence of substances that facilitate the merging of particles, there are no studies taking into account the relationships between the chemical properties of plant biomass of agricultural origin and the energy expenditure incurred in the production of pellets. The aim of the study was to analyse the measurements of the content of water, carbon, hydrogen, nitrogen, sulphur and chlorine in plant biomass of agricultural origin in the context of the impact of these features on the energy expenditures incurred in its pelleting.

Materials and Methods

For the research, the following types of straw were selected: winter wheat, triticale, rye, cereal mix and buckwheat. These materials were obtained from four sources. Wheat straw, rye, buckwheat and cereal mix came from the Agricultural Holding located in Snopków. Triticale straw came from the Plant Breeding Farms of Małopolska in Krakow, the Palikije branch.

The obtained material was ground with an H 111 flail shredder equipped with a sieve with 8 mm holes. Then, samples were taken for further laboratory tests that define the content of:

- water - gravimetric method according to PN-EN 14774-2:2010;
- carbon, hydrogen - IR absorption method according to CEN / TS 15104:2006;
- nitrogen - measuring automatic analyzer according to CEN / TS 15104:2006;
- sulfur - automatic measurement of IR analyzer according to PN-G-04584: 2001;
- chlorine - Eschki method according to PN-ISO 587:2000 p.7.2.1.

An agglomeration of material shredded this way was performed with a pelleting machine with a fixed unilateral flat matrix and a thickness of 25 mm and holes with a diameter of 8 mm. The rotational speed of the thickening rolls was 11.67 $rad \cdot s^{-1}$ and the drive of the rolls was transferred from an electric motor with a power of 7.5 kW through a set of gears.

For the study of the energy intensity of the process of the compaction of the studied plant materials a measuring system was used, which consisted of the above-mentioned pelleting machine and a power network meter Lumel N14, coupled with a recording computer.

A statistical analysis of test results encompassed the determining of average values, standard deviations and Pearson’s linear correlation coefficients. A one-way analysis of variance was also carried out. The significance of the differences between the average values was determined using Tukey’s test. The level of significance adopted was $\alpha=0.05$.

Results and Discussion

The average moisture content of the test material under consideration is presented in Figure 1.

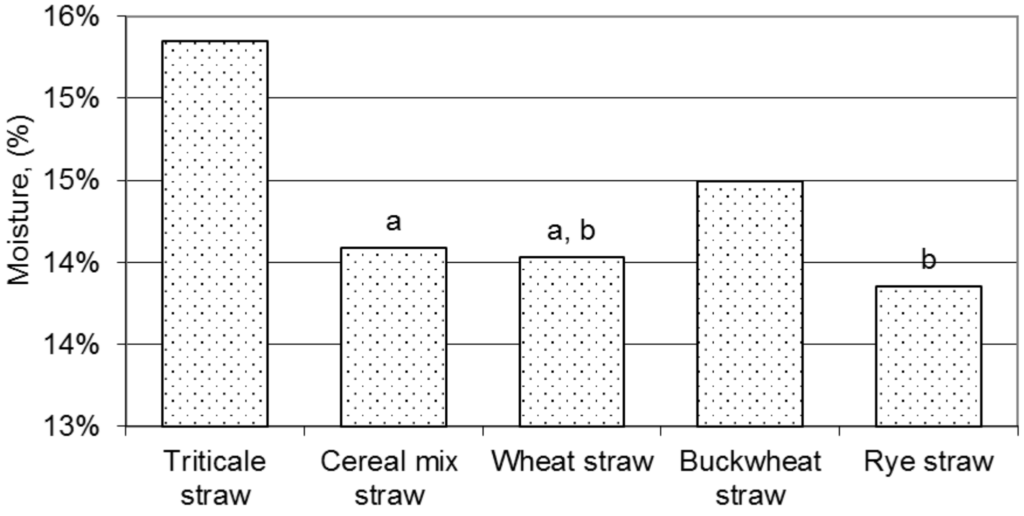

Figure 1. Mean contents of organic matter, water and ash in the samples of cereal straw; values, a, b – homogeneous groups (α=0.05)

Rysunek 1. Średnie zawartości wody w próbkach słomy zbóż; wartości, a, b – grupy jednorodne (α=0,05)

The water content of the raw materials in question usually stood at the level of from 13.85% for rye straw to 14.49% for buckwheat straw. Only the triticale straw humidity was higher and amounted to 15.35% (Fig.1).

The values of the standard deviation for the performed measurements of moisture, depending on the type of the raw material, ranged from 0.012 to 0.073%. On the basis of the analysis of the variance of this parameter a significant difference between the average values for each group of raw materials (p = 0.00000) was shown, and Tukey's test indicated two homogeneous groups - for cereal straw and mixtures of winter wheat and for winter wheat straw and rye (Figure 1). Comparing the results of the water content with the literature data it can be concluded that in the test conditions the proportion of this parameter was comparable with cereal straw [Denisiuk, 2009; Rybak, 2006; Wandrasz and Wandrasz, 2006].

Because of the large spread of values in the results obtained, the results of indications carried out for the content of carbon, hydrogen and nitrogen in the raw materials considered are shown in Figure 2, while for the sulphur and chlorine, in Figure 3.

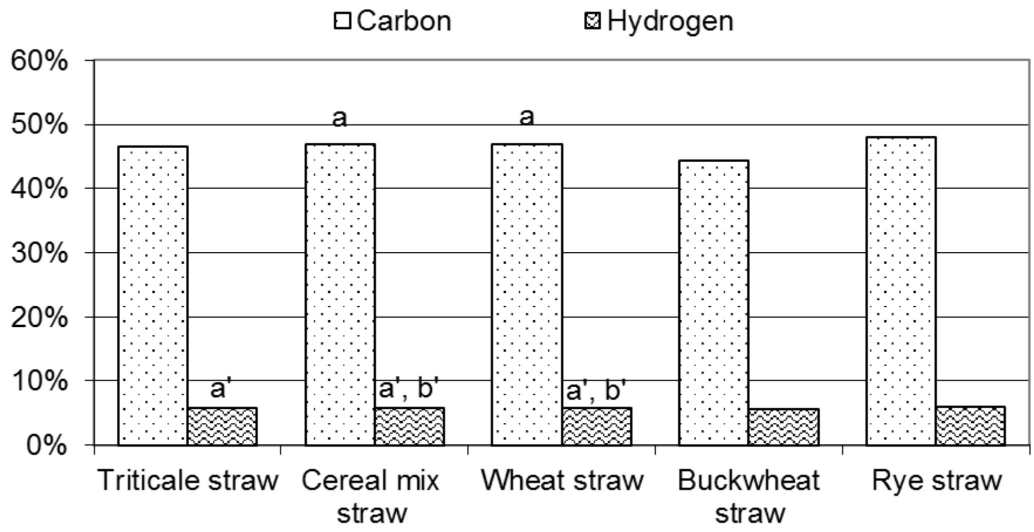

Figure 2. Mean contents of carbon and hydrogen in the samples of cereal straw; values, a, a'-b' – homogeneous groups (α=0.05)

Rysunek 2. Średnie zawartości węgla i wodoru w próbkach słomy zbóż; wartości, a, a'-b' – grupy jednorodne (α=0,05)

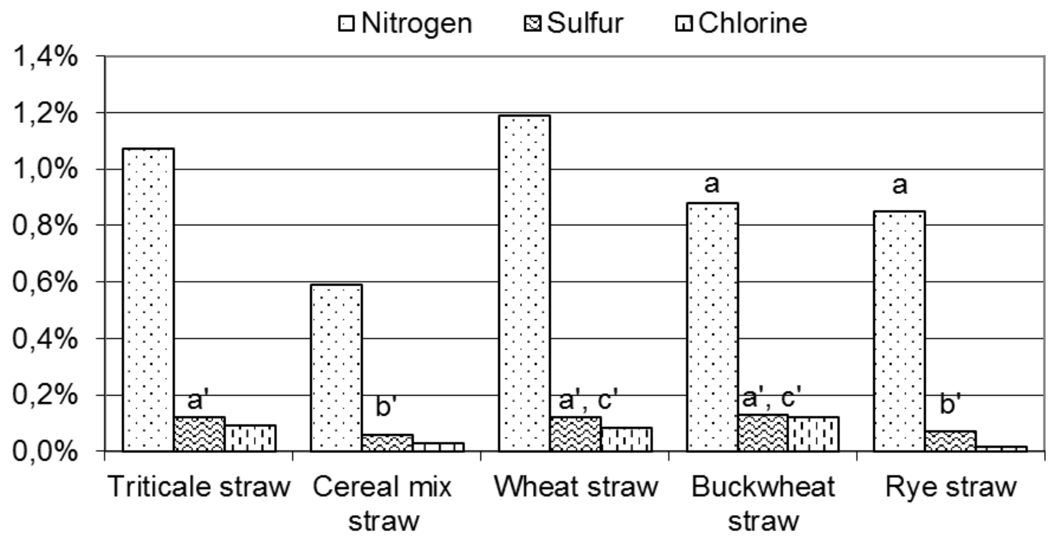

Figure 3. Mean contents of nitrogen, sulfur and chlorine in the samples of cereal straw; values, a, a'-c' – homogeneous groups (α=0.05)

Rysunek 3. Średnie zawartości azotu, siarki i chloru w próbkach słomy zbóż; wartości, a, a'-c' – grupy jednorodne (α=0,05)

The average proportion of coal in the studied plant material generally ranged from less than 47% (triticale straw) to less than 48% (rye straw). For buckwheat straw the carbon content was lower amounting to 44.4% (Fig.2). The hydrogen content of the test material was similar and stood at from 5.56% - buckwheat straw to 5.92% - rye straw (Fig.2).

The values of the standard deviation of these parameters, depending on the type of raw material, were in the ranges of 0.016-0,041 and 0.008-0,024%, respectively. Based on the analysis of variance, significant differences between the means of each group of raw materials were also found (p=0.00000), while Tukey's test indicated only one homogenous group for coal (cereal straw and mixtures of winter wheat) and two for hydrogen (Fig.2). Comparing the obtained contents of these elements with the literature data it can be concluded that, in the test conditions, their proportion for cereal straw was also comparable [Denisiuk, 2009; Rybak, 2006; Wandrasz and Wandrasz, 2006].

The average proportion of nitrogen in the plant material studied ranged from less than 0.6% (straw cereal mix) to about 1.2% (winter wheat straw) (Fig.3). The straw cereal mix also contains the smallest amount of sulphur, as it was 0.06%. The highest amount of this element appeared in buckwheat straw - 0.13% (Fig.3). Rye straw was characterised by the lowest content of chlorine, the proportion of which amounted to 0.018%, and the highest was in the case of buckwheat straw - 0.123% (Fig.3).

The standard deviation for these parameters, depending on the type of raw material, amounted to 0.008-0.033, 0.008-0.016, and 0.001-0.002%. The analysis of variance showed a significant difference between the means of each group of raw materials (p = 0.00000), while Tukey's test indicated only one homogenous group for nitrogen and four for sulphur (Fig.3). Comparing the obtained contents of these elements with the literature data it can be decided that their proportion in the test conditions was comparable to cereal straw [Denisiuk, 2009; Rybak, 2006; Wandrasz and Wandrasz, 2006]. The contents of these elements - nitrogen, sulphur, chlorine - in plant biomass are very small, but nevertheless they are important because they affect the products of combustion (flue gases) and the operation of the heating devices (boiler corrosion) [Kowalczyk-Juśko, 2009; Świętochowski, et al., 2011].

By evaluating the selected raw materials in the context of the energy intensity of their pelleting, the energy expenditure was determined, which is shown in figure 4.

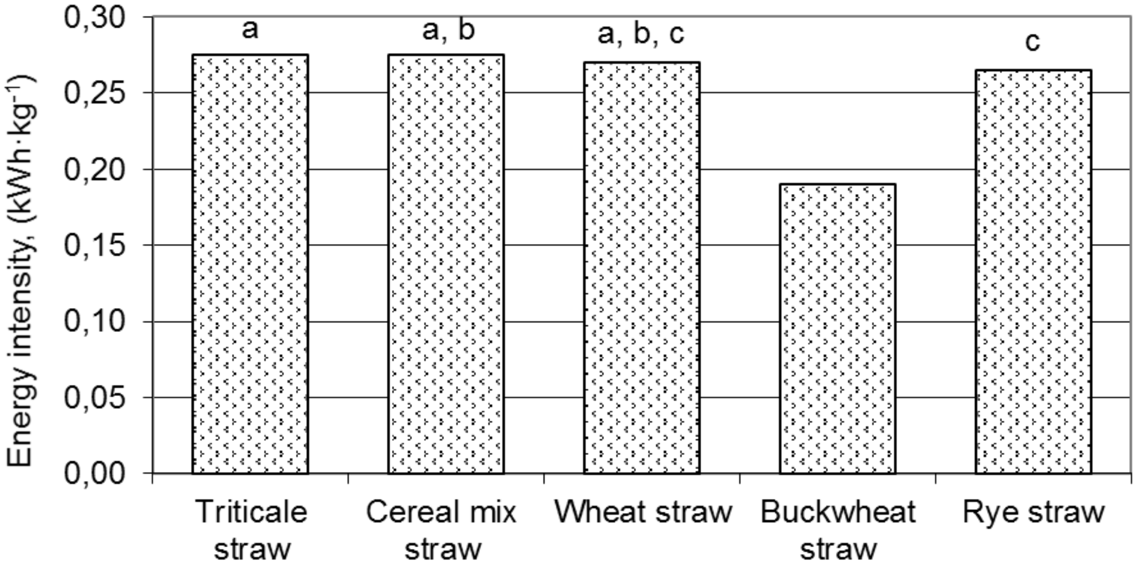

Figure 4. Energy intensity; values a-c – homogeneous groups (α=0.05)

Rysunek 4. Nakłady energii elektrycznej; wartości, a-c – grupy jednorodne (α=0,05)

Energy expenditures incurred when pelleting the raw materials in question generally ranged from 0.265-0.275 kWh·kg^{-1}, only for buckwheat straw this parameter was lower and amounted to 0.190 kWh·kg^{-1} (Fig. 4). The standard deviations for this parameter, depending on the type of raw material, ranged from 0.002-0.004 kWh·kg^{-1}. After the analysis of variance a significant difference between the mean in each group of raw materials was shown (p=0.00000), and Tukey's test indicated three homogeneous groups (Fig.4). The electric energy inputs obtained at the test conditions were comparable with the literature data [Hejft, 2002; Obidziński and Hejft, 2007].

For the raw materials under consideration, statistical analyses of the results obtained showed a negative linear trend between the electric energy input and the content of water, total sulphur and chlorine, and a positive trend between the electric energy input and the content of carbon, hydrogen and nitrogen. Wherein, the coefficients of correlation and the quantity of electricity: content of carbon, hydrogen and chlorine are significant ($p<0.05$).

Conclusions

Based on the survey, it is possible to draw the following conclusions:

1. Under the test conditions the lowest power consumption occurred during the compaction of buckwheat straw for which the least amount of carbon and hydrogen, and the largest amount of chlorine and sulphur, were determined. The energy intensity of compaction for other raw materials was about 45% higher.

2. The mutual proportions between the considered chemical compositions meant that among the examined species of straw, buckwheat straw biomass was the material with the most favourable properties for pressure agglomeration.
3. An analysis of the test results most frequently pointed to the following homogeneous groups: cereal straw mixture and winter wheat straw, and also winter wheat straw and rye.
4. The content of water, carbon, hydrogen, nitrogen, sulphur, and chlorine in the test material under consideration is a factor determining its suitability for energy purposes. Nevertheless, the large variation in the elemental composition of organic matter, as well as their impact on the process of the compaction of individual agricultural raw materials, indicates the need for further research in this area and its dissemination.

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