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Utilization of materials from agriculture to produce pellets

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Abstract

Wood pellets without bark are increasingly popular. Their greatest positives include a high degree of operating comfort, low ash content and low emission CO, NOx, SO_2, OGC, PM production during combustion. Their main negative is the high production cost. One option to reduce the price of pellets is the production of pellets from waste products from agriculture. As starting material, there may be used different types of biomass, such straw, grass and various organic materials. Price of alternative pellets may be half of wood pellets price. Properties of alternative pellets are worse in comparison with wood pellets. The article deals about utilization of different types of biomass for pellets production. In this experimental work were made 4 types of pellets – from spruce wood without bark content (reference sample), miscanthus giganteus, wheat straw and rape straw. There were tested several properties of pellets samples: total heating value (calorific value), amount of fines, mechanical durability, water resistance and ash content. The results confirmed that wood pellets have the highest quality, but alternative pellets can be interesting cheaper choice to wood pellets, if consumer is satisfied with worse parameters.

Keywords: Pellets production , Waste from agriculture, Miscanthus giganteus, Wheat straw

Streszczenie

Utylizacja materiałów z rolnictwa do produkcji peletów

Drzewne pelety bez kory są coraz bardziej popularne. Ich największymi zaletami są: wysoki komfort obsługi, niska zawartość popiołu oraz niska produkcja emisji CO, NOx, SO_2, OGC, PM podczas spalania. Ich główną wadą jest wysoki koszt produkcji. Jedną z opcji zmniejszenia ceny peletów jest produkcja peletów z produktów odpadowych, pochodzących z rolnictwa. Jako wstępne materiały mogą być wykorzystane różne typy biomasy: słoma, trawa oraz różne organiczne materiały. Cena alternatywnych peletów może być połowiczna w porównaniu z ceną peletów drzewnych. Z kolei właściwości peletów alternatywnych są gorsze w porównaniu z peletami drzewnymi. Artykuł dotyczy wykorzystania różnych typów biomasy do produkcji peletów. W pracy wyprodukowano eksperymentalnie 4 rodzaje peletów: z trocin drzewnych świerkowych bez kory (referencyjna próba), ze słomy pszenicznej oraz ze słomy rzepakowej, a także z miskanta olbrzymiego. Testowano kilka właściwości peletów: całkowite ciepło spalania (wartość opałowa), zawartość drobnych cząstek, mechaniczną wytrzymałość, wodoodporność oraz zawartość popiołu. Wyniki badań potwierdziły, że drzewne pelety osiągają najwyższą jakość, ale alternatywne pelety mogą stanowić tańszą opcja dla drzewnych peletów, jeśli konsument jest zadowolony z gorszych właściwości.

Słowa kluczowe: Produkcja peletow, Odpady rolnicze, Miskantus olbrzymi, Słoma pszenna

1. Introduction

Biofuels are more and more popular and used as energy source for heating of family houses. The development of renewable energy constitutes a crucial role for the future [1]. Dendromass and phytomass plays important role in reducing fossil fuel consumption. It is caused by decreasing fossil fuels reserves and increasing their prices [2].

In the home conditions solid biofuels are the most common form of biofuels. Currently, there is a trend using of all trees and plants parts, so use the waste wood components, such as branches and twigs, crushed into wood chips [3]. This can be directly combusted in the boiler rooms of different sizes with automatic operation. Wood waste in the wood processing industry, especially wood sawdust, can be pressed in mills to wood pellets and wood briquettes [4]. This form of biofuel meets energy, ecological and environmental criteria, criteria for safety and comfort combustion [5]. The greatest advantage of wood pellets using is their ability to use the automatic heat sources in the home [6], where they can automatically replace boilers using natural gas. At present is disadvantage of using wood pellets their relatively high price, which moves above the 200 € per 1 ton. Many owners of wood pellets heat sources is looking for a cheaper alternative. They can be many types of phytomass pellets (made from straw, grass) or various types of plant seeds (corn, sunflower). Price of these alternatives can be half of wood pellets price. Using of these biofuels in wood pellets heat sources can cause various problems, like slugs creation in combustion chamber and in heat exchanger or can cause greater emission production [7].

The most important pellets property is total heating value respectively calorific value. This parameter shows how much energy is in pellets [8]. Important parameter for pellets properties is also abrasion resistance and fines content [9, 10]. Pellets of low abrasion resistance have low quality, because high quantities of fines are produced in the storage system. It can cause operational failures. In turn, minimal amounts of fines in the storage system indicate on a high quality of pellets [11, 12]. In addition, water has a crucial role in the pelletizing process. Pellets, which contain the low amount of water, generally have good quality and appropriate fuel properties [13]. Ash content is also parameter which can be very important. Cheaper phytomass has higher ash content in comparison with wood pellets. Higher ash content can cause various problems during combustion in boiler [14, 15].

Paper deals about differences in pellets made from various biomaterials (spruce wood without bark content, miscanthus giganteus, wheat straw and rape straw) and shows how input material can change parameters of pellets (total heating value, calorific value, amount of fines, abrasion resistance, water resistance and ash content).

2. Used biomaterials

For experimental production of pellets were used 4 types of biomaterials:

- Spruce wood – Spruce wood sawdust without bark content was used as reference sample for comparison. Relative humidity of this material was 9,0 %. Calorific value of this material was 16,47 $MJ.kg^{-1}$. Chemical composition of fuel was 49,84 % C, 6,03 % H_2, 43,2 % O_2, 0,12 % N_2, 0,01 % S, 0,005 % Cl. Chemical composition of ash: 49,5 % SiO_2, 19,8 % CaO, 3,9 % MgO, 5,1 % Al_2O_3, 7,8 % K_2O.

- Miscanthus giganteus – Relative humidity of this material was 11,0 %. Calorific value of this material was 15,72 $MJ.kg^{-1}$. Chemical composition of fuel was 46,66 % C, 5,84 % H_2, 41,7 % O_2, 0,74 % N_2, 0,15 % S, 0,22 % Cl. Chemical composition of ash: 54,4 % SiO_2, 4,7 % CaO, 2,3 % MgO, 0,1 % Al_2O_3, 20,4 % K_2O.

- Wheat straw – Relative humidity of this material was 13,5 %. Calorific value of this material was 15,12 $MJ.kg^{-1}$. Chemical composition of fuel was 45,64 % C, 5,96 % H_2, 42,4 % O_2, 0,73 % N_2, 0,082 % S, 0,19 % Cl. Chemical composition of ash: 54,4 % SiO_2, 4,7 % CaO, 2,3 % MgO, 0,1 % Al_2O_3, 20,4 % K_2O.

- Rape straw – Relative humidity of this material was 15,5 %. Calorific value of this material was 14,95 $MJ.kg^{-1}$. Chemical composition of fuel was 47,11 % C, 5.92 % H_2, 40,02 % O_2, 0,84 % N_2, 0,27 % S, 0,47 % Cl. Chemical composition of ash: 22,11 % SiO_2, 20,24 % CaO, 1,24 % MgO, 1,73 % Al_2O_3, 23,81 % K_2O.

Chemical composition of biofuels and chemical composition of ashes are in dry state.

3. Production of pellets samples

Pellet production is complex process and it is necessary that starting material – wood sawdust must meet certain conditions [7, 9, 12]. It cannot contain undesirable objects. Biggest size of sawdust fraction must be smaller than diameter of holes in the matrix of pellet mill [4, 10]. The humidity of input material should be around 15%. Manufactured pellets must be cooled and stored properly [6, 9, 12]. Pellets from biomass are usually made in factories with pelletizing line which can produce more than 2 tons pellets per hour. These manufactories have usually perfect working automatic technology and it can work with no failures [16]. Pellets made by this way of production have stable quality and meet the standards and certifications. For good parameters of produced pellets is necessary also good quality of inlet raw material [7]. This all need to be paid and it is showed in price of these pellets.

In the laboratory of University of Zilina has been designed and implemented experimental device for pelletizing according to the scheme on Fig. 3.1. It consists of input material tank (in which is delivered biomass for production of pellets), crusher (which crush material to fractions of size max. 6 mm), crushed material tank (where the crushed material is temporarily stored), dryer (where is possibly wet material dried for optimal humidity), mixing machine with capacity of 50 dm^3 (where is dried material mixed with water), pellet mill with capacity of 70 – 100 $kg.h^{-1}$ (where is prepared biomass material pressed to pellets), cooler and duster with fan (final product - pellets are cooled to room temperature and dusted) and produced pellets tank (where are pellets temporarily stored before packing).

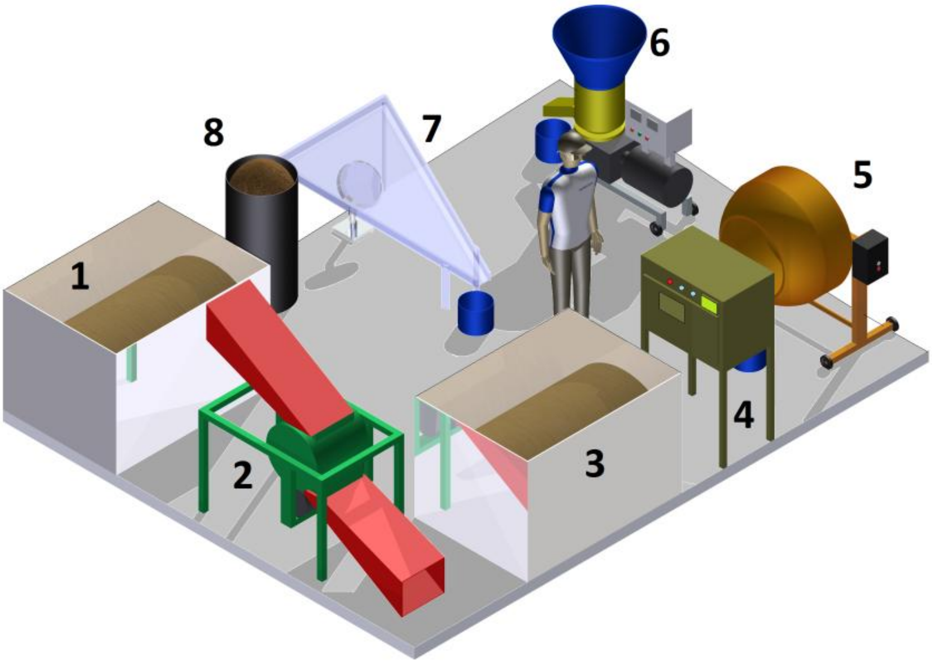

Fig. 3.1. Experimental device for pelletizing: 1-input material tank, 2-crusher, 3- crushed material tank, 4- dryer, 5- mixing machine, 6- pellet mill, 7- cooler and duster with fan, 8- produced pellets tank

Each material required special manufacturing process. There were produced 4 types of pellets samples for testing:

1. Spruce wood without bark content (Sample A) – production of Sample A was the easiest in comparison with other samples. Input material was crushed to fractions with size less than 5 mm and it was dry. It was added approximately 5 % of water before pelletizing process in mixing machine. It was possible produce 80 - 100 kg of pellets per hour.
2. Miscanthus giganteus pellets (Sample B) – production of Sample B was more difficult in comparison with Sample A. Input material was crushed to fractions with size about 10 cm and it was dry. Material had to be crushed in crusher to fractions with size less than 6 mm. Crushing process was very slow. After crushing it was very difficult to find the correct amount of added water. It was added approximately 6 % of water before pelletizing process in mixing machine. Pelletizing process also was not ideal. It was possible produce only about 10 - 15 kg of pellets per hour.
3. Wheat straw pellets (Sample C) - production of Sample C was very similar to Sample B production. Input material was not crushed and it was dry. Material had to be crushed in crusher to fractions with size less than 6 mm. Crushing process was slower than Sample B crushing process because of wheat straw flexibility. After crushing it was also very difficult to find the correct amount of added water. It was added approximately 7 % of water before pelletizing process in mixing machine. Pelletizing process also was not ideal. It was possible produce only about 5 - 10 kg of pellets per hour.

4. Rape straw pellets (Sample D) - production of Sample D was very similar to Sample B and Sample C production. Input material was not crushed and it was relatively dry. Material had to be crushed in crusher to fractions with size less than 6 mm. Crushing process was slower than Sample B crushing process because of wheat straw flexibility. After crushing it was also very difficult to find the correct amount of added water. It was added approximately 5 % of water before pelletizing process in mixing machine. Pelletizing process also was not ideal. It was possible produce only about 5 - 10 kg of pellets per hour.

4. Methods of experiments

There were 6 parameters of wood pellets determined:

Total heating value (calorific value) – it was determined according to STN EN ISO 1716 [17] and STN EN 14918 [18] by using of calorimeter LECO AC 500. A sample of wood pellet with weight about 1,0 g was burned in combustion vessel filled with oxygen to the pressure 31,0 bar. Combustion vessel was immersed in 2,0 dm^3 of distilled water. During burning of sample was measured temperature increase of water. Final total heating value and calorific value is average value from 5 measurements.

Calorific value was calculated by the equation:

$$Q_i = Q_s - 2{,}453.(w + 9.H_2)\ [MJ.kg^{-1}] \qquad (4.1)$$

where Q_i is calorific value [$MJ.kg^{-1}$], Q_s is total heating value [$MJ.kg^{-1}$], w is eelative humidity [$kg.kg^{-1}$] and H_2 is hydrogen content [$kg.kg^{-1}$].

Mechanical durability (DU test) - this is a measure of how well the pellets can stand handling. Every time pellets are handled, some of them break and all of them show some wear, which will increase the amount of fines. It was determined as quality parameter according to EN 15210 [19] by using of special device – LignoTester (Fig. 4.1). There 100 g of pellets sample placed in stream of air for 60 s with pressure of air 70 mbar and after this was sample weighted. Final mechanical durability is average value from 4 measurements.

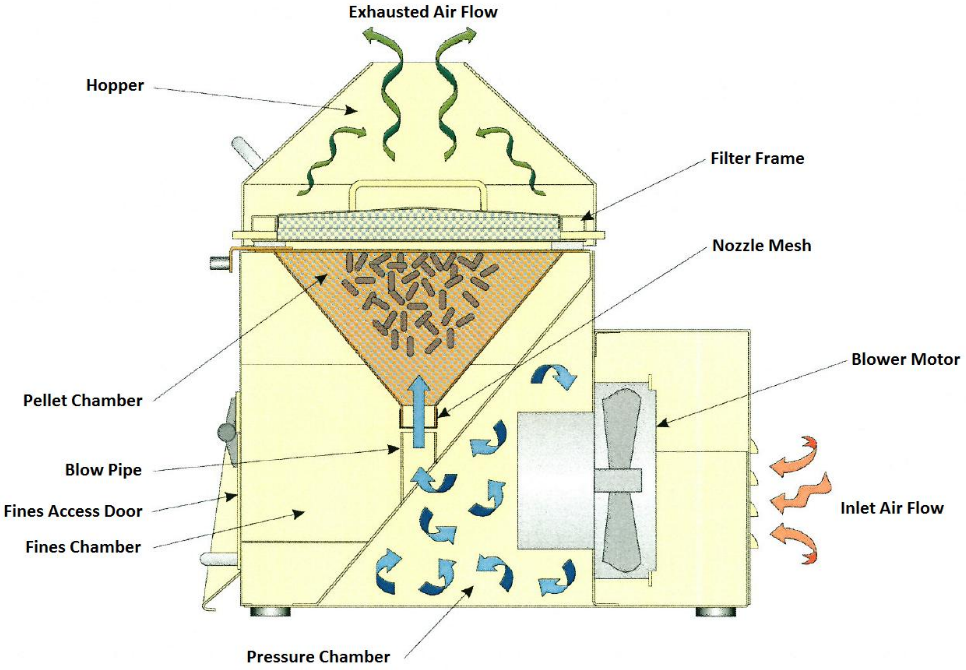

Fig. 4.1. Lignotester [22]

Amount of fines (F test) – fines hinder pellets from tumbling down to the in-feed auger, thus disturbing fuel feed to the boiler. Boilers are adjusted to burn pellets, but if fines arrive in the burning chamber, the flame may get too hot as fines particles burn faster than pellets. In the worst case the ash might sinter, which means that the burner must be cleaned after it has cooled down. The amount of fines should preferably be declared for each bulk delivery, and is measured at the final point in the factory production chain. Fines should preferably be less than 1% by weight. Amount of fines was measured on Lignotester (Fig. 4.1) in accordance with EN 15210 [19], where samples were placed in stream of air for 30 s with pressure of air 30 mbar. After this was weighted amount of fines under the sieve. Final amount of fines is average value from 4 measurements.

Water resistance – it is another pellets quality parameter. This method of determining the quality of pellets is only approximate and serves only to compare different samples of pellets. From each sample of the produced pellets were selected two large pellets at the same size. Sample was placed in a glass container filled with water of about 0,2 dm^3. Consequently, time is measured until the pellets disintegrate completely. The longer the disintegration time of pellets means higher quality of pellets. Final disintegration time is average value from 3 measurements.

Ash content – was determined on the basis of standard STN EN 14775 [20]. Samples were dried in dryer at temperature 105 °C ± 2 °C. After drying were samples temporarily placed in a desiccator. Then empty corundum plate was weighted after heating on 550 °C ± 10 °C. 5 g of sample were placed to the plate and it was weighted with accuracy 0,1 mg. Plate was placed in the cold furnace which was heated by the following procedure: Over 30 min steady increase furnace temperature to 250 °C at a rate 7.5 °C.min^{-1}. Temperature of 250 °C was kept for 60 minutes due to combustion of the sample released volatiles. For 30 minutes continued uniform temperature increase to 550 °C by 10 °C.min^{-1}. Temperature of 550 °C was kept for at least 120 minutes. Plate with ash was removed from the furnace and it was weighted with accuracy 0,1 mg. Ash content was determined from the equation:

$$A_d = \frac{(m_3 - m_1)}{(m_2 - m_1)} . 100\ [\%] \tag{4.2}$$

where m_1 is the mass of the empty plate in grams, m_2 is the mass of plate with sample in grams, m_3 is the mass of plate with ash in grams. Final ash content is average value from 3 measurements.

5. Results and discussion

At first it was measured the most important parameter of fuel – total heating value. Calorific value was calculated in accordance to STN EN 14918. The results are very depending on total heating value (calorific value) of input material. Average values of total heating value and calorific value are shown in Fig. 5.1. The highest total heating value 18,675 ± 0,072 MJ.kg^{-1} and calorific value 17,09 ± 0,066 MJ.kg^{-1} was observed on wood pellets. It was caused by using of quality input material – spruce wood sawdust without bark content and by reduction of moisture content during pelletizing process, where the temperature achieves more than 120 °C. The lowest total heating value 18,017 ± 0,094 MJ.kg^{-1} and calorific value 16,38 ± 0,085 MJ.kg^{-1} was measured on straw pellets. This is also related to input material properties.

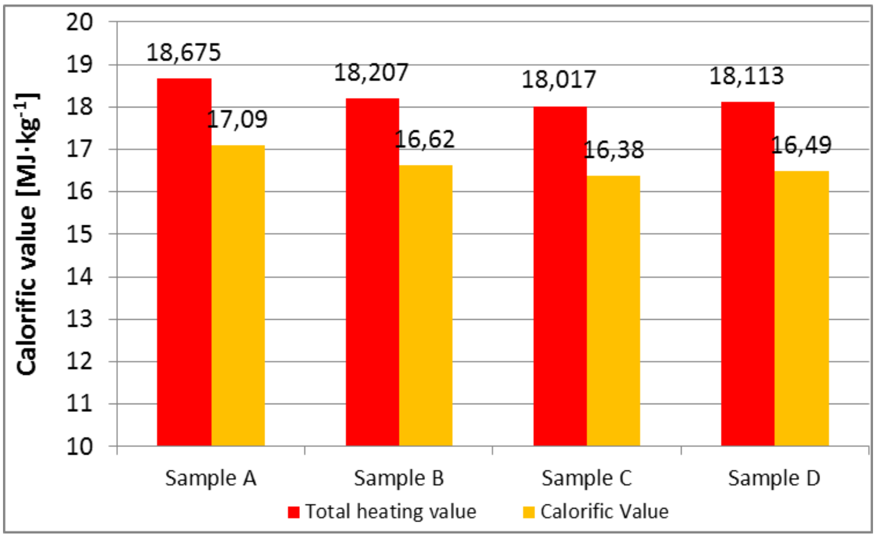

Fig. 5.1 Total heating value and calorific value of pellets samples

Very important pellets parameter is their quality. Quality of pellets is very important because pellets during transport must be solid and not damaged. First measured quality parameter is mechanical durability. Average values of mechanical durability of pellets samples are shown on Fig. 5.2. The highest mechanical durability was measured on wood pellets samples with average value 91,11 ± 0,81 %. This mechanical durability is very low in comparison with factory made wood pellets with value about 97 – 99 %. It is caused by using of small pellet mill where the pellet pressure and temperature are lower. The highest mechanical durability of Sample A in comparison with other samples is caused by high content of lignin in spruce wood. Lignin in temperature about 120 °C melts and after cooling works like glue. Other samples have much lower mechanical durability because their input material has much lower content of lignin.

Similar results were also observed on other quality parameter – amount of fines. Average values of amount of fines of pellets samples are shown on Fig. 5.2. The lowest average amount of fines 0,924 ± 0,061 % was measured on wood pellets sample. It is also related on lignin content and its binder function. The highest amount of fines was measured on Sample C – wheat straw pellets with average value 3,756 ± 0,146 %. Lower amounts of fines of experimentally produced pellets in comparison with factory produced pellets are also caused by lower pellet pressure and temperature.

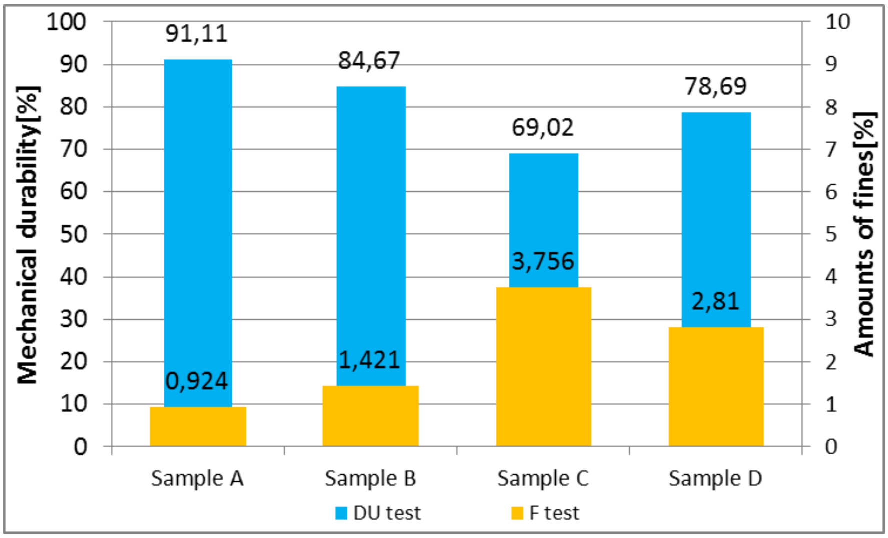

Fig. 5.2 Mechanical durability and amount of fines of pellets samples

The last measured quality parameter was water resistance. Average disintegration times of pellets samples during water test are shown on Fig. 5.3. The results are very interesting because wood pellets sample (with the good other quality parameters) reached the lowest disintegration time during water test. The average value of disintegration time was 100 ± 12 s. All other samples had higher values of disintegration time. Sample D, rape straw pellets, was the best in water resistance with average value 210 ± 24 s. This phenomenon could be caused by different structure of cellulose. Cellulose of Sample 2, Sample 3 a Sample 4 cannot absorb so much water as wood cellulose in Sample 1.

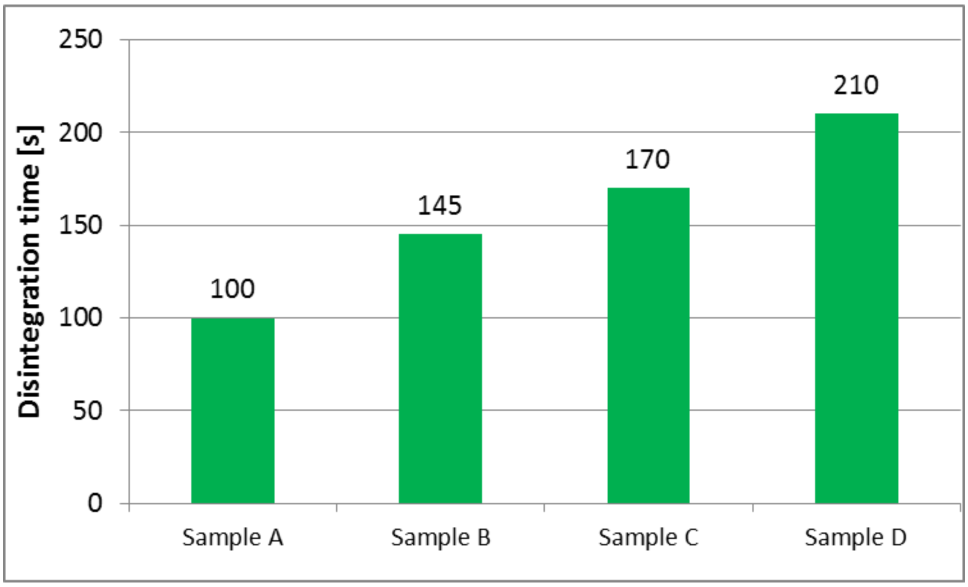

Fig. 5.3 Disintegration time of pellets samples during water test

Another measured parameter of pellets was ash content. This parameter showed the differences between pellets made from wood biomass and phytomass. Phytomass like straw or grass has much higher ash content. This fact also influenced that Sample 1 (wood pellets) had the lowest ash content 0,51 ± 0,04 % and other samples had ash content from 3,95 ± 0,14 % to 5,21 ± 0,23 %.

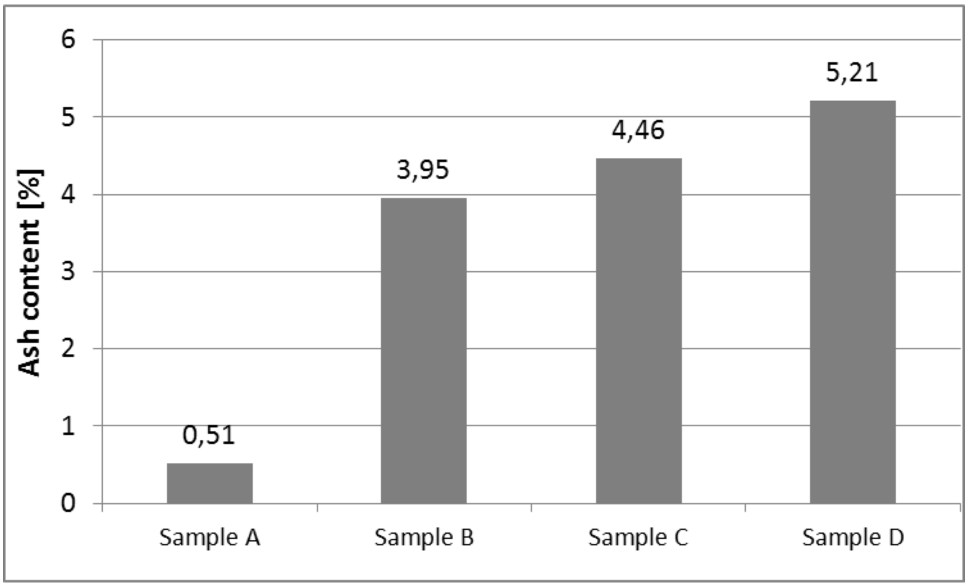

Fig. 5.4 Ash content of pellets samples

6. Conclusions

Input material for production of pellets is very important and has the greatest effect on pellets properties. The results of this paper confirmed that input material can influence total heating value (calorific value), mechanical durability, amount of fines, water resistance and ash content.

It was confirmed the assumption that pellets made from spruce wood sawdust without bark content has the best properties in comparison with other samples except water resistance, where wood pellets had the worst results. Energy properties of all pellets were approximately identical with small differences. Higher differences were observed in mechanical parameters in quality of pellets and ash content. Quality results of experimentally produced pellets are worse in comparison with factory produced pellets where higher pressures and temperatures are during pelletizing.

If pellets from phytomass will be produced on factory conditions and the parameters of pellets, especially quality parameters, will be in accordance with EN 14961-6 [21], they could be sufficient for common using. For using of phytomass pellets in small heat sources in households is necessary solving of other problems with combustion, especially low ash melting temperature. These combustion problems are solved in other works.

Acknowledgment

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