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FEASIBILITY STUDY OF MEDIUM ROTATION ENERGY PLANT UTILIZATION FOR BIOFUEL PRODUCTION

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Timber is predominant resource of the biomass used for the purposes of energy production. Recently, plantations of medium rotation trees of hybrid species have been increasingly cultivated in order to produce timber to be used as a bio-fuel. Coppice plantations are cultivated on the basis of intense techniques in order to achieve accelerated wood production or any other production related to woody crops. Plant growth period of long rotation trees amounts for nearly 30–60 years, whereas that of medium rotation trees of hybrid species – only 15–20 years.

Physical characteristics of chaffs of the following medium rotation energy plants have been determined: Quaking aspen (PopulusTremula), Robinia and the wild cherry tree (Pseudoacacia). The main fraction of the timber chipped using Pezzolato drum chipper has been comprised of the 8-16 mm sized particles. The ash content of medium rotation energy plants was found to be low: amounted from 1.87 % (of the wild cherry tree) to 2.4 % (of Robinia), whereas calorific values of the plants under investigation were found to be rather high: amounting for approx. 18.7 MJ/kg. These are close to calorific values of birch which is considered to be the main benchmark or reference in Lithuania.

Change in bulk density was found under variable moisture content of wood. Comparison to the bulk density of the absolutely dry wood shows the density of aspen and wild sweet cherry to be rather similar and vary only in range of error; whereas density of robinia is by 3–4 % lower. Increase in moisture content resulted in bulk density of all the sorts of wood to increase in a very similar manner, consequently it was assumed to be identical in all the calculations made. Decrease in moisture content resulted in increase of collapse (fall) angle: of aspen – from 62 to 77°, of robinia – from 90 to 115°, wild sweet cherry – from 65 to 82°. Lower effect of moisture content was found on the valued of flowing angle. It respectively varied as follows: of aspen – from 34 to 40°, of robinia – from 34 to 40°, of wild sweet cherry – from 36 to 42°.

Key words: energy plants, biofuel, aspen, robinia, wild cherry, properties, calorific values.

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INTRODUCTION

In the recent years in Lithuania, medium rotation hybrid trees plantations have been cultivated. Wood of these trees is also foreseen to use for production of biofuel. Green wood plantations are cultivated according to intensive technologies aiming to get wood or other products related to turned to wood plants (Assessment of Lithuania…, 2015). If growth period of long rotation trees reaches 30-60 years, growth period of medium rotation hybrid plants is only 15-20 years (Biofuel potential, 2015; Recommendations, 2015).

The most popular and productive trees of medium rotation are hybrid aspen (*Populustremula*), robinia (*Pseudoacacia*) and wild cherry (*Prunusavium*). These are rather new perspective plants areas of plantations of which have not reached 300 ha so far (Genutis *et al*., 2003; Scholz *et al*., 2001; Vares *et al*., 2007; Jakimavicius, 2008). Non-fertile (soil scale is lower than 32) areas less suitable for agricultural production are suitable growth of energy plants plantations. These are re-cultivated gravel-pits, security zones by water reservoirs, wind protective zones, fire-protective zones in conifers woods.

In Lithuania, medium rotation plants plantations have been started to propagate rather recently. One of the first such type plantations was propagated in Jonava district, Uzusaliai municipality, Gireliai village. However, characteristics of hybrid plants and their suitability for biofuel in Lithuania is rather little researched in literature. In literature sources, wood characteristics of growing in woods robinia, aspen and wild cherry have been analysed; however, we have not succeeded to find parameters needed for biofuel characteristics to these trees cultivated in plantations (Bartkevicius *et al*., 2013).

The aim of the research is to analyse suitability of wood of hybrid aspen, robinia and wild cherry for biofuel production. To reach our aim, it is necessary to analyse physical-mechanical characteristics of wood chip: filled density, fractual composition, collapse and flowing angles, calorific values, ashness.

MATERIALS AND METHODS

Research object. The research was performed in Aleksandras Stulginskis University (ASU) and Lithuanian Energy Institute Laboratory of Calorific equipment research tests. Chopped wood of hybrid aspen, robinia and wild cherry was used for the research. Drum chopper Pezzolato PTH 700/660 was chosen for wood chopping.

Moisture of wood chop was determined according to the approved methodology 5 samples were taken and weighted (Vares *et al*., 2007; Jakimavicius, 2008). Moisture was removed from the sample raw material drying it in a dryer under the temperature 105 °C. Dried samples were weighted by a scale METTLER TOLEDO SB 16001, with ±0.01g precision; then, their empty weights were weighted. Moisture and average moisture of each sample were calculated.

Filled density was determined by pouring wood chop into a cylindrical form vessel and, aiming to determine their mass (m), weighting it by scale METTLER TOLEDO SB 16001, not pressing it. The measured volume of the used cylindrical vessel (V) was equal 0.0119 m^3.

Fractional composition of the chop was determined according to the methodology spread in EU countries, using sieves with holes of various diameters (Puida, 2016). The set of sieves with 400 mm diameter was used in which sieves with round holes are placed one into another (in the order from the upper sieve): 63 mm, 45 mm, 16 mm, 8 mm, 3.15 mm and 1 mm diameter. Fractional composition of wood chop was determined using sieve set (Zaltauskas, 2001), where sieves are placed one on another in the following order: 63 mm, 45 mm, 16 mm, 8 mm, 3.15 mm and 1 mm diameter. 0.5 kg sample mass was sieved by a special sieve shaker Haver EML Digital plus. Operational parameters of a sieve shaker: vibration duration 1 min, vibration interval 10 s, vibration amplitude 1 mm.

When projecting equipment of wood chop transportation to furnaces and chop metering units and accumulation reservoir, and determining their constructive parameters, it is important to determine drop angles of wood chop. A special stand produced in Agricultural engineering and safety Institute was used to determine drop and flowing angles. The stand was used to determine flowing angle – αn and drop angle – α_{gr} (Jasinskas, Zvicevicius, 2008; LST CEN/TS 15149-2.2006).

Calorific values of wood (hybrid aspen, robinia and wild cherry) chip were determined according to the approved research methodology (CEN/TS 14918.2006/P.2008). The following equipment was used for the research: muffel laboratory electric furnace Nabertherm LVT/9/11/P330 No 258760, measuring limits 0–1100 °C, measuring error ± 10 °C; electric scale XP2003SDR, No B117433784, measuring exactness 0–2100 g, measuring error ± 6 mg; calorimeter IKA C 5000, No K39 713430 with calorimetric bomb IKA C 5012, No 01.501390 (Figure 1), measuring limits till 40 kJ/g, measuring exactness ± 0.03 %; electronic scale XS205DU/M, No B045084959, measuring limits 0–220 g, measuring exactness ± 0.2 mg.


a)

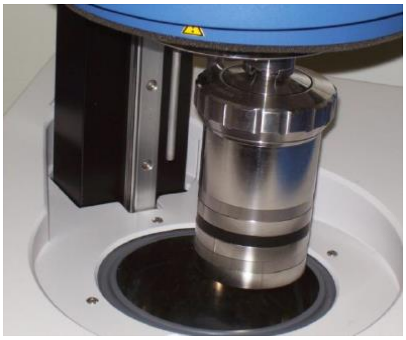
b)

Figure 1. a) Calorimeter „IKA C5000“. b) Calorimetric bomb IKA C 5012.

The upper dry calorific value Q_v was found by a calorimeter. Further, the lower calorific value Q_a was calculated by a formula (CEN/TS 14918.2006/P.2008) presented in literature (1).

$$Q_a = Q_V \cdot \frac{1-A}{100} \cdot \frac{1-W}{100} - C_S \cdot \frac{W}{100} \quad (1)$$

where Q_v – the upper calorific value of a sample (absolutely dry material, without ash), kJ/kg; W – moisture of a sample mass, %; A – ashness of a sample mass, %; C_s – secret water evaporating heat, kJ/kg.

Ash content of wood chip (hybrid aspen, robinia and wild cherry) was determined by a methodology stated in the standard (Sateikis, Lynikiene, 2007; LST CEN/TS 14775.2005). For the experiments, we used equipment used for determination of calorific value. Ash content of dry mass expressed by percentage of dry mass (As) was calculated according to the formula (2).

$$A_S = \frac{M_3 - M_1}{M_2 - M_1} \cdot 100 \cdot \frac{100}{100 - W_n} \qquad (2)$$

where M_1 – mass of empty a plate, g; M_2 – mass of a plate and sample, g; M_3 – mass of a plate and ashes, g; W_n – moisture of a sample used for analysis, %.

Results of the performed research are presented in graphs and diagrams. An experimental value X obtained from 3-5 parallel results was used to obtain separate points in graphs. Data of the experiment were processed according to methodologies calculating average value of parallel measurements and average square deviation of a separate measurement.

RESULTS

Moisture of wood chip samples is presented in Fig.2. As we may see, the moistest chips after cutting and chopping is of hybrid aspen – 38.28 ±0.07 %, and the smallest moisture was of robinia – 25.36 ±2.53 %. However, if keeping chopped wood in the same natural conditions (for 6 months) layer – hybrid aspen dried the quickest; moisture of hybrid aspen reached 6.4±0.24 %, and robinia dried the slowest – 9.14 ±0.12 %. This is explained by a higher density of robinia which conditions migration of moisture.

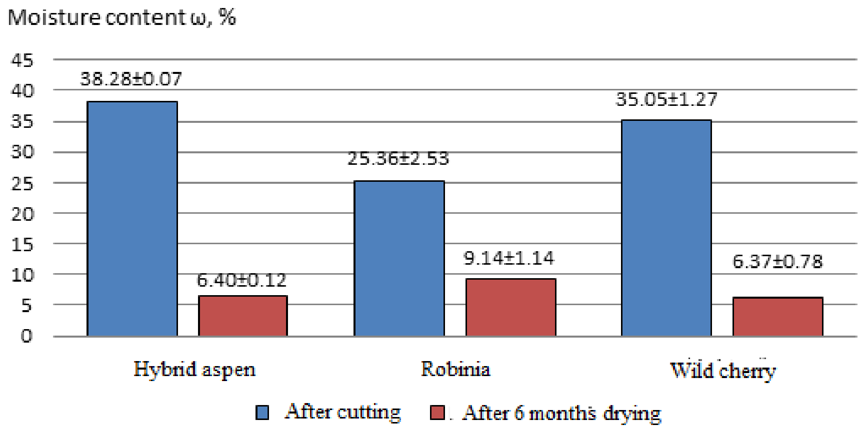

Figure 2. Moisture content of hybrid aspen, robinia and wild cherry chip.

Filled density of plants chopped by chopper Pezzolato PTH 700/660 (hybrid aspen, robinia and wild cherry) after cutting and after 6 months drying in natural conditions is presented in Table 1. Changes of filled density were evaluated with changes of wood moisture. With decrease of moisture of hybrid aspen from 38.3 to 6.4 %, density varied from 341.61±7.62 238.67±6.63 kg/m^3; with decrease of robinia moisture from 26.4 to 9.14 %, density varied from 302.67±8.97 to 235.33±4.26 kg/m^3; with decrease of moisture of wild cherry from 35.1 to 6.4 %, density varied from 342.67±4.81 to 236.67±2.6 kg/m^3.

When solving transportation of wood chop as friable material to furnaces and depositories, it is necessary to know collapse and flowing angles of materials. It is all important due to constructive parameters of bunkers so that materials do not get vaulted. Quantity of moisture in wood chaf influences collapse and flowing angles. Collapse and flowing angles of wood (hybrid aspen, robinia and wild cherry) were determined by experiments under the indicated moisture quantity (see Table 2).

Table 1. Mill fractional composition, %

Plant sort	Chaff moisture content *W*, %	Bulk density *ρ*, kg/m^3
Hybrid aspen	38.28±0.07	341.67±7.62
	6.40±0.24	238.67±6.63
	Dry matter	223.31
Robinia	25.36±2.53	302.67±8.97
	9.14±0.12	235.33±4.26
	Dry matter	214.15
Wild cherry	35.05±1.27	342.67±4.81
	6.37±0.07	236.67±2.6
	Dry matter	221.71

Table 2. Values of collapse α_{gr} and flowing angles α_n

Plant sort	Chaff moisture content *W*, %	Colapse angles α_n, degrees	Flowing angles α_n degrees
Hybrid aspen	38.28±0.07	34±1	62±2
	6.40±0.24	40±2	77±1
Robinia	25.36±2.53	34±2	90±2
	9.14±0.12	40±1	95±3
Wild cherry	35.05±1.27	36±1	65±1
	6.37±0.07	42±2	82±2

As it may be seen from experiments results, moisture has higher effect on collapse angle. With decrease of moisture, collapse angle increased: aspen – from 62 to 77 degrees, robinia – from 90 to 95 degrees, wild cherry – from 65 to 82 degrees. Lower impact of moisture was determined for the size of flowing angle. It varied accordingly: aspen – from 34 to 40 degrees, robinia – from 34 to 40 degrees, wild cherry – from 36 to 42 degrees. Considering collapse angles, constructive parameters of depositories (bunkers) and supply to furnace mechanisms walls' were determined (leaning angles of walls should be higher than the determined ones). Based on these results, it is possible to calculate the size of wood chop dispersion areas when storing them.

Requirements are always set for the prepared wood biofuel, especially its fractual composition (wood chop size should be in the limits of 3–100 mm). Having evaluated fractual composition of chopped hybrid plants (Fig.3, 4, 5), it has been determined that the biggest fraction of hybrid aspen and robinia accumulates on the sieve with round 3.15–8 mm diameter holes, accordingly 345.77±13.62 g and 302.17±32.43 g, and the main fraction of wild cherry accumulates on the sieves with round 3.15–8 mm and 8–16 mm diameter holes, accordingly 232.45±6.65 g and 187.00±19.90 g.

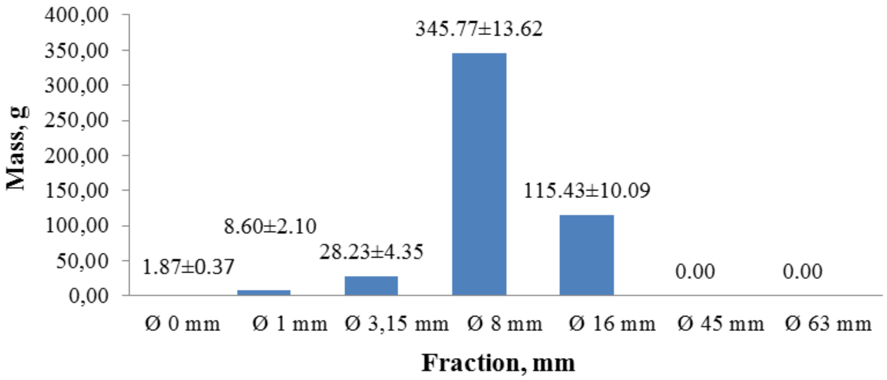

Fig ure3. Hybrid aspen fractional composition

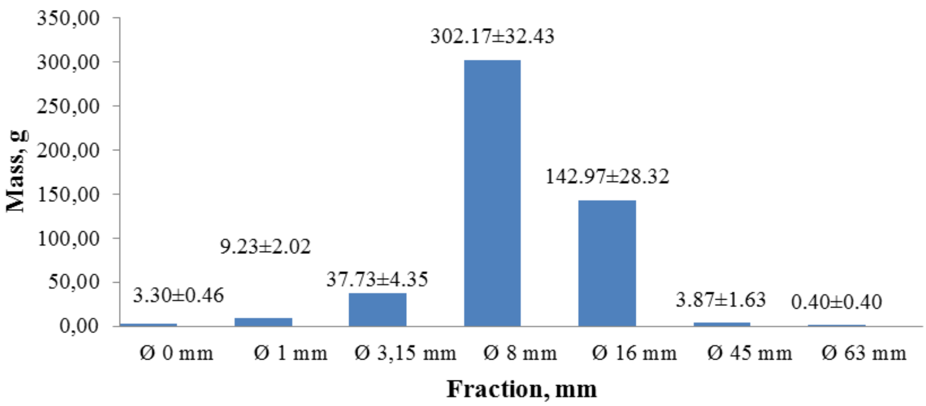

Figure 4. Robinia fractional composition

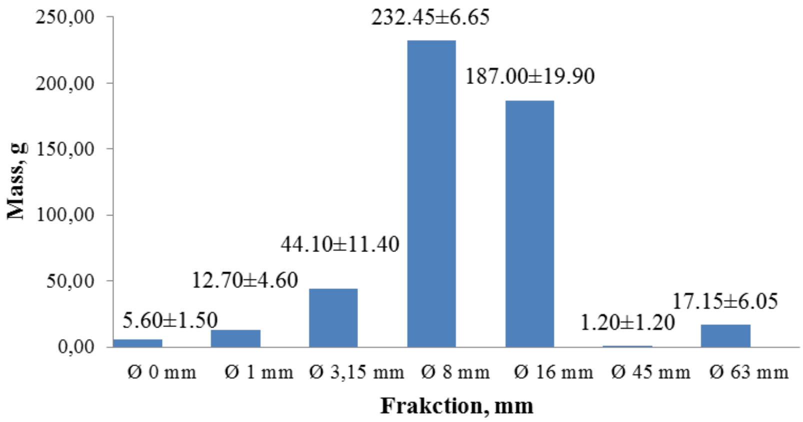

Figure 5. Wild cherry fractional composition

When producing biofuel, calorific value and ashness are the most important physical characteristics of wood chop. Calorific value is the energy obtained after burning of 1 kg of hard fuel caloricity of which is expressed by MJ/kg. Calorific values of wood chop (*Q*a – lower calorific value of dry mass, MJ/kg) were determined by experiments. Research results are presented in Fig. 6.

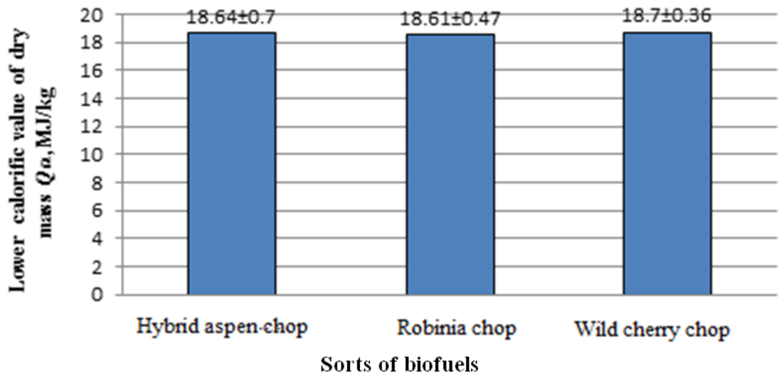

Figure 6. Lower calorific value of fuel dry mass, MJ/kg

Based on the results, we may state that calorific values of the researched wood sorts are almost identical: hybrid aspen 1864 ± 0.7 MJ/kg, robinia 18.7 ± 0.36 MJ/kg and wild cherry 18.61 ± 0.7 MJ/kg. The obtained results show that wood of chopped hybrid plants is almost the same as that of the best long rotation plants (birch). So, we may conclude that, according to the sizes of calorific values, the researched medium rotation plants correspond to the requirements of high quality biofuel.

Ashness (*A*s – ash content of dry mass, %) of wood chop was determined by experiments (hybrid aspen, robinia and wild cherry). Research results are presented in Fig. 7.

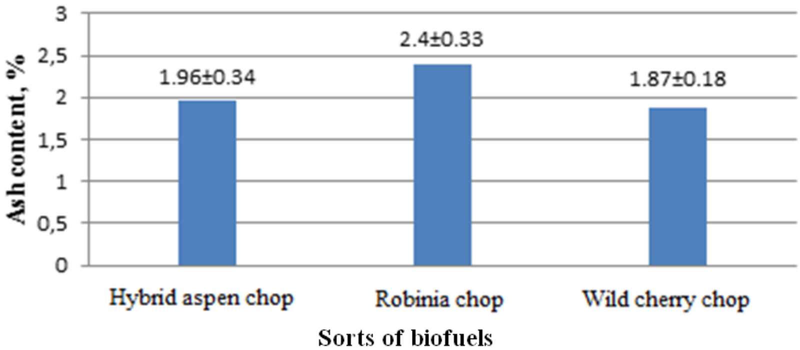

Figure 7. Ash content of fuel dry mass, %

It has been determined by research that robinia has the highest ashness: its ashness reached 2.4±0.33 %, and the lowest ashness is that of wild cherry: 1.87±0.18 %.

Based on the research results and prices of wood and biofuel (Forest Exchange, 2016), it is possible easily to justify the economic viability of investigated medium rotation energy plants usage for biofuel production. Last year the biofuel exchange data show that of 1 m^3 robinia and wild cherry wood logs price ranges from 240 to 250 € /m^3. The price of biofuel chop ranges from 26 to 37 € /m^3. From 1 m^3 area of robinia and wild cherry wood can be prepared in about 2.5 m^3 chopped biofuel (taking into account the density of the wood and investigated chop bulk density). In monetary expression it is in the range from 65 to 92 € (Forest Exchange, 2016).

Having compared the price of 1 m^3 of logs of robinia and wild cherry with the obtained quantity of biofuel from 1 m^3 of wood (2.5 m^3 wood chop), we may see that the price of wood logs is 2.7–3.7 times higher than biofuel obtained from the same quantity of wood. While producing the biofuel from the wood of hybrid aspen, the price of wood logs and production of biofuel differ insignificantly.

CONCLUSIONS

1. Evaluating quality of wood chop prepared by drum chopper, it has been determined that the biggest fraction of hybrid aspen and robinia accumulates on the sieves with round 8 mm holes – hybrid aspen – 345.77±13.62 % chop mass, robinia – 302.17±32.43 %, and wild cherry – on 8 and 16 mm diameter sieves – 232.45±6.65 % and 187.00±19.90 % chop mass.

2. Experiment results show that moisture has higher effect on collapse angle. With decrease of moisture, collapse angle increased: aspen – from 62 to 77 degrees, robinia – from 90 to 19 degrees, wild cherry from 65 to 82 degrees. Smaller moisture effect has been determined for the size of flowing angle. It varied accordingly: aspen – from 34 to 40 degrees, robinia – from 34 to 40 degrees, and wild cherry from 36 to 42 degrees.

3. Having compared filled density of absolutely dry wood, it may be seen that densities of aspen and wild cherry are similar and vary only in the error limits, and density of robinia is smaller 3–4 %.

4. Ash content of medium rotation energetic plants is small; it reached from 1.87 % (wild cherry) to 2.4 % (robinia). Calorific values of the researched plants are rather high, about 18 MJ/kg. They are close to caloricity of the accepted in Lithuania standard – birch.

5. Having determined and evaluated the main criteria raised for biofuel (fineness of chop, calorific value, ashness), we may state that hybrid plants of medium rotation (aspen, robinia and wild cherry) are absolutely suitable for production of qualitative biofuel.

6. Having evaluated characteristics of wood and the price of raw wood, we may recommend to use the entire wood of hybrid aspen for biofuel (stems, branches, tops), and robinia and wild cherry – only branches and tops; it is more rational to use the remaining part of their wood in furniture production or other industrial branches.

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