RESEARCH OF WILLOW PREPARATION AND UTILIZATION FOR ENERGY PURPOSES

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Abstract
For the middle and short rotation energy plants chopping, the conical screw chopper is the most appropriate to use, because this chopper cut plant stems by conical screw with a sharpened outer edge, therefore can cut the longer chips. There were investigated the biometric characteristics of willow stems and physical-mechanical properties of chaff, such as humidity, bulk density, fall and natural crumble angles, chaff fractional composition, ash content as well as the calorific value. Determined bulk density of osier willow chaff decreased from 136.4 to 123.9 kg m^{-3} DM, and the natural crumble angle changed from 39 to 47 degrees, whereas the fall angle – from 66 to 78 degrees. After evaluation of willow chaff fractional composition it was estimated that the largest part of fraction was received on the sieves with the diameter of 8 and 16 mm holes – from 62.1 to 75.8%, and very small amount of the dust was formed – from 0.02 to 0.08%. Research results of willow chaff ash content and calorific value shows that the estimated ash content was relatively low and reached only 1.44%, it shows that the chaff of such energy plants as willows burns relatively well and in comparison with other energy plants, determined the lower calorific value of willow chaff dry mass was relatively big – 18.5 MJ/kg. Presented research results show that the usage of osier willows for bio-fuel is justified very well. Chopped by conical screw chopper plants can be used in the boiler rooms of average or big power (more than 0.5 MW), which have special burning devices suitable for burning the wet and partially dried bio-fuel.

Key words: energy plants, willows, conical screw chopper, chaff properties, fractional composition, ash content, calorific value.

INTRODUCTION

Recently, when the environmental crisis-induced excessive people hands in exploiting natural resources including massive fossil fuel use become the big driving force for the use of renewable energy then so biomass energy again received fresh momentum and become a focus for some circles (BIOMASS PROJECTS, 2016).

The European Union (EU) is being approached in 2020 for the realization of the 20-20-20 targets but on the other hand they began to prepare the draft for the new policy climate and energy issues from years 2020-2030. EU has proposed a new target in 2030 including a 40% decrease in greenhouse gas emissions, a 30% decrease in energy consumption and 27% for the use of renewable energy (BIOMASS PROJECTS, 2015). History shows how biomass policies is the main driver for the development of various sorts of biofuel market in Europe. It is also widely used as a model of a particular region or country to implement renewable energy policies, especially biomass sector (BIOMASS PROJECTS, 2016).

The plant biomass for energy purposes is a major source of renewable energy. Currently, biomass accounts for about half of the renewable energy used in the European Union (BLUMBERGA, 2008; ŠATEIKIS, 2006; MATIAS AND DEVEZAS, 2007; SCHAUMANN, 2007). European Union countries, estimated the volume of biomass energy by 2020 increase to 3-3.5 times, and by 2030 – 3.5-4.5 times (GREEN PAPER, 2000). Predicted that the EU renewable energy consumption in 2020 year reach 20% of total domestic consumption, and biomass energy will deposit about 13% of total domestic consumption (65% of the total renewable energy). The target for share of energy from renewable sources in the final consumption of energy in 2020 for Lithuania is equal to 23% according to proposed Directive on renewable energy sources (RES) (ANENERGYPOLICY, 2007; JASINSKAS AND LIUBARSKIS, 2005). People in many countries of the World are growing and using for biofuel many different sorts of short rotation trees – willows, poplar, short rotation aspen, etc. (SCHAUMANN, 2007; ANENERGYPOLICY, 2007; JASINSKAS AND LIUBARSKIS, 2005). The Government of Saskatchewan is evaluating whether biomass crops can be successfully used as an affordable, reliable, and environmentally sustainable bioenergy source. The objective of this study was to determine the first 3-year-rotation biomass yields of 30 willow cultivars planted in central Saskatchewan. Annual willow morphological data were collected throughout the first rotation, and stem biomass equations were developed. A willow yield map was produced for these willow cultivars across climates and soils of Saskatchewan (AMICHEV ET AL., 2015). The use of willow as a bioenergy source appears promising, but further research is needed.

Green biomass energy stock – quick-growing trees and bushes, willow, a tall perennial grass. There are more than 500 ha of cultivated willow (Salix Viminalis) plantations in Lithuania, which has become to use as a hard bio-fuel. Therefore, with increasing uptake of renewable energy sources are necessary new technologies research and development work.

Energy plants cultivation and their usage for fuel contribute to solve a number of environmental problems (PIENKOWSKI, 2010; FILHO AND BADR, 2004; LUKASZEWICZ ET AL., 2009; KRYŽEVIČIENĖ, 2003; JONIEC AND FURCZAK, 2010; JASINSKAS ET AL., 2008; STAJNKO ET AL., 2009; JASINSKAS AND SCHOLZ, 2008; VARES ET AL., 2007):

- vegetate plants improves the environmental climate;
- improves soil structure and allows for a smaller demand for chemical fertilizer;
- burning of plant biomass reduces environmental pollution by harmful substances.

Energy plants and their plantations are useful to grow around the residential facilities, farmhouses, because plants may improve the ambient air microclimate. As a result, the energy plant plantations is best to plant the prevailing wind side to separate of the population and household residential premises from polluting facilities: the factories and plants, water treatment plants, landfills, roads. For projection of environmentally sound farm, it is appropriate to distinguish energy plant plantations between the residential sector of the livestock farms and sheds, silage trench, manure pits, manure storage, etc. (VARES ET AL., 2007; FABER ET AL., 2007).

Harvesting technologies of short rotation energy plants depends on many factors: the biological properties of plant maturity, humidity, and weather conditions. For plant harvesting can be used two technologies: direct – plant harvesting by self-propelled harvester or indirect – removal of plant stems and pressing or loose stems harvesting, storage and chopping (JASINSKAS AND SCHOLZ, 2008; FABER ET AL., 2007). Naturally, the direct stem harvesting technology prevails, in which the plant stalks are cut, chopped and removed from the field. Indirect harvesting technology is used less frequently.

For plant chopping in the energy plant chopping mechanisms three types of choppers are usually used: drum, disc, and conical screw. They differ in the construction of the chopping mechanism, whereas their supply mechanisms are similar. The results of the experiments have shown that a larger chaff is received by chopping with the drum and disc choppers. However, by chopping the stems with the disc chopper, the amount of the dust in the chaff is very huge (by 8-10%). For the middle and short rotation energy plants chopping the conical screw chopper is the most appropriate to use. The chaff in this chopper is being cut by conical screw with a sharpened outer edge. Therefore, this chopper can cut the longer chips (JASINSKAS AND SCHOLZ, 2008).

Therefore, it is appropriate to determine the technological-technical parameters of willow stems chopping and to evaluate the most important chaff properties.

The aim of this work – to investigate the technical means of willow stems preparation for biofuel by using the conical screw chopper and to determine the biometrical characteristics of willow stems and physical-mechanical properties of chaff, such as humidity, bulk density, flow angles, chaff fractional composition, ash content and calorific value.

MATERIALS AND METHODS

The experimental analysis of the wet (approximately 50% of humidity) willows was carried out in 2014-2015 in the base of the Institute of Agricultural Engineering and Safety, Aleksandras Stulginskis University (ASU) and in the plantations of osier willows (*Salix viminalis*L.) belonging to Lithuanian Research Centre for Agriculture and Forestry (LRCAF).

The stems of osier willows of various diameters and 3 years of growth were cut down on the early spring (on February 2015). There were measured the diameters of the stems in 1 m of the height from the soil surface: Gl.1 (28 mm); Gl.2 (20 mm); Gl.3 (15 mm); Gl.4 (13 mm).

The stems of plants were chopped with the mounted to the tractor stationary conical screw chopper *Laimet-21*. There were investigated the biometric characteristics of energy plants' stems and physical-mechanical properties of chaff, such as humidity, bulk density, fall and natural crumble angles, the chaff thinness (fractional composition), ash content as well as the calorific value.

Estimation of biometric characteristics of the energy plants` stems.

Measurements of stems: the length and diameter of stems. Five stems from the plantation were selected and measured. The length of the stem was determined by the measuring tape (1 mm proximity). The diameter of the stem was determined by the calliper (0.1 mm proximity) in 1 m of the height.

The *mass* of the stem was determined by weighting the stems with the weight (by 0.1 g proximity). The average weight of 5 stems was estimated and written down with a measurement deviation.

*The moisture content of stems*was determined in the chemical laboratory according to the standard methodology CEN/TC 14774-1:2005). To determine the moisture content, 3 stems were chopped and 3 samples were taken for 200 g each. The moisture of the stem was the ratio between the water amount in the sample and the mass of the sample. The average mass of three stems was estimated and written down with a measurement deviation.

*The density of stems***.** When the diameter of the stems had already been found, the volume V_{st} of 1 m length of the stem and the plot m^2 of the stem`s cross-section was estimated. Since the mass $m_{st}$ of 1 m length of the stem was known (the proximity of the weight 0.1 g), the density $\rho_{st}$ of the stem`s mass was estimated. When the moisture content of the stems was estimated, the density of each stem and the average density of the dry matter (DM) with the confidence interval of the data dispersion were estimated.

Equipment and measuring devices used during the experiment were as follows:

- weight SB 16001, weight limit 0-16 kg, measuring range 0.1 g;
- ruler, measurement range 1 mm;
- callipers, measurement range 0.05 mm.;
- cylinder to determine the chaff`s density:
  - diameter d_i = 0.18 m;
  - heighth_i = 0.23 m;
  - volumeV_i= 0.00585 m^3.

Characteristics of the chaff chopped with a conical chopper.

Three types of choppers are usually used in the energy plant chopping mechanisms: drum, disc, and conical screw. These choppers have different construction of the chopping mechanism, but their supply mechanisms are similar. For willow stems chopping was used the conical screw chopper, because this chopper can cut the longer and high quality chips (Fig. 1).

The individual stems are being chopped. The chopped mass is supplied in the bags from which the samples of the chaff are taken to determine their physical-mechanical properties.

Fig. 1. – Conical screw blade and example of chaff

The density of the chaff's mass. At first, empty 5 dm^3 cylinder is weighted and the chaff is poured by the top edge. Then the cylinder with the chaff is weighted. Finally, the mass and the density of the chaff were estimated. The experiment is repeated 5 times.

*The moisture of the chaff*is determined in the same way as biometric characteristics of the plant.

*Determination of thechaff`s fall and natural crumble angles.*These angles of the chaff are necessary for projection of the chaff`s storages and mechanisms for the chaff`s transportation to the boiler-rooms and storages. They are determined by the stands, whereas fall and natural crumble angles are determined with the help of the special device (JASINSKAS AND SCHOLZ, 2008).

Fractional composition of the chaff.

To determine the chopping quality of the plant`s stems (fractional structure), the same research methodology is used as in Germany and other EU countries (EU DD CENT/TS15149 – 1: 2006; CEN/TS 14961: 2005). The chaff fractional composition is determined using a set of sieves of 400 mm diameter. The sieves are placed on top of one another with the round holes (in the sequence from the top sieve): 63 mm, 45 mm, 16 mm, 8 mm, 3.15 mm, and 1 mm of diameter. The sample (3 kg of mass) is being sifted with a special shaker *Haver EML Digital plus*. The set of sieves in the horizontal surface is being vibrated for 2 minutes (Fig. 2). The mass left on the sieves is weighted and the portion of every fraction is estimated by percent’s. Each experiment repeated 5 times.

Fig. 2. – Laboratory sieve shaker *Haver EML Digital plus*

Determination of willow quality indicators, ash content and calorific value.

The research of the produced energy plant chips` quality indicators – ash content and heat parameters (calorific value) is performed in the Laboratory of Heat Equipment Research and Testing, Lithuanian Energy Institute (LEI) according to the standard methodology used in Lithuania and in other European countries:

- in the experimental mechanism of moisture No. 8B/1 according to LST EN 14774-1:2010 standard requirements;
- in the experimental mechanism of ash content No. 8B/5 according to LST EN 14775:2010 standard requirements;
- in the experimental mechanism of heating No. 8B/2 according to LST EN 14918:2010 standard requirements.

One of the most important quality indicators of the chips is their calorific value. To determine this index, the succinct `IKA C5000` was used. To make the experiment more accurate, the chip samples of unconventional energy plants were dried. The experiment was repeated 5 times with each type of the chips. The measurement deviation was 0.02%. The experiment deviation was evaluated by estimating the arithmetic averageof the data of every repeated experiment.

RESULTS AND DISCUSSION

The results of experimental research have shown: biometric characteristics of energy plants` stems, the analysis of the chaff chopping quality, chaff`s density, and flow angles. Moreover, fractional composition and moisture content of the energy plants were determined, and the ash content and calorific value of willow chaff were evaluated.

4 types of osier willow stems were investigated which were classified according to the thickness (diameter) of their stem.

Biometrical properties of energy plants.

The individual growth rate and development, as well as reaction to biotic and abiotic factors are common to biometric characteristics of the plant development for different plant species. The research results of biometrical characteristics of osier willows are presented in Tab. 1.

The results of biometric characteristics of energy plants` stems show that willow stems of three-year-old growth grew from 2.5 m to 4.4 m of height. The diameter of every willow stem depended on the height of the willow. The taller the willow, the thicker was its stem. When the diameter of stems was Gl.1 (28 mm), its length reached 4.5 m, and when the diameter of willow stems was twice smaller Gl.4 (13 mm), the height was 2.5 m.

Analysing the stems` mass of the osier willow, the same tendency as with their lengths could be seen, i.e., when was the bigger diameter of the osier willow stems, the bigger was the mass of full length stem. The mass of full length willow stem Gl.4 was 73% smaller than Gl.1.

While estimating the moisture content of osier willow, it was determined that when was the bigger diameter of the osier willow Gl.1 (28 mm), the smaller was its moisture content – 52.49 ± 0.55%. The largest moisture content was of Gl.4 (13 mm) –54.56 ± 0.39%. Stems of such moisture content can be used for the fuel in the boiler-rooms with the fire-places which are suitable to burn the wet wood.

When the moisture content of the stems is determined, the density of the stem`s dry matter can be estimated. The smallest density of the stem was estimated in Gl.1 (28 mm) – 694.47 ± 74.50 kg m^{-3}, whereas the largest of Gl.3 (15 mm) – 893.76 ± 60.50 kg m^{-3}.

Tab. 1. – The biometrical properties of osier willow stems (*Salix viminalis*L.)

Indicators and measurement units	Plant stems			
	Gl.1 (28 mm)	Gl.2 (20 mm)	Gl.3 (15 mm)	Gl.4 (13 mm)
Lengthof stem, mm	4445.33 ±80.04	4150.33 ± 95.74	2754.33 ± 92.24	2546.33 ± 68.01
Diameter of stem, at 1.0 m distance from the soil surface, mm	28.0 ± 1.26	19.92 ± 0.96	15.18 ± 0.86	13.25 ± 0.80
Mass of full stem length, g	1019.0± 48.93	758.47 ± 45.11	383.87 ± 40.92	250.50 ± 38.95
Moisture content of stem, %	52.49 ± 0.55	53.46 ±0.46	53.74 ± 0.42	54.56 ± 0.39
Density of stem dry mass, kg m^{-3} DM	695.47 ± 74.50	870.06 ± 66.18	893.76 ± 60.50	815.34±24.79

Physical-mechanical properties of willow stems. Physical-mechanical properties of individual osier willow stems after 3 months of cutting and chopping with conical screw chopper were determined (moisture content, bulk density, fall α_{gr} and natural crumble α_n angles), and the test results of willows stems chaff are presented in Tab. 2.

Tab. 2. - Physical-mechanical properties of osier willows *(Salix viminalis*L.*)*stems chaff (chopped with the conical screw chopper)

Plant species	Chaff moisture content, %	Chaff parameters			Flow angles	
		Mass, g	Volume, m^3	Density, kg m^{-3}	$\alpha_{n,}{}^{0}$	$\alpha_{gr,}{}^{0}$
Gl.1 (28 mm)	32.54 ±0.34	2287.5±0.87	0.003	206.57±0.72 (136.43±0.84 DM)	47±6.6	78±7.5
Gl.2 (20 mm)	26.34±0.24	633.53±0.22	0.003	204.52±0.52 (128.01±0.13 DM)	42±5.5	70±7.4
Gl.3 (15 mm)	25.73± 0.19	830.66±0.12	0.004	177.67±0.53 (124.24±0.05 DM)	40±3.5	68±4.2
Gl.4 (13 mm)	22.88± 0.18	521.03±0.09	0.003	173.67±0.43 (123.94±0.06 DM)	39±3.2	66±3.6

From the data presented in Tab. 2 we can to see that bulk density of the willow chaff decreased from 136.43 ± 0.84 kg m^{-3} DM to 123.94 ± 0.06 kg m^{-3} DM. It is possible to state that with the increase of the stem diameter, the produced chaff bulk density also increases.

It was determined that the natural crumble angle of the osier willow stems` chaff changed from 39 to 47 degrees, whereas the fall angle – from 66 to 78 degrees. Received results of physical-mechanical properties of the chaff can be used to estimate the size of the willow chaff`s storages and sites (on the basis of the natural crumble angle, it is possible to determine how the chaff which is being poured from the transport will change). Moreover, on the basis of chaff`s crumble angle, the constructive parameters of storages and walls of the supply to the fire-places mechanisms (the crumble angles of the walls should be larger than the determined limitary) can be determined.

Fractional compositionof willow plant stems chaff. The chaff of osier willow was used for experimental research. To perform the analysis of fractional composition, a set of sieves of 400 mm diameter with round holes of 1 mm, 3.15 mm, 8 mm 16 mm, 45 mm were used. Fractional composition of the plant`s chaff is provided in Fig. 3 – Fig. 6.

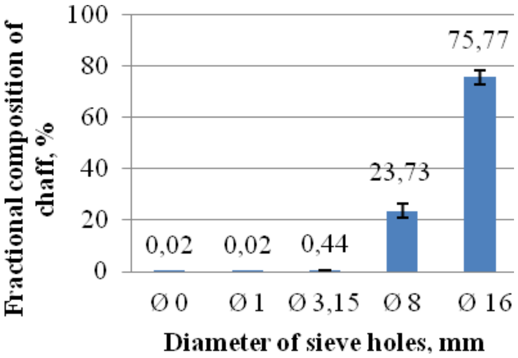

Fig. 3. – Gl.1(28 mm) fractional composition

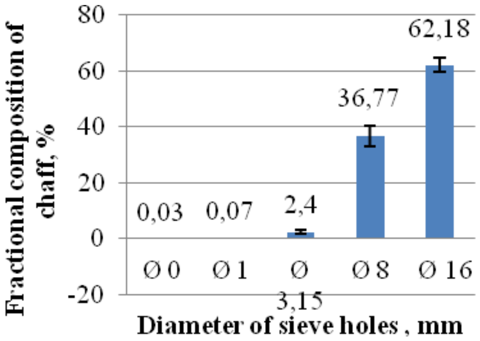

Fig. 4. – Gl.2 (20 mm) fractional composition

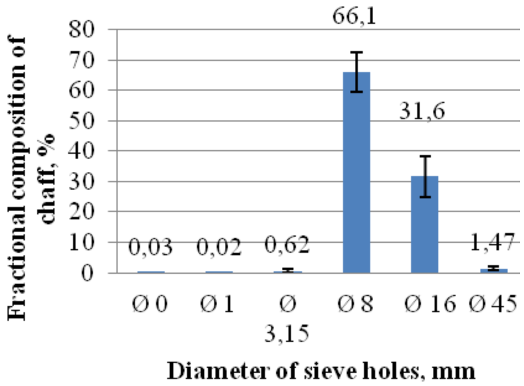

Fig. 5. – Gl.3 (15 mm) fractional composition

When the fractional composition of the plant`s chaff was determined according to the methodology used in the EU countries, it was estimated that the largest fractional composition was received when the diameter of the sieves holes was 8 mm and 16 mm. Moreover, it was determined that the willows which had a thicker stem (Gl.1 and Gl.2), the largest portion of the chaff`s fraction concentrated on the sieves with the holes of 16 mm diameter (accordingly 75.77% and 62.18%), whereas the willows which had the thinness stems (GL.3 and GL.4), the largest portion of the chaff`s fraction concentrated on the sieves with the holes of 8 mm diameter (accordingly 66.1% and 62.1%). It was determined, that very small amount of the dust was formed (from 0.02 to 0.08 %).

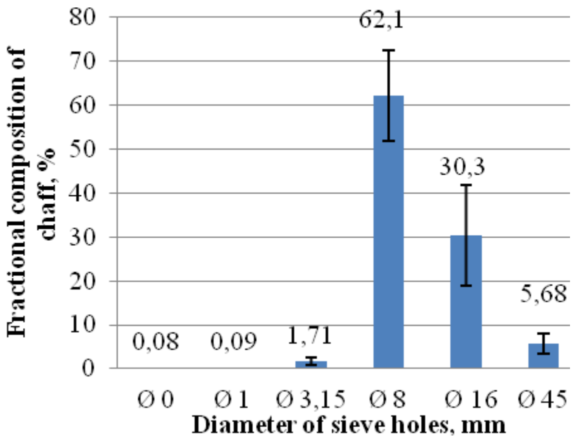

Fig. 6. – Gl.4 (13 mm) fractional composition

Determination of willow stem`s chaff`s ash content and calorific value.

The analysis of willow chaff`s ash content and calorific value shows that the estimated ash content of is relatively low and reached only 1.44%. The small amount of ashes shows that the chaff of such energy plants as willows burns relatively well and in comparison with other energy plants with the small calorific value, determined the lower calorific value of willow chaff dry mass is relatively big – 18.5 MJ/kg).

The results of these experiments show that the usage of osier willows for bio-fuel is justified very well. Cut and chopped stems can be used in the boiler rooms of average or big power (more than 0.5 MW), which have special burning devices suitable to burn the wet and partially dried bio-fuel.

CONCLUSIONS

Presented research results of willow stems biometrical properties and physical-mechanical properties of chaff, such as moisture content, bulk density, flow angles, chaff fractional composition, ash content and the calorific value. Investigated bulk density of willow chaff decreased from 136.43 ± 0.84 to 123.94± 0.06 kg m^{-3} DM, and the natural crumble angle changed from 39 to 47 degrees, the fall angle varied from 66 to 78 degrees. Research results of willow chaff fractional composition show, that the largest part of fraction was received on the sieves with the diameter of 8 and 16 mm holes – from 62.1 to 75.77%, dust amount was very small (0.02-0.08%). After burning of willow chaff determined ash content was relatively low and reached only 1.44%, estimated the lower calorific value of willow chaff dry mass was relatively big – 18.5 MJ/kg. After analysis of presented research results should be concluded, that chopped by conical screw chopper osier willows can be used in the boiler rooms of average or big power.

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