Agronomy Research **14**(1), 259–268, 2016

Investigations of fibre plants preparation and utilization of solid biofuels

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Abstract. Presented research results of technological-technical means and operations for solid biofuel preparation: chopping, milling, pelleting and burning of fibre plants – 3 sorts of fibre hemp (Beniko, Bialobrzeskie and Epsilon 68) and fibre nettle (sown in 60 x 60 cm). These fibre plants were grown in the experimental fields of Lithuanian Research Centre for Agriculture and Forestry, Upytė Experimental Station, and in Aleksandras Stulginskis University were investigated the technical means of these plants preparation and usage for energy purposes. It was used the standard methodology for solid biofuel preparation of fibre plants, and was investigated the technique for plant chopping, milling and pelleting. There were determined fibre plant mill fractional composition while usage the hummer miller prepared mill. There were determined the fibre plant pellet quality indicators – moisture content and bulk density. The fibre plant pellet moisture content ranged from 6.4% to 8.8%, and pellet density reached 1,082.7–1,186.2 kg m^{-3} DM (dry matter). Pellet elemental composition, ash content and calorific value were determined at the Lithuanian Energy Institute. The ash content after the burning of fibre plant pellet was not high and varied from 3.6 to 5.9%. Determined net calorific value of fibre hemp and fibre nettle dry mass was relatively high 17.2–17.5 MJ kg^{-1}, it was close to calorific value of some wood species.

Key words: Fibre hemp, fibre nettle, pellets, elemental composition, ash content, calorific value.

INTRODUCTION

One of the most important renewable energy sources in Lithuanian is plant biomass, which is an eco-friendly local fuel: wood, specially cultivated trees, straws, tall grasses, triticale and other unconventional energy crops). These energy resources already make a big part of the local fuel. Plant biomass compared with fossil fuels has many advantages: relatively low costs, less dependence on weather changes, the promotion of local economic structures' development and alternative sources of incomes for plant growers. As renewable energy sources can be grown and fibrous plants – fibre hemp and fibre nettle. These plants grow well in Lithuanian climatic conditions (Jankauskiene et al., 2006; Jasinskas & Scholz, 2008; Jankauskiene & Gruzdeviene, 2010).

The market of energy fuel in Lithuania highly depends on import. There is no any fossil fuel except small amount of oil and peat in Lithuania. The biofuel as wood and wood residues, straws and energy plants is the most interesting sphere how to increase renewable resources in the energy balance. Electricity generation from biofuel was 6.1% in 2014 year (Sabaliauskas, 2015). There is an intention to develop energy plant plantations, also better use forest wastes and agricultural crops residues – straws. Till 2020 year heat generation from solid biofuel will reach 67% in Lithuania (Verbickas et al., 2013).

There is big potential of crops wastes, but the straw is not so friendly for combustion equipment, because the content of chlorine compare with wood is 7–10 times bigger and nitrogen 10–12 times. These materials stimulate corrosion (Verbickas et al., 2013). Therefore, the cultivation of energy plants has perspective due to its closeness to wood.

Plants as fibrous hemp and fibrous nettle were chosen for it‘s productivity and high calorific value. Hemp originated in Central Asia. The most useful is seeding hemp (Cannabis sativa L.). It is an annual plant. This type is used for seeds and fibre. Scientists also suppose it usage for energy purposes. Ability of fibrous hemp to yield more than 24 tons of green biomass per hectare (corresponding to 10.9 t ha^{-1} of dry biomass) within 140 days (Kolarikova et al., 2014). The green biomass can be used for biogas production, seeds for biofuel and stems for briquetting and pelleting production. Hemp is not climate demanding and prefer wet and rich soils. It can be grown in dried peat bogs. The wet clay soil is not recommended. Hemp also can be used in crop rotation due to its ability to enrich soil in form of leaves and roots. Moreover, it has heavy metal absorption properties so it can be used to renew contaminating fields (Jasinskas & Scholz, 2008).

Three varieties of fibre hemp were chosen for this research: polish cultivars Beniko and Bialobrzeskie, which are medium-early and French cultivar Epsilon 68 – late, maturing.

The great nettle (Urtica Dioica L.) is common perennial plant in Lithuania. It is not soil and climate demanding. The nettle is used in textile, medical, cosmetic and food industries. There are possibilities to use nettle for biofuel production as briquettes or pellets. The annual dry matter yield (DMY) of nettle ranged from 6 to 10 t ha^{-1} (Butkute et al., 2015).

Harvesting technologies of unconventional 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 and milling, or indirect – removal of plant stems and pressing or loose stems harvesting, storage and chopping (Faber et al., 2007; Borkowska & Molas, 2012; Jasinskas et al., 2014). Naturally, the direct stem harvesting technology prevails, in which the plant stalks are cut, chopped and pressed into bales or bundles of chaff and are removed from the field. Indirect harvesting technology is used less frequently.

Plant chaff use for biofuel is not convenient; therefore, it is expedient to mill and press this chaff into briquettes or pellets and to determine the mechanical and energetic properties of pellets produced from plant biomass. It is convenient to use the pellets in small and medium thermal plants because the operations of pellet supply and combustion can be fully automated (Sultana & Kumar, 2012; Cherney & Verma, 2013; Niedziołka et al., 2015). Therefore, it is appropriate to determine the technological-technical parameters of fibre plants chopping, milling and pellet preparation of biofuel.

The possibilities of fibre plants utilization and usage for energy purposes in Lithuania has been poorly investigated, researches have been carried out in the Institute of Agricultural Engineering and Safety, Aleksandras Stulginskis University.

The aim of this work – to investigate the technical means of fibre plants mass preparation for biofuel, to assess quality indicators of these energy plants' chopping, milling and pelleting, to determine pellet the basic properties: density, elemental composition, ash content and calorific value.

MATERIALS AND METHODS

There were investigated three sorts of fibre hemp: Beniko, Bialobrzeskie and Epsilon 68, and one sort of fibre nettle (sown in 60 x 60 cm). These plants were grown in the experimental fields of Lithuanian Research Centre for Agriculture and Forestry, Upytė Experimental Station, and in Aleksandras Stulginskis University were investigated the technical means of these plants preparation and usage for energy purposes. It was investigated the technique for plant chopping, milling and pelleting.

The chopping and milling quality of fibre plant, produced for biofuel, should satisfy the requirements of the combustion chamber, chopped mass transportation machinery and storage. For the first step of stem chopping was used a drum chopper of Maral 125 forage harvester (Jasinskas et al., 2014). Before the production of biofuel pellets, the prepared chaff should be chopped to the form of the mill. For the chaff milling a Retsch SM 200 mill was used.

The milling quality was determined using the standard methodology (DD CEN/TS 15149-1:2006). The fractional composition of the chopped plants was determined using a set of 200 mm diameter sieves with round holes of diameters 0 mm, 0.25 mm, 05 mm, 0.63 mm, 1 mm and 2 mm. The mass remaining on the sieves was weighed, and the sample fraction percentages were calculated. Each test was repeated 5 times (DD CEN/TS 15149-1:2006).

For pellet production was used a small capacity granulator 'Peleciarka' (produced 2011 by Company *POLEXIM*, Poland), 7.5 kW with a horizontal granulator matrix, the diameter of the pellets was 6 mm granulated milled plants (Fig. 1). Main constructive parameters of granulator are as follows: the distance between the flat die and rollers is 0.05–0.3 mm; the rotation speed of die is 3,000 min^{-1}; the mass flux is 200–350 kg h^{-1} (Instruction manual, 2011).

The moisture content of milled raw material is determined: the fibre hemp 'Beniko' 7.8 ± 0.1 %, the fibre hemp 'Bialobrzeskie' 8.3 ± 1.2 %, the fibre hemp 'Epsilon 68' 7.4 ± 0.4 % and the fibre nettle 7.9 ± 0.2%.

The mill was granulated in the traditional way: before the mill entered the granulator, the mill was mixed thoroughly to achieve homogeneity. Next, the raw material was moistened, and the dosage unit was supplied to the press chamber, wherein the mill was moved by rollers through the matrix holes of 6 mm diameter. The biomass was pressed through holes to form of pellets. The pellet cooling period was 24 hours, and after a full pellet cooling and relaxation process their biometric parameters:

dimensions, humidity, volume and density, were evaluated. The pellet parameters were determined by measuring their height and diameter (accurate to 0.05 mm). Experimental trials were randomly selected for each plant species with 10 pellets.

Figure 1. Small capacity granulator with a horizontal granulator matrix.

Pellets weight was assessed by KERN ABJ scales (accurate to 0.001 g). The weights were calculated for each type of plant using 10 of the granules with the average meaning the error.

Pellets moisture content was determined in a laboratory drying chamber oven according to the standard method (CEN/TC 14774-1:2005). The pellet volume was calculated using the pellet size (diameter and length).

Pellet density was calculated after determination of pellet volume and pellet size (diameter and length) and pellet mass. It also was determined the bulk density of pellet, granules poured into 5 dm^3 container, weighing and calculating the bulk density (Niedziołka et al., 2015).

Pellet elemental composition, ash content and calorific value were determined at the Lithuanian Energy Institute (LEI) Thermal equipment research and testing laboratory in accordance with the valid Lithuania and EU countries standard methodology:

- using the basic elements analyser Flash 2000, Nr. 2011 F0055,
- according to LST EN 14774-1:2010 standard, in moisture test rig Nr. 8B/1,
- according to LST EN 14775:2010 standard, in ash content test rig Nr. 8B/5.

Calorific value (KJ kg^{-1}) of the plant chaff was determined by a IKA C 5000 calorimeter (IKA, Germany) by the standard methodology (BS EN 14918:2009).

RESULTS AND DISCUSSION

There were determined the fractional composition of chopped by drum chopper and milled by hammer mill fibre plants – fibre hemp (Beniko, Bialobrzeskie and Epsilon 68) and fibre nettle (sown in 60 x 60 cm). The fractional composition was determined applying methodology widespread in EU countries, using sieves with holes of various diameters. Fractional composition of prepared mill (%) dependence on sieves holes diameter (mm) is presented in Figs 2–5.

Dependance of a part of fibre hemp Beniko mill fraction (%) from the holes of sieves is presented in Fig. 2. Having evaluated fraction composition of mill, we can see that the highest mill fraction was on 0.25 mm sieves (37.8 ± 2.0%). There was no fraction on a sieve with holes 2 mm diameter, and too big amount of dust was found – 27.6 ± 1.9%.

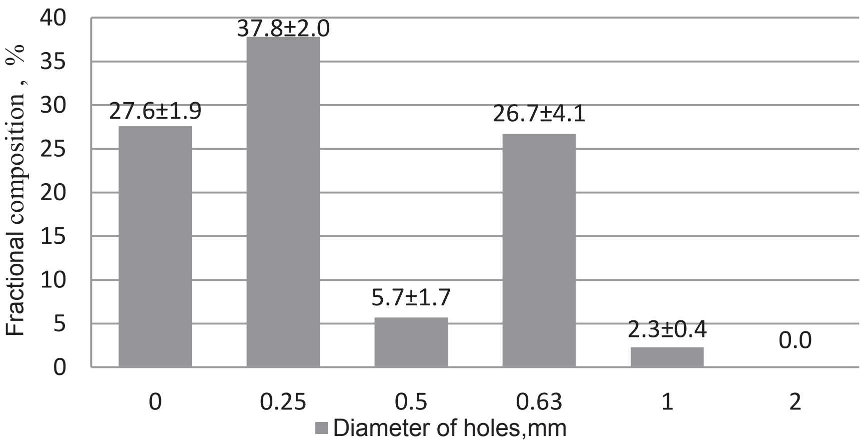

Figure 2. Fraction composition of fibre hemp Beniko mill.

Dependance of a part of fibre hemp Bialobrzeskie mill fraction (%) from the holes of sieves is presented in Fig. 3. After evaluation of mill factional composition from the chart, we can see very similar view like of the fibre hemp Beniko. The highest fraction of plant mill accumulated on a sieve with holes 0.25 mm diameter – 38.7 ± 1.8%, and a little less on 0.63 mm diameter holes sieve – 26.6 ± 4.3%. There was no fraction on a sieve with holes 2 mm diameter, and as well as for hemp Beniko, too much amount of dust was found – 27.0 ± 1.8%.

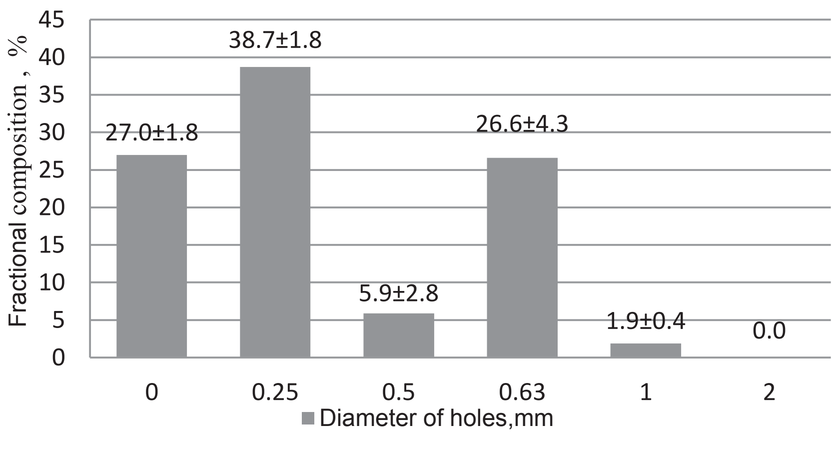

Figure 3. Fraction composition of fibre hemp Bialobrzeskie mill.

Dependance of fibre hemp Epsilon 68 mill fraction (%) from the holes of sieves is presented in Fig. 4. The highest fraction of plant mill also accumulated on a sieve with holes 0.25 mm diameter – 36.6 ± 1.8%. There was no fraction on a sieve with holes 2 mm diameter, and too big amount of dust was found – 25.1 ± 0.5%.

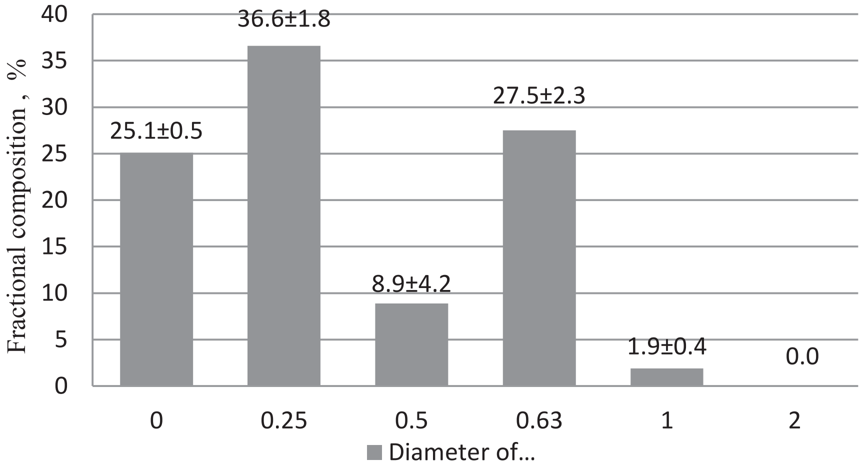

Figure 4. Fraction composition of fibre hemp Epsilon 68 mill.

Dependence of a part of fibre nettle mill fraction (%) from the holes of sieves is presented in Fig. 5. Having evaluated fraction composition of mill, from the chart we can see very similar view like of the fibre hemp research results. The highest mill fraction was on 0.25 mm sieves (38.7 ± 2.6%). There was no fraction on a sieve with holes 2 mm diameter, and too big amount of dust was found – 27.0 ± 2.7%.

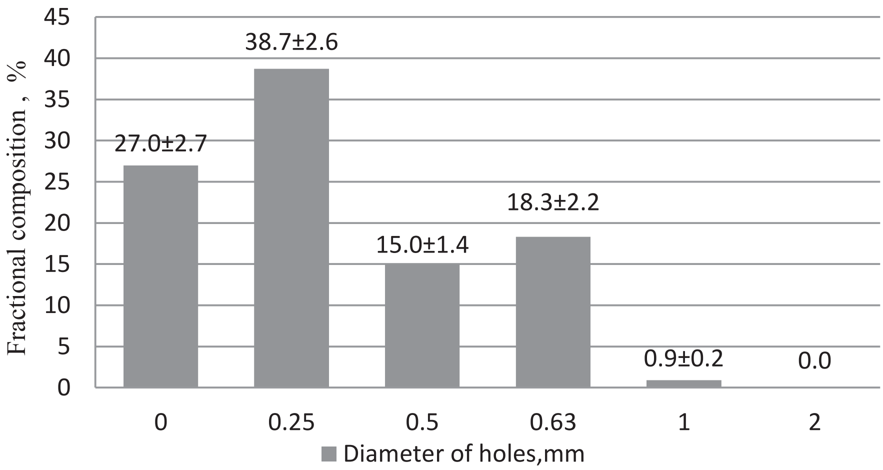

Figure 5. Fraction composition of fibre nettle mill.

Evaluating milling quality of fibre hemp (Beniko, Bialobrzeskie and Epsilon 68) and fibre nettle mill it can be stated that all plants were milled into too small fraction. There were determined, that the biggest mill fraction was on 0.25 mm sieves – from 36.6 ± 1.8% to 38.7 ± 2.6%, and too big amount of dust was found – from 25.1 ± 0.5% to 27.6 ± 1.9% (recommended maximum amount of dust 10–15%). There was no fraction on a sieve with 2 mm diameter holes.

All investigated fiber plants are suitable for burning after appropriate preparation. Investigated fiber plants were pressed into pellets of 6 mm diameter and were determined pellet physical-mechanical properties: moisture content and bulk density (Table 1).

Table 1. Physical-mechanical characteristics of fibre plant pellets

Fiber plant pellets	Moisture content, %	Bulk density, kg m^{-3}
Fibre hemp Beniko	6.8 ± 0.1	1,203.1 ± 35.7 1,121.3 ± 35.7 DM
Fibre hemp Bialobrzeskie	7.8±0.1	1,247.2 ± 45.2 1,149.9 ± 45.2 DM
Fibre hemp Epsilon 68	8.8 ± 0.1	1,187.2 ± 30.2 1,082.7 ± 30.2 DM
Fibre nettle	6.4 ± 0.1	1,267.3 ± 36.8 1,186.2 ± 36.8 DM

Determined pellet moisture content ranged from 6.4 to 8.8%. Bulk density in dry matters (DM) of fibre hemp Epsilon 68 pellets was the smallest – 1,082.7 ± 30.2 kg m^{-3} DM, and the density of fibre nettle was the biggest – 1,186.2 ± 36.8 kg m^{-3} DM. Density of all investigated fibre plants was sufficiently high, it has exceeded 1 t m^{-3} DM.

Research results of other non-traditional energy plants pellet biometrical content data shows that the virginia mallow and cup plant pellet moisture contents ranged from 9.6% to 11.6%. The virginia mallow pellet density was also big – 969.3 kg m^{-3} DM, but cup plant pellet density was significantly lower than fibre plant and reached only 788.5 kg m^{-3} DM (Siaudinis et al., 2015).

Determined elemental composition of three sorts of fibre hemp and one sort of fibre nettle shows that were received similar amounts of elements for all sorts of plants: C (carbon) content was the biggest and reached 45.9–46.7%, H (hydrogen) content varied from 5.2 to 5.9%, and other chemicals composition of N (nitrogen) and S (sulphur) was small in volume % (Table 2).

The ash content of fibre nettle was the biggest and reached 5.9%, lower ash content was of the hemp, it varied from 3.6 to 3.8% and was about 1.6 times lower than fibre nettle biofuels. The high ash content indicates that investigated of fibre nettle pellets burned insufficiently.

The average calorific value when burning of all investigated sorts of fibre hemp and fibre nettle pellets of DM was very similar and varied from 17.2 to 17.5 MJ kg^{-1}. This calorific value of fibre plant pellets was relatively high, close to calorific value of some wood species.

According to other sources, the calorific value of fibre hemp variety 'Bialobrzeskie' was 17.76–18.98 MJ kg^{-1} DM (Poisa & Adamovics, 2011).

Table 2. Pellet elemental composition, ash contents and calorific value

Parameters	Value	Deviation, ± %
Fibre hemp Beniko		
C (carbon) content, %	46.29	1.08
H (hydrogen) content, %	5.94	0.43
N (nitrogen) content, %	0.37	0.31
S (sulphur) content, %	0.11	0.27
O (oxygen) content, %	43.65	-
Ash content, %	3.64	0.02
Moisture content, %	6.88	0.07
Dry biofuel lower calorific value, MJ kg^{-1}	17.21	0.47
Fibre hemp Bialobrzeskie		
C (carbon) content, %	46.74	1.09
H (hydrogen) content, %	5.16	0.43
N (nitrogen) content, %	0.35	0.31
S (sulphur) content, %	0.12	0.27
O (oxygen) content, %	43.82	-
Ash content, %	3.80	0.08
Moisture content, %	7.52	0.07
Dry biofuel lower calorific value, MJ kg^{-1}	17.52	0.35
Fibre hemp Epsilon 68		
C (carbon) content, %	46.61	1.07
H (hydrogen) content, %	5.94	0.43
N (nitrogen) content, %	0.29	0.30
S (sulphur) content, %	0.09	0.26
O (oxygen) content, %	43.52	-
Ash content, %	3.55	0.01
Moisture content, %	6.88	0.07
Dry biofuel lower calorific value, MJ kg^{-1}	17.33	0.39
Fibre nettle		
C (carbon) content, %	45.91	1.09
H (hydrogen) content, %	5.74	0.43
N (nitrogen) content, %	0.73	0.31
S (sulphur) content, %	0.11	0.27
O (oxygen) content, %	41.60	-
Ash content, %	5.91	0.03
Moisture content, %	6.48	0.07
Dry biofuel lower calorific value, MJ kg^{-1}	17.16	0.57

CONCLUSIONS

1. There were investigated three sorts of fibre hemp: Beniko, Bialobrzeskie and Epsilon 68, and one sort of fibre nettle (sown in 60 x 60 cm). These plants were grown in Lithuanian and were investigated the technical means of these plants preparation and usage for energy purposes. It was investigated the technique for plant chopping, milling and pelleting.

2. After evaluating of milling quality of fibre hemp and fibre nettle mill it can be stated that all plants were milled into too small fraction. There were determined, that the biggest mill fraction was on 0.25 mm sieves – from 36.6 ± 1.8% to 38.7 ± 2.6%, and too

big amount of dust was found – from 25.1 ± 0.5% to 27.6 ± 1.9%. There was no fraction on a sieve with 2 mm diameter holes.

3. Determined pellet moisture contents ranged from 6.4 to 8.8%. Bulk density in dry matters (DM) of all investigated fibre plants was sufficiently high, it has exceeded 1 t m^{-3} DM. The density of fibre hemp Epsilon 68 pellets was smallest – 1,082.7 ± 30.2 kg m^{-3} DM, and the density of fibre nettle was the biggest – 1,186.2 ± 36.8 kg m^{-3} DM.

4. Research results of fibre plant pellet elemental composition showed the similar amounts of elements for all sorts of plants: C (carbon) content was the biggest and reached 45.9–46.7%, H (hydrogen) content varied from 5.2 to 5.9%, and other chemicals composition of N (nitrogen) and S (sulphur) was small in volume.

5. The ash content of fibre nettle was the biggest and reached 5.9%, lower ash content was of the hemp, it varied from 3.6 to 3.8% and was about 1.6 times lower than fibre nettle biofuels.

6. The average calorific value when burning of all investigated sorts of fibre hemp and fibre nettle pellets varied from 17.2 to 17.5 MJ kg^{-1} DM. This calorific value of fibre plant pellets was relatively high, close to calorific value of some wood species.

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