Investigation of fibrous plant pellet production and utilization for energy purposes

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Abstract

There are presented the research results of technological-technical means and operations for solid biofuel production: chopping, milling, pelleting and burning of fibrous plants: two sorts of seeder hemp (*Canabis sativa*) – "Fedora 17" and "Futura 75", and fibrous nettle (*Urtica dioica* L.). Investigated fibrous plants were grown in the experimental fields of Lithuanian Research Centre for Agriculture and Forestry, Upyte Experimental Station, and in Aleksandras Stulginskis University, Institute of Agricultural Engineering and Safety were investigated the technological-technical means of these plants processing, biofuel pellet production and usage for energy purposes. There were presented research results of fibrous plant chopping and mill preparation quality, in justice of use the hummer milling equipment prepared mill fractional composition, and were determined the produced pellet quality indicators – moisture content and bulk density. The fibrous plant pellet moisture content ranged from 7.8% to 10.2%, and pellet density reached 975–1068 kg m^{-3} DM (dry matter). Pellet elemental composition, ash content, calorific value and harmful emissions while pellet burning were determined at the Lithuanian Energy Institute. Determined ash content after pellet burning varied from 3.5% to 6.9%; net calorific value of investigated fibrous plant dry mass was relatively high and reached 17.5–17.8 MJ kg^{-1}. After determination of harmful substances (CO, CO_2, NO_x, C_xH_y) emissions into the environment while burning of fibrous plant pellet, it was concluded, that the emissions did not exceed the permissible limits and had a minimal harmful impact on the environment.

Keywords: fibrous hemp, fibrous nettle, pellet properties, ash content, calorific value, harmful emissions.

1. Introduction

Some authors emphasize that the cultivation of some fibrous plants species for energy purposes are superior over annuals, since they have higher energy potential, needs less growing expenses and have higher production profitability (Kryževičienė et al., 2005; Lewandowski et al., 2003). For many years, in many European countries the main target is focused on the local as well as non-native species, which has high biomass productivity and could be successfully used for bioenergy purposes (McKendry, 2002).

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 – fibrous hemp and fibrous nettle. These plants grow well in Lithuanian climatic conditions (Jankauskiene and Gruzdeviene, 2010; Jasinskas and Scholz, 2008).

Till 2020 year heat generation from solid biofuel will reach 67% in Lithuania (Verbickas et al., 2013). There is no any fossil fuel except small amount of oil and peat in Lithuania. Energy fuel market in Lithuania highly depends on import. 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. There is an intention to develop energy plant plantations, also better use forest wastes and agricultural crops residues – straws. 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. So the cultivation of energy plants has perspective due to it's closeness to wood (Verbickas et al., 2013).

Energy 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 seeder 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 or shives 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 it's ability to enrich soil in form of leaves and roots. And it has heavy metal absorbtion properties so it can be used to renew contaminating fields (Jasinskas and Scholz, 2008).

This article is intended to present the data of investigations of two sorts of seeder hemp (*Canabis sativa*) – "Fedora 17" and "Futura 75", and fibrous nettle (*Urtica dioica* L.).

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 great nettle ranged from 6 to 10 t ha^{-1} (Butkute et al., 2015).

Plant 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 (Jasinskas et. al., 2014; Faber et al., 2007). 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.

It is not convenient to use plant chaff for biofuel. 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 (Niedziołka et al., 2015; Cherney and Verma, 2013). Therefore, it is appropriate to determine the technological-technical parameters of fibrous plants chopping, milling and pellet preparation of biofuel.

The possibilities of fibrous 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 (Jasinskas et. al., 2014).

The aim of this work – to investigate the technical means of fibrous plants preparation for biofuel, to determine quality indicators of these energy plants' chopping, milling and pelleting, to determine the main pellet properties: density, elemental composition, ash content, calorific value and harmful emissions into the environment.

2. Materials and Methods

There were investigated two sorts of seeder hemp (*Canabis sativa*) – "Fedora 17" and "Futura 75", and one sort of fibrous nettle (*Urtica dioica* L.). 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.

Fibrous plant chopping and milling quality 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. 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 standard methodology (Jasinskas et. al., 2014).

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 the milled plants were granulated by a small capacity (100-120 kg h^{-1}) granulator with a horizontal granulator matrix, the diameter of the pellets was 6 mm (Figure 1).

Figure 1. Small capacity granulator with a horizontal granulator matrix

The mill was granulated in the traditional way: before the mill entered the granulator, the mill was mixed thoroughly to achieve homogeneity. Later 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 pellets. When the pellets were cooled, 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 20 pellets.

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, calorific value and harmful emissions 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, No. 2011 F0055;
- according to LST EN 14774-1:2010 standard, in moisture test rig No. 8B/1;
- according to LST EN 14775:2010 standard, in ash content test rig No. 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).

Were determined the limit values of emissions while burning the pellets in the small capasity (10 kW) boiler. Harmful emisions: CO, CO_2, NO_x, C_xH_y were evaluated by using the standard methodology (Jasinskas et. al, 2011).

Analysis of variance (ANOVA) was performed for three replications by employing the F test and LSD (at the 95% probability level) to assess significance (Tarakanovas and Raudonius, 2003).

3. Results and Discussion

There were determined the fractional composition of chopped by drum chopper and milled by hammer mill fibrous plant – fibrous hemp (“Fedora 17” and “Futura 75”), and fibrous nettle. 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 Figures 2, 3 and 4.

Dependance of fibrous hemp “Fedora 17” mill fraction (%) from the holes of sieves is presented in Figure 2. The highest fraction of plant mill accumulated on a sieve with holes 0.25 mm diameter – 35.8 ± 2.5%. There was no fraction on a sieve with holes 2 mm diameter, and too big amount of dust was found – 26.0 ± 0.4%.

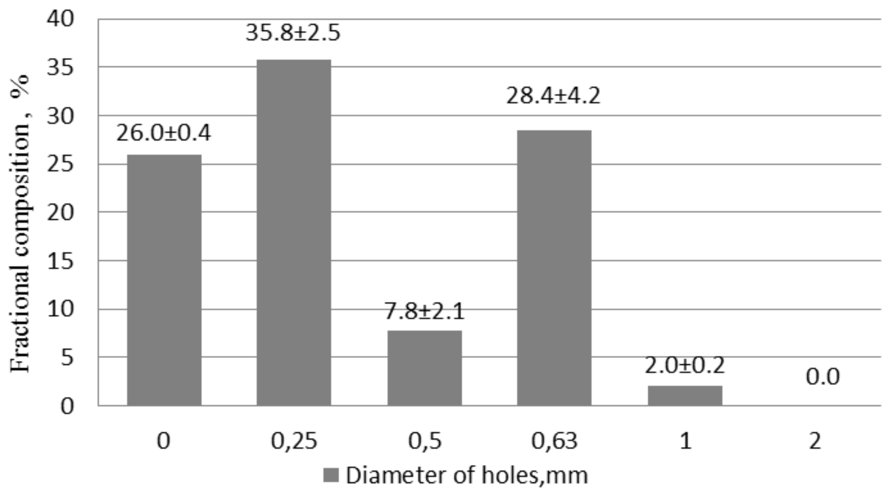

Figure 2. Fraction composition of fibrous hemp “Fedora 17” mill

Dependance of a part of fibrous hemp “Futura 75” mill fraction (%) from the holes of sieves is presented in Figure 3. Having evaluated fraction composition of mill, we can see that the highest mill fraction also was on 0.25 mm sieves (35.4 ± 4.2%). There was no fraction on a sieve with holes 2 mm diameter, and also was too big amount of dust – 25.9 ± 3.1%.

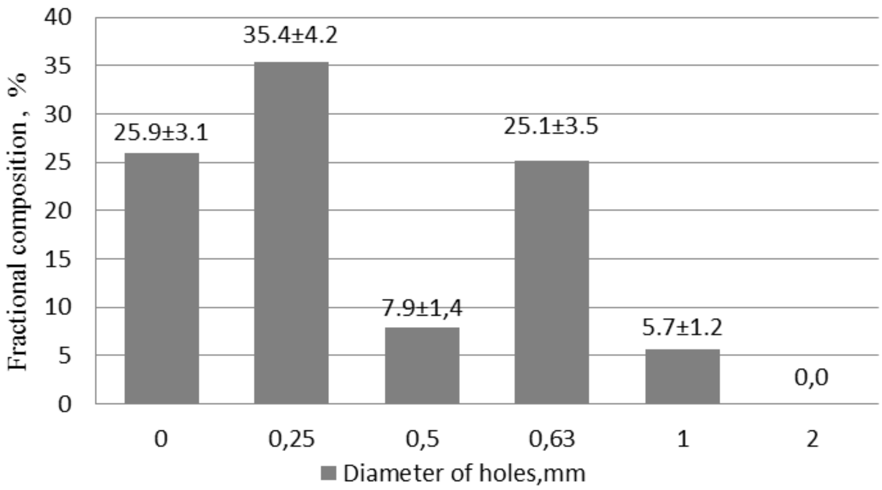

Figure 3. Fraction composition of fibrous hemp "Futura 75" mill

Dependance of a part of fibrous nettle mill fraction (%) from the holes of sieves is presented in Figure 4. Having in the charts research results of mill fraction composition, we can see very similar view like of the fibrous 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 also too big amount of dust was found – 27.0 ± 2.7%.

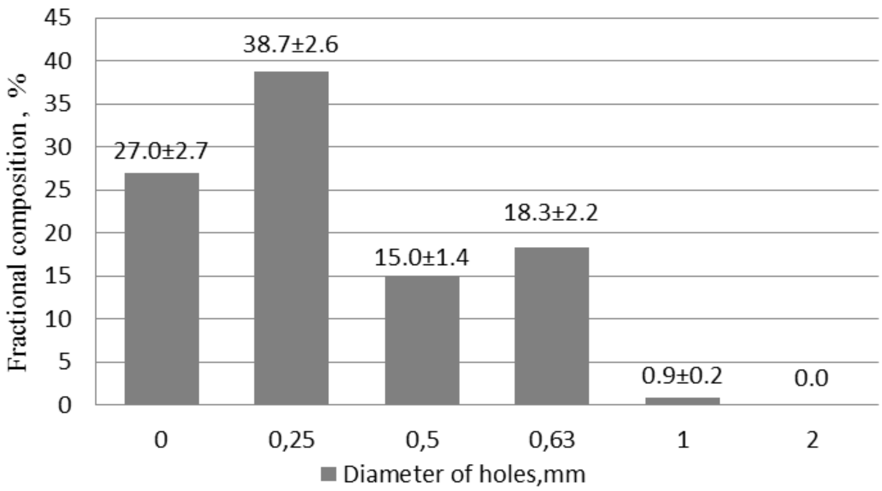

Figure 4. Fraction composition of fibrous nettle mill

Evaluating milling quality of fibrous hemp ("Fedora 17" and "Futura 75") and fibrous 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 35.4 ± 4.2% to 38.7 ± 2.6%, and too big amount of dust was found – from 25.9 ± 3.1% to 27.0 ± 2.7% (recommended maximum amount of dust 10–15%). There was no fraction on a sieve with 2 mm diameter holes.

Investigated fibrous plants are suitable for burning after appropriate preparation. In order to continue using for energy purposes, investigated fibrous 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 fibrous plant pellets

Fiber plant pellets	Moisture content, %	Bulk density, kg m^{-3}
Fibrous hemp "Fedora 17"	7.8 ± 0.1	1143.4 ± 30.5 1054.2 ± 30.5 DM
Fibrous hemp "Futura 75"	10.2 ± 0.2	1085.9 ± 27.2 975.1 ± 27.2 DM
Fibrous nettle	9.9 ± 0.1	1185.2 ± 25.3 1067.8 ± 25.3 DM

Determined pellet moisture content ranged from 7.8 to 10.2%. Bulk density in dry matters (DM) of fibrous hemp “Futura 75” pellets was the smallest – 975.1 ± 27.2 DM kg m^{-3} DM, and the density of fibrous nettle was the biggest – 1067.8 ± 25.3 kg m^{-3} DM. Density of all investigated fibrous plants was sufficiently high, it has exceeded 0.97-1.07 t m^{-3} DM.

Determined elemental composition of two sorts of fibrous hemp and one sort of fibrous nettle shows that were received similar amounts of elements for all sorts of plants: C (carbon) content was the biggest and reached 45.8–47.5%, H (hydrogen) content varied from 5.4 to 5.6%, and other chemicals composition of N (nitrogen) and S (sulphur) was small in volume % (Table 2).

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

Parameters	Value	Deviation, ± %
Fibrous hemp “Fedora 17”		
C (carbon) content, %	47.37	1.15
H (hydrogen) content, %	5.47	0.48
N (nitrogen) content, %	0.37	0.32
S (sulphur) content, %	0.02	0.28
O (oxygen) content, %	43.25	-
Ash content, %	3.51	0.14
Moisture content, %	7.83	0.07
Dry biofuel lower calorific value, MJ kg^{-1}	17.78	0.74
Fibrous hemp “Futura 75“		
C (carbon) content, %	47.48	1.14
H (hydrogen) content, %	5.44	0.45
N (nitrogen) content, %	0.43	0.33
S (sulphur) content, %	0.01	-
O (oxygen) content, %	42.52	-
Ash content, %	4.14	0.30
Moisture content, %	10.16	0.07
Dry biofuel lower calorific value, MJ kg^{-1}	17.73	0.72
Fibrous nettle		
C (carbon) content, %	45.76	1.13
H (hydrogen) content, %	5.60	0.46
N (nitrogen) content, %	0.87	0.31
S (sulphur) content, %	0.10	0.27
O (oxygen) content, %	32.26	-
Ash content, %	6.93	0.13
Moisture content, %	9.89	0.07
Dry biofuel lower calorific value, MJ kg^{-1}	17.48	1,04

The ash content of fibrous nettle was the biggest and reached 6.9%, lower ash content was of the hemp, it varied from 3.5 to 4.1% and was about 1.8 times lower than fibrous nettle biofuels. The high ash content indicates that investigated of fibrous nettle pellets burned insufficiently.

The average calorific value when burning of all investigated sorts of fibrous hemp and fibrous nettle pellets was sufficiently high and very similar, it varied from 17.5 to 17.8 MJ kg^{-1}. Determined calorific value of fibrous plant pellets was relatively high, close to calorific value of some energy plant species.

Research results of investigated fibrous hemp “Fedora 17”, “Futura 75” and fibrous nettle properties and emissions by burning showed, that all the indicators was very similar (significantly higher was CO emissions when burning the fibrous nettle pellet – reached 2484 ppm). After determination of harmful substances (CO, CO_2, NO_x, C_xH_y) emissions into the environment while burning of fibrous plant pellet, it was concluded, that the emissions did not exceed the permissible limits and had a minimal harmful impact on the environment.

4. Conclusions

There were investigated two sorts of seeder hemp – "Fedora 17" and "Futura 75", and one sort of fibrous nettle. These plants were grown in Lithuania and were investigated the technique for these plants preparation and usage for energy purposes.

After evaluating of milling quality of fibrous hemp and fibrous 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 35.4 ± 4.2% to 38.7 ± 2.6%, and too big amount of dust was found – from 25.9 ± 3.1% to 27.0 ± 2.7%. There was no fraction on a sieve with 2 mm diameter holes.

Determined pellet moisture content ranged from 7.8 to 10.2%. Density of all investigated fibrous plants was sufficiently high and it has exceeded 0.97-1.07 t m^{-3} DM.

Investigated elemental composition of fibrous hemp and fibrous nettle shows that were received similar amounts of elements for all sorts of plants: C (carbon) content was the biggest and reached 45.8–47.5%, H (hydrogen) content varied from 5.4 to 5.6%, and other chemicals composition of N (nitrogen) and S (sulphur) was small in volume, %.

The ash content of fibrous nettle was the biggest and reached 6.9%, lower ash content was of the hemp, it varied from 3.5 to 4.1% and was about 1.8 times lower than fibrous nettle biofuels.

The calorific value when burning fibrous hemp and fibrous nettle pellets varied from 17.5 to 17.8 MJ kg^{-1}. Determined calorific value of fibrous plant pellets was relatively high, close to calorific value of some energy plant species.

After determination of harmful substances (CO, CO_2, NO_x, C_xH_y) emissions into the environment while burning of fibrous plant pellet, it was concluded, that the emissions did not exceed the permissible limits and had a minimal harmful impact on the environment.

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