RESEARCH IN OAK WASTE PREPARATION AND UTILIZATION FOR BURNING

Algirdas Jasinskas[1], Rolandas Domeika[1], Egidijus Sarauskis[1], Ramunas Mieldazys[1], Vytautas Kucinskas[1], Andres Annuk[2]

[1]Aleksandras Stulginskis University, Lithuania; [2]Estonian University of Life Sciences, Estonia

algirdas.jasinskas@asu.lt

Abstract. Various kinds of wood waste may be also used as biofuel – not only in the industry and furniture obtained waste timber, but also small branches, tree bark, leaves. In Lithuania, oak is a well growing and high-quality wood; therefore, it is appropriate to investigate the oak waste preparation and utilization for burning. In the paper, test results of oak bark, leaves and their mixture preparation for the burning process (milling, pelleting) and the prepared pellet properties (moisture content, density, ash content, calorific value) are presented. Research investigations were carried out in laboratory basis of the Institute of Agricultural Engineering and Safety, Aleksandras Stulginskis University, Lithuania. Fractional composition of oak bark, leaves and their mixture mill was determined on sieves with holes of various diameters after chopping and milling of the investigated oak waste. The biggest mill fraction was accumulated on 0.25 mm sieves – from 30.9 to 46.2 %, and too big amount of dust was found – from 22.0 to 24.3 %. Prepared oak bark, leaves and their mixture pellet moisture content ranged from 8.1 to 12.5 %, and bulk density – from 975.8 to 1122.2 $kg \cdot m^{-3}$ DM (dry matter). The ash content of oak waste was very high, varied from 10.4 to 14.7 % and was about 10 times higher than wood-based biofuels. The determined calorific value when burning of oak bark, leaves and their mixture pellets varied from 17.3 to 17.7 $MJ \cdot kg^{-1}$. This calorific value of oak waste pellets was relatively high, close to the calorific value of some herbal plants and wood species. The presented research results show that oak bark, leaves and their mixture can be used as a solid biofuel because the main parameters of this plant satisfy the main requirements for solid biofuels.

Keywords: oak bark, leaves, mixture, mill, pellet, properties, fractional composition, ash content, calorific value.

Introduction

In Lithuania and other European countries wood resources are limited and can be used in other processes as well; a lot of attention is paid to testing pellets, which are produced from various non-woody types of biomass. Studies by Filbakk et al. [1] show that pellets with elevated bark share have a relatively higher bulk density and a lower amount of fines, but, at the same time, the ash content increases as well.

Work done by Verma et al. [2] describes the combustion efficiency and emissions rate from various types of pellets. In the paper, pellets produced from wood, apple, peat, reed canary grass, sunflower husk and citrus pectin waste were considered. While producing solid fuel wood pellets, they are compressed of high density and high combustion efficiency. Their geometry and cylindrical form facilitate transport over long distances, compact storage and control feeding to burners and boilers [3].

Production of biomass to pellets with low moisture content, high energy density and homogeneous shape makes the product more suitable for transport and storage compared with the unrefined material. It is also relatively easy to replace fossil fuels with pellets in the existing power or heat plants [4].

A range of physical, chemical and mechanical properties of wood pellets have an impact on the quality of biomass fuel. In particular, the influence of bulk density, moisture, ash, fines content and net calorific value on the efficiency and emission rates in biomass energy systems is proven in a work done by Johansson et al. [5]. The work done by Stahl et al. [6] states that efficiency of the combustion process is decreasing if fuel with high ash content is used. Research done by Samuelsson et al. [7] points out another important factor to consider: the moisture content in raw biomass, which influences the bulk density and net calorific value of the final product. The mean diameter and mean length of the pellets should be considered as well, because standardized pellet feeding technologies are on the market in the EU [8]. Research done by Dias et al. [9] shows that pellets with a larger diameter have lower boiler efficiency, and pellets with lower mechanical durability contain more fines.

Work done by Stahl et al. [6] defines the influence of bulk density on the boiler efficiency. In boilers without automatic control systems, changes in bulk density can affect behavior of the combustion process and increase heat losses. Mechanical durability, the amount of fines and bulk density are factors important in maintaining a good quality of pellets during the transportation process.

Filbakk and other scientists state that a large concentration of fines can create problems with proper pellet combustion and efficiency decreases as a result [1; 10; 11]. It can be concluded, that there is a set of parameters which are essential for a proper combustion process.

Different kinds of wood waste may be used for burning – not only in the industry and furniture obtained waste of timber, but also small branches, tree bark, leaves. There were presented studies of different kinds of energy forests and agro-residues preparation and usage in the Lithuania's domestic energy supply [12]. In Lithuania, oak is a well growing and a high-quality wood; therefore, it is appropriate to investigate the oak waste preparation and utilization for burning.

The aim of the research work is to investigate technical means of oak waste preparation for biofuel and to assess the physical-mechanical properties and quality indicators of these wastes milling, pelleting and utilization for burning.

Materials and methods

Experimental research investigations of oak waste preparation and utilization for energy purposes were carried out in laboratory basis of the Institute of Agricultural Engineering and Safety, Aleksandras Stulginskis University, Lithuania. Chopping quality of plant and prepared pellets used for fuel should satisfy the requirements for the combustion chamber, chopped and pressed mass transportation machinery and storage. During experimental research of oak wastes, a drum chopper of forage harvester *Maral 125* was used for chopping of oak bark and leaves. Further on, wishing to use the prepared chopped chaff for production of pellets, it is necessary to chop it to mill consistency (to 1-2 mm particles). Mill *Retsch SM 200* was used for this purpose [13].

Plant milling quality was determined using the widespread in the European Union countries methodology and system [14]. Fractional composition of milled oak wastes was determined using a set of 200 mm diameter sieves. Sieves with round holes are placd one on another (in succession starting from the upper sieve): 2 mm, 1 mm, 0.63 mm, 0.5 mm and 0.25 mm diameters. When sieving a 3 kg mass sample with a special sieve shaker *Haver EML Digital plus*, a set of sieves in horizontal surface is turned in semicircle for 2 minutes. The mass remaining on sieves is weighted, and the sample part of every fraction in percentage is calculated. Each test is repeated 3 times.

Mill density. Empty 6 dm^3 cylinder is weighted. The prepared mill of oak wastes is filled in the cylinder till the upper edge. The vessel with mill is weighted and themass of mill is calculated.

Mill moisture content is determined in chemical laboratories according to the standard methodology [13; 15]. The samples were weighted and dried for 24 hrs in the temperature of 105 ºC. The moisture content of each sample was calculated in percents.

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. 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 (if it was too dry for granulation), and was supplied to the press chamber, wherein the mill was moved by rollers through the matrix holes of 6 mm diameter and was pressed through the holes to form of pellets.

After the pellets cooling, their dimensions, moisture content, 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.

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 error.

Pellets moisture content was determined analogous to mill, in a laboratory drying chamber oven according to the standard method [15]. The pellet volume was calculated using the pellet size (diameter and length).

Pellets elementary composition and ash content 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 analyzer Flash 2000, No. 2011 F0055;
- according to the LST EN 14774-1:2010 standard, in moisture test rig No. 8B/1;
- according to the LST EN 14775:2010 standard, in ash content test rig No. 8B/5.

Calorific value (kJ·kg^{-1}) of oak wastes pellets was determined by a C 2000 calorimeter (IKA, Germany), by the standard methodology (BS EN 14918:2009) [16].

Results and discussion

There were the physical-mechanical characteristics determined – moisture content and bulk density of chopped by drum chopper and milled by hammer mill oak waste – oak bark, leaves and their mixture (1:1). These characteristics are important for projecting and choosing of transportation and storage equipment.

The determined moisture content and bulk density of oak waste chopped by drum chopper of forage harvester *Maral 125* and milled by mill *Retsch SM 200* are presented in Table 1.

Table 1

Physical-mechanical characteristics of oak waste mill

Oak waste mill	Moisture content, %	Bulk density, kg·m^{-3}
Bark	6.1 ± 0.4	278.3 ± 4.5 (261.3 DM)
Leaves	9.6 ± 0.2	214.7 ± 5.2 (194.1 DM)
Bark and leaves mixture	7.9 ± 0.3	246.5 ± 4.8 (227.0 DM)

As it may be seen from Table 1, the bulk density of oak bark mill is the biggest – 261.3 kg·m^{-3} DM (dry matter), and the density of oak leaves is the lowest – 194.1 kg m^{-3} DM and almost 1.3 times lower than oak bark mill.

Fractional composition after chopping and milling of the investigated oak waste – oak bark, leaves and their mixture mill was determined applying methodology widespread in the EU countries, using sieves with holes of various diameters. Fractional composition of prepared mill (%) dependence on the sieve hole diameter (mm) is presented in Fig. 1, Fig. 2 and Fig. 3.

Dependance of a part of oak bark mill fraction (%) from the holes of sieves is presented in Fig. 1. Having evaluated the fraction composition of mill, we can see that the highest mill fraction was on 0.25 mm sieves (46.2 ± 6.6 %). There was no fraction on a sieve with holes 2 mm diameter, and too big amount of dust was found – 24.3 ± 2.3 %.

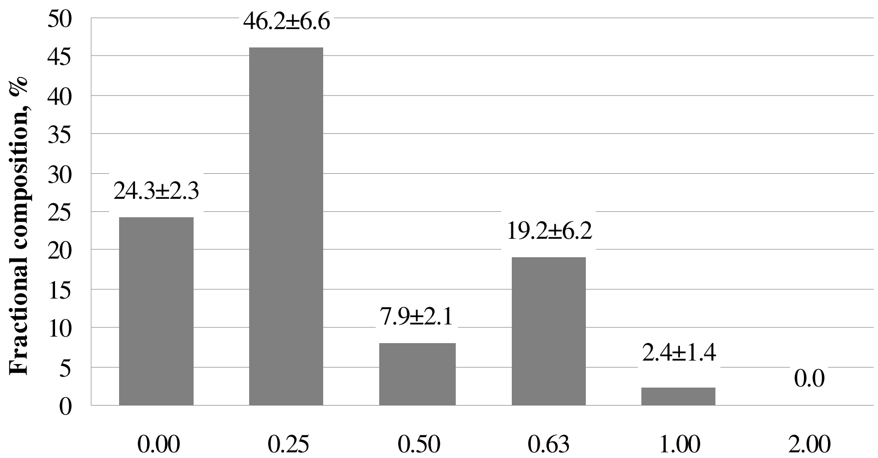

Fig. 1. **Fraction composition of oak bark mill (diameter of holes in mm)**

Dependance of a part of oak leaves mill fraction (%) on the holes of sieves is presented in Fig. 2. After evaluation of mill factional composition from the chart, we can see that the highest fraction of oak leaves mill accumulated on the sieve with holes 0.25 mm diameter – 30.9 ± 2.9 %, and a little less on 0.63 mm diameter holes sieve – 28.1 ± 3.2 %. There was no fraction on the sieve with holes 2 mm diameter, and as well as for oak bark, too high amount of dust was found – 22.0 ± 2.5 %.

Dependance of oak bark and leaves mixture (1:1) mill fraction (%) on the holes of sieves is presented in Fig. 3. The highest fraction of mixture mill accumulated on the sieve with holes 0.25 mm diameter – 37.4 ± 5.4 %. There was no fraction on the sieve with holes 2 mm diameter, and too big amount of dust was found – 23.8 ± 2.1 %.

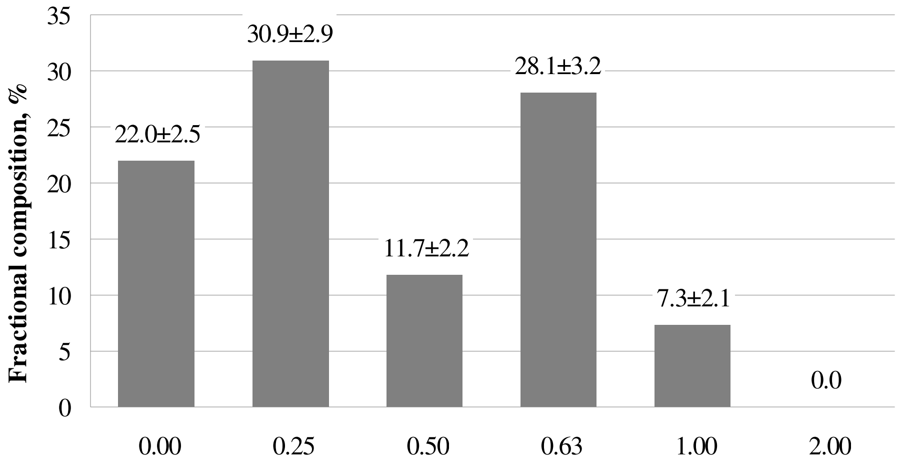

Fig. 2. **Fraction composition of oak leaves mill (diameter of holes in mm)**

Evaluating the milling quality of oak wastes (oak bark, leaves and their mixture mill), it can be stated that oak wastes were milled into too small fraction. It was determined that the biggest mill fraction was on 0.25 mm sieves – from 30.9 ± 2.9 % to 46.2 ± 6.6 %, and too big amount of dust was found – from 22.0 ± 2.5 % to 24.3 ± 2.3 %. There was no fraction on the sieve with holes 2 mm diameter.

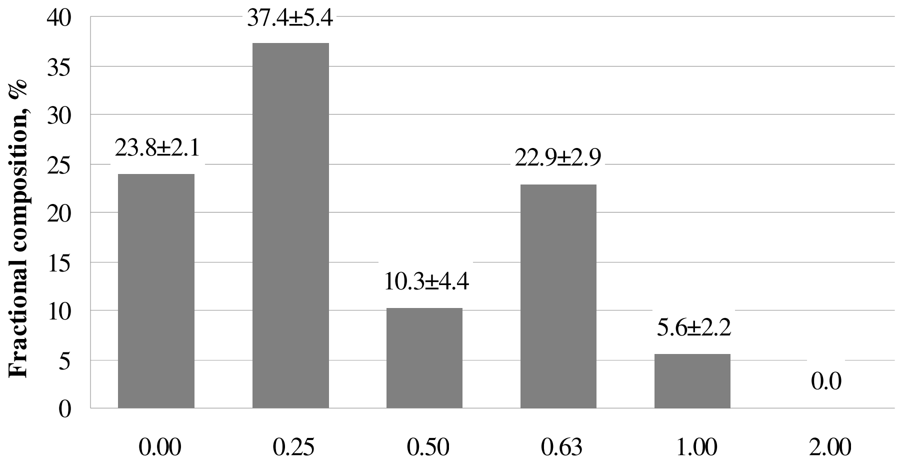

Fig. 3. **Fraction composition of oak bark and leaves mixture mill (diameter of holes in mm)**

All investigated oak waste products are suitable for burning after appropriate preparation. In order to continue using them for energy purposes, the investigated oak wastes were pressed into pellets of 8 mm diameter. The physical-mechanical properties of pellets were determined: moisture content and bulk density (Table 2).

Table 2

Physical-mechanical characteristics of oak waste pellets

Oak waste pellets	Moisture content, %	Bulk density, kg·m^{-3}
Bark	8.1 ± 0.1	1221.1 ± 64.4 (1122.2 DM)
Leaves	12.5 ± 0.2	1111.5 ± 42.4 (975.8 DM)
Bark and leaves mixture	10.6 ± 0.1	1131.2 ± 91.0 (1011.3 DM)

The determined pellet moisture contents ranged from 8.1 to 12.5 %. Bulk density in dry matters (DM) of oak leave pellets was the smallest – 975.8 kg·m^{-3}, and the density of oak bark was the biggest – 1122.2 kg m^{-3}.

The oak bark, leaves and their mixture pellet elemental composition, ash content and calorific value ratio analysis showed a similar C (carbon) content of 46.3-47.3 %; H (hydrogen) content varied from 4.7 to 5.3 %, and other chemicals composition of N (nitrogen) and S (sulphur) was small in volume % (Table 3).

Table 3

Pellet elemental composition, ash contents and calorific value

Parameters	**Value**	**Deviation, ± %**
Oak bark		
C (carbon) content, %	46.33	1.13
H (hydrogen) content, %	5.23	0.43
N (nitrogen) content, %	0.88	0.31
S (sulphur) content, %	0.08	0.27
O (oxygen) content, %	37.14	-
Moisture content, %	8.12	0.07
Ash content, %	10.34	0.22
Dry biofuel lower calorific value, MJ·kg^{-1}	17.42	0.69
Oak leaves		
C (carbon) content, %	47.32	1.14
H (hydrogen) content, %	4.67	0.45
N (nitrogen) content, %	1.28	0.32
S (sulphur) content, %	0.08	0.28
O (oxygen) content, %	31.99	-
Moisture content, %	12.52	0.07
Ash content, %	14.66	0.60
Dry biofuel lower calorific value, MJ·kg^{-1}	17.72	0.90
Oak bark and leaves mixture		
C (carbon) content, %	47.18	1.23
H (hydrogen) content, %	5.25	0.47
N (nitrogen) content, %	1.06	0.31
S (sulphur) content, %	0.09	0.27
O (oxygen) content, %	34.56	-
Moisture content, %	10.60	0.07
Ash content, %	11.87	0.45
Dry biofuel lower calorific value, MJ·kg^{-1}	17.26	1.13

The ash content of oak wastes was very high, varied from 10.4 to 14.7 % and was about 10 times higher than wood-based biofuels. The high ash content indicates that the investigated oak waste pellets burned insufficiently.

The average calorific value when burning oak bark, leaves and their mixture pellets was very similar and varied from 17.3 to 17.7 MJ kg^{-1}. This calorific value of oak waste pellets was relatively high, close to the calorific value of some herbal plants and wood species.

Conclusions

1. After evaluating of oak wastes milling quality, it can be stated that oak wastes were milled into too small fraction. The biggest mill fraction was accumulated on 0.25 mm sieves – from 30.9 ± 2.9 % to 46.2 ± 6.6 %, and too high amount of dust was found – from 22.0 ± 2.5 % to 24.3 ± 2.3 %.
2. The determined moisture contents of oak waste pellets ranged from 8.1 to 12.5 %. Bulk density of oak leave pellets was the smallest – 975.8 kg·m^{-3} DM (dry matter), and the density of oak bark was the biggest – 1122.2 kg·m^{-3} DM.
3. Analysis of oak bark, leaves and their mixture pellet elemental composition showed a similar C (carbon) content of 46.3-47.3 %, H (hydrogen) content varied from 4.7 to 5.3 %, and other chemicals composition of N (nitrogen) and S (sulphur) was small in volume %.
4. The ash content of oak wastes was very high, varied from 10.4 to 14.7 % and was about 10 times higher than wood-based biofuels. The average calorific value when burning of oak bark, leaves

and their mixture pellets varied from 17.3 to 17.7 $MJ \cdot kg^{-1}$. This calorific value of oak waste pellets was relatively high, close to the calorific value of some herbal plants and wood species.

References

1. Filbakk T., Jirjis R., Nurmi J., Høibø O. The effect of bark content on quality parameters of Scots pine (Pinus sylvestris L.) pellets. Biomass and Bioenergy, vol. 35, 2011, pp. 3342-3349.
2. Verma V.K., Bram S., Delattin F., Laha P., Vandendael I., Hubin A., De Ruyck J. Agro-pellets for domestic heating boilers: Standard laboratory and real life performance. Applied Energy, vol. 90, 2012, pp. 17-23.
3. Hartmann H., Lenz V. Biomass energy heat provision in modern small-scale systems. 2012, pp. 1351-1400 (in RA Myers Encyclopedia of Sustainability Science).
4. Obernberger I, Thek G. The pellet handbook: the production and thermal utilization of biomass pellets. London: Earthscan Publications, 2010.
5. Johanssona L., Lecknerb B., Gustavssona L., Cooperc D., Tullina C., Potterc A. Emission characteristics of modern and old-type residential boilers fired with wood logs and wood pellets. Atmospheric Environment, vol. 38, 2004, pp. 4183-4195.
6. Stahl M., Wikström F. Swedish perspective on wood fuel pellets for household heating: A modified standard for pellets could reduce enduser problems. Biomass and Bioenergy, vol. 33, 2009, pp. 803-809.
7. Samuelsson R., Thyrel M., Sjöström M., Lestander T. A. Effect of biomaterial characteristics on pelletizing properties and biofuel pellet quality. Fuel Processing Technology, vol. 90, 2009, pp. 1129-1134.
8. Kirsanovs V., Timma L., Zandeckis A., Romagnoli F. The quality of pellets available on the market in latvia: Classification according En 14961 requirements. Scientific Journal of Riga Technical University. Environmental and Climate Technologies, vol. 8, 2012, pp. 36-40.
9. Dias J., Costa M., Azevedo J.L. Test of a small domestic boiler using different pellets. Biomass and Bioenergy, vol. 27, 2004, pp. 531-539.
10. Rabacal M., Fernandes U., Costa M. Combustion and emission characteristics of a domestic boiler fired with pellets of pine, industrial wood wastes and peach stones. Renewable Energy, vol. 51, 2013, pp. 220-226.
11. Sultana A., Kumar A. Ranking of biomass pellets by integration of economic, environmental and technical factors. Biomass and Bioenergy, vol. 39, 2012, pp. 344-355.
12. Raslavičius L., Kučinskas V., Jasinskas A. The prospects of energy forestry and agro-residues in the Lithuania's domestic energy supply. Renewable and Sustainable Energy Reviews, vol. 22, 2013, pp. 419–431.
13. Jasinskas A., Scholz V. Evaluation of technologies of plant biomass harvesting and preparation for fuel: coursebook. Raudondvaris, 2008. 74 p. (in Lithuanian).
14. EU DD CEN/TS 15149-1:2006. Solid biofuels – Methods for the determination of particle size distribution. Part 1: Oscillating screen method using sieve apertures of 3.15 mm and above. 56 p.
15. CEN/TC 14774-1:2005. Solid biofuels – Methods for the determination of moisture content – Oven dry method – Part 1: Total moisture – Reference method. 2005.
16. BS EN 14918:2009. Solid biofuels. Determination of calorific value. 64 p.