The use of forest waste in the energy sector

Danuta Proszak- Miasik¹, Slawomir Rabczak¹

¹Rzeszow University of Technology, al. Powstańców Warszawy 12, 35-959 Rzeszów, Poland
dproszak@prz.edu.pl

Abstract. Forest areas cover almost 30% of the territory of Poland, of which about 70% are coniferous forests, the rest are deciduous and mixed forests. Annually, about 9,000 trees are cut from these areas, which give about 36 km² of wood. Analyzing we can assume that we will obtain 10m³ of bark, 15m³ of brushwood, 20m³ of branch and carpinus, 19 m³ of sawdust and 36m³ of sawn timber from 100m³ of wood obtained in the forest. Wood obtained from forest areas is used not only as one of the main construction and industrial materials, but also as an energy raw material. For energetic wood, we include all forms of biomass obtained directly from the forest felling: needles, leaves, carpels, bark, branches, sawdust, shavings, cones and from recovery, crates, pallets, sleepers. The calorific value of the collected samples was examined. As a fuel, it can be used the wood biomass that has not been processed in the form of firewood or fuel, or processed in the form of sawdust, wood chips, briquettes, pellets or wood dust. This publication shows the combustion process of fuel obtained from wood biomass. Factors that influence the calorific value obtained and the value of the heat of combustion are described. The paper presents the results obtained from the incineration of waste obtained from forest areas. The study uses cones and sawdust obtained from the following tree species: fir, poplar, birch and beech. The influence of moisture content in wood as the main factor influencing the calorific value of fuel was also discussed.

1. Introduction

Currently, much attention is devoted to the use of renewable energy sources in the aspect of energy supply security. [1-5] Forests are the rouge of renewable biomass which is wood.

Forest areas occupy 29.5% of Poland's area, which is 9.2 million ha of the country's territory. The wood obtained from these areas is used in many fields of the economy, including the furniture, construction and paper industries. Wood, however, is not only a construction material, but also an energy raw material.

The best firewood comes from deciduous species with a compact structure and high hardness (beech, birch, maple, hornbeam, oak). Coniferous wood species (pine, spruce, larch, fir) have higher calorific value in terms of mass. However, due to the content of resins and essential oils, they burn faster and pollute the hearth and chimney.

Regardless of the species, the wood to be burnt must be properly dried. Wood moisture should be 12-20%. Then it burns without smoking and does not lose heat to evaporate water. The seasoning
period, depending on the species, ranges from 1.5 to 2 years. Wood can be suitable for burning faster if it is dried in special air circulation chambers.

Wood after drying (not depending on the species) has a similar composition of the elemental elements, it is about 2% nitrogen (N), 6.1% hydrogen (H), 49.5% carbon (C) and 44.2% oxygen (O). In addition, there are minerals and water in the wood that are transferred from the roots to the leaves. The amount of these components informs in which phase of growth it was found and from what part of the plant it came from. The higher the content of minerals, the higher the ash content after burning wood.

As fuel you can use the so-called coarse wood as well as wood waste (otherwise known as post-harvest residues) are, among others, carp, bark, branches, sawdust, cones. They are created during logging, forest clearing and wood processing. The waste consists mainly of cellulose, lignin and hemicelluloses.

Another important physical feature of wood that affects its calorific value and energy value is the density expressed in kg per unit volume. The wood density is a variable value depending on the water content and therefore the density comparison only makes sense for air or completely dry wood. The density of wood is variable for a particular species and depends on the content of white and heartwood, age of the tree, the habitat conditions in which the tree grew, from what part of the tree was obtained (corner, middle section of the arrow, crown) and other factors. The density for the type of wood tested is:

- in the air-dry state:
  - beech wood (heavy wood), \( \rho = 680 \text{ kg/m}^3 \),
  - birch wood (moderately heavy wood), \( \rho = 640 \text{ kg/m}^3 \),
  - spruce wood (light wood), \( \rho = 430 \text{ kg/m}^3 \),
  - fir wood (light wood), \( \rho = 410 \text{ kg/m}^3 \),
  - aspen wood (very light wood), \( \rho = 450 \text{ kg/m}^3 \).

- based on the density of the wood in the freshly cut state:
  - beech, birch wood - density of 900-1000 kg / m\(^3\),
  - aspen - wood with a density of 800-900 kg / m\(^3\),
  - spruce wood - wood with a density of 700-800 kg / m\(^3\).

2. Forest wastes and their acquisition
The main group of wood waste consists of piece waste - they come from the sawmill industry and are solid waste, so-called "Clean", in addition, chips, sawdust and shavings, bark, cones remain.

Wood chips are obtained by fragmenting wood into particles with a length of 5-50 mm, this waste has the shape of a rhombus. After grinding from 1.4 m\(^3\) solid wood, a ton of wood chips is obtained. The energy value of chips depends on the type of wood from which it was obtained and on the humidity. Wood chips used for energy purposes should contain 25-45% humidity. Wood chips should be stored under a roof without side walls, on dry ground with drainage used to constantly supply air.

Cones are female inflorescences of conifers and some deciduous plants containing seed husks and seeds (they are protected by rigid seed husks). Seeds develop over several years (eg for pine, this period lasts 3 years). After obtaining the full maturity of the seeds, the cone releases them and then falls off.

The bark is a tree-covering shell, located on the outside of the trunk, branches and roots. The main constituent of the bark is cellulose and lignin. The task is to insulate and protect the roots and stems
from damage. This part of the tree accounts for as much as 10-15\% of harvested wood, its calorific value is between 18.5 MJ / kg and 20 MJ / kg, and its bulk density is in the range of 250-350 kg / m³, ashes formed during combustion this wood waste has a tendency to slag [6].

**Sawdust** are particles measuring 1 mm to 5 mm, they constitute about 10\% from harvested wood. Sawdust is a valued fuel used in boiler plants, which is created during the processing of deciduous or coniferous wood, harvesting wood from forest crops, milling, and cutting wood in sawmills, as well as in wood processing plants [6].

3. **Storage and storage of wood waste**

Wood has a natural ability to absorb moisture, which is an additional difficulty during storage of this fuel. Lumber should be stored even under a roof or in wooden shelters. For storage of chips, sawdust and bark, completely enclosed rooms are required with efficient ventilation and provided fire protection requirements. Wood waste is difficult to store because it is easily rottable, i.e. microbiological decomposition after reaching more than 30\% humidity. However, dried ones are much more flammable than conventional fuels. Wood, and especially waste resulting from it, can be stored in a residential building after reaching a humidity of no more than 20\% [7].

4. **Acquisition and preparation of samples for testing**

Samples of sawdust (shavings) of various species of deciduous trees (birch, beech, aspen) were collected for testing and coniferous (fir, spruce), as well as several spruce cones. These samples were obtained during the felling of trees on the forest surface, which was under preparation for afforestation with native species of trees. On the day and also during the week preceding the sampling, it was sunny, thanks to which the obtained waste did not collect water from the surroundings, it results from the fact that the humidity of the waste did not increase.

Spruce cones were taken from the highest point of the tree which is the crown (tuft), and then secured in a cardboard box.

Sawdust was collected after the completion of the cutting and pre-treatment of the wood, the waste was carefully collected from the stock with careful attention to the selection of "clean" sawdust without contamination, eg leaves, soil, grass, etc. Each type of sawdust was secured in separate cardboard boxes. All samples were subjected to a natural drying process in the utility room of a residential building, this process lasted two months. This treatment was aimed at reducing the humidity of wood waste. Sawdust was scattered on wooden slabs (any type of wood) so that they do not get mixed up. The samples after this time were transported to the laboratory and tested.

The following devices were used to carry out the laboratory tests, which were used to prepare and carry out the measurement of the combustion heat for solid fuels:

- laboratory grinder IKAM M 20 - used to crush wood waste,
- analytical balance XA / X 220- for weighing the right amount of sample,
- STD SLW 53 laboratory dryer - for drying samples to calculate the moisture content,
- FCF SSHA muffle furnace - for roasting samples to calculate ash content,
- Parr type 6300 calorimeter for measuring the heat of combustion.

4.1 **Samples**

**The birch sawdust** investigated was obtained from silver birch (Betula pendula). This tree is a deciduous and bent species, i.e. its external and internal parts can carry out life processes, including water transport [6]. Acquired birch wood has a reddish or yellowish tinge, is strong, hardly fissile, medium hard and dispergular. Birch reaches up to 30 m in height and 80 cm in diameter, it grows dry
and wet, sandy, well tolerates high and low temperatures, grows quickly in youth, gradually decreases in intensity, lives 90-100 years (Figure 1).

The beech sawdust harvested was obtained from the tree which is the European beech (Fagus sylvatica), it is a deciduous species, non-chard, the perennial disperse is characterized by the possibility of distinguishing vessels (quite large) in the wood in the spring. White colored wood with a yellowish-pink color is suitable for all types of stoves and fireplaces. The wood is compact and hard with a high calorific value, which ensures longer combustion. Beech wood is most often used in water construction, because it is durable in water and high humidity. The common beech reaches a height of 30-50 m and 1-1.5 m of breast height, lives up to 300 years, initially, the tree grows very slowly, but with age, its increase increases to 150 years, and then ceases altogether. He likes to grow loamy or clayey sandy soils and fresh or poorly moist soil [6].

Figure 1. Samples prepared for testing

Aspen sawdust was obtained from aspen poplar (Populus tremula). This tree belongs to the species of deciduous, non-core, decomposition trees [8, 6]. Wood with a delicate, homogeneous structure, white in color with a green-gray shade, while the wood is light and soft. It is used for the production of shingles, cellulosics and artificial fibers, as well as used in the match industry. The aspen poplar reaches a height of 30 m to 35 m and a width of 1 m in breast height. He lives about 100 years in his youth and very quickly increases the amount of growth. In forest management, it is a valued species and considered a pioneer species in this field, as other species of trees develop under its cover. Poplar peat dies in areas consisting of dry stony, sandy and boggy soils [6].

Fir firs were obtained from silver fir (Abies alba). Fir is one of the species of coniferous trees, shadowy, growing slowly in the first eight years, while it ceases to grow after reaching 200 years, measures 1.5 m in diameter, and grows up to 40-50 m in height. It is a species sensitive to low temperatures and the occurrence of contaminants in the air. Fir tree is demanding in terms of habitat conditions, it does not tolerate sandy, swampy and wet soils as well as clayey, impermeable heavy soils. Plants containing siliceous soils and loamy soil poor in lime are the best. Matt wood with a golden-white shade, soft, light, without resin wires, flexible, durable, does not form heartwood and annual rings are visible [9, 10].

Spruce sawdust was obtained from spruce (Picea abies). Norway spruce is classified as coniferous, shade-bearing, resinous, without heartwood. The tree grows up to a height of 50m and measures 1.5-2 m in diameter, lives 250 years or more, grows slowly in the early age, significantly increases the rate of growth between 30-50 years, then grows slowly but for the rest of your life. Spruce is a species that is not very resistant to smoke, spring frosts and strong wind. It is most often covered by shallow soils with high humidity. Wood shining white, sometimes with a light yellow shade, in which annual rings are clearly visible. In addition, it is soft, light, used due to its low
mechanical properties for cellulose products, as teletechnical poles and as resonant wood. The spruce has a female inflorescence of 3-5 cm in the upper part of the crown, in the form of a dark red or light green cone and male inflorescences in the form of egg-colored yellowish-red cats. The form protecting the pollinated seeds is a hanging cone, reaching 10-15 cm in length and 3-4 cm wide, with variable shape of scales covering the seeds. In the age of 30-40 years, spruce conspires cones, which mature in the autumn of the first year, open at the end of the winter season or early spring [10].

5. Methodology and scope of research
The samples of wood taken were made:
- calculation of humidity in an air-dry sample,
- calculation of analytical humidity in the sample,
- analysis of the heat of combustion of the analytical sample,
- calculation of the ash content in the analytical sample.

The humidity test in an air dry sample consisted of weighing a certain amount of a sample from a given type of wood waste into a pre-weighed mold. All weights and the time at which weigh out the samples were saved. After 24 h, the samples were weighed again and the results were saved, calculations were made.

Testing of analytical moisture in the sample requires the samples to be dried in the dryer. Prior to the drying process, the crucibles were weighed and about 1 g of the waste was added. Data saved. All samples were placed in the device, the drying program was activated for 1.5 h at 105 °C. After the drying process, the crucibles were weighed, the results were saved and the calculations made.

Combustion sample heat test required a Parr 6300 calorimeter (figure 3). Before placing the sample in the crucible, it had to be ground beforehand in a laboratory mill. Then the crucian placed on the analytical balance and the amount of given forest waste in the range of 0.9-1.1 g was weighed, the weight was recorded. The finished crucible was placed in the calorimeter bomb head and an auxiliary fuse was installed in the sample. The head was placed in the bomb cylinder (figure 2), rotated 1/16
turn closing the bomb. The lid was closed, the measurement was started and the sample weight was entered into the calorimeter system. After completion, the value of the sample's combustion heat was read from the device and recorded. Measurements were made for each type of forest waste. [6]

**Examination of the ash content in the analytical sample** consisted of weighing the crucible and the crucible with the sample and placing all samples in the muffle furnace. A program was set up in which after 30 minutes, the temperature was raised to 500 °C, then after a further 40 minutes, the temperature was increased to 815 °C and roasted for 90 minutes. After the roasting process, the crucibles and the residue were weighed, the results were recorded.

6. Results and discussions

6.1 Moisture content
From the research carried out to determine the moisture content of fresh and surface dry wood waste, a result confirming the dependence of moisture on the calorific value was obtained. The obtained calorific value for fresh samples is much smaller than for surface dry samples, because a large part of the heat during combustion was used for the process of evaporation of water from fuel.

![Figure 4. Dependence of heating value on humidity.](image)

The dependence of the calorific value on the moisture in the wood is shown in the graph (figure 4). It was observed that the waste obtained in the form of aspen sawdust has the same calorific value in the same humidity as birch sawdust. The highest calorific value at a given humidity is achieved by beech sawdust, the smallest - spruce sawdust. The calorific value of wood waste is inversely proportional to the content of water in it. For example, when comparing the calorific value of fir sawdust at a moisture content of 22.55% and 63.23%, the following was obtained: 17.04127 MJ / kg and 7.79872 MJ / kg. It was also observed that the most calorific parts of the spruce tree are its cones.

6.2 Ash content
According to the conducted research, it was found that the ash content resulting from the burning of a given waste depends on the type of wood, and it was also found that the wood building materials have a big influence on this factor. Comparing ash content obtained after burning spruce cones and sawdust of various tree species, it was found that this content is within 0.35-0.42 for sawdust and is over 12 times higher for spruce cones. Such a significant difference is caused by an uneven distribution of mineral substances in the tree (figure 5, 6).
Figure 5. Ash obtained after calcination of samples: a) fir-colored sawdust, b) spruce sawdust, c) sawdust, d) aspen sawdust, e) birch sawdust, f) spruce cone

The higher the content of mineral compounds in the material, the more ash will be obtained after it has been burned. Most of the nutrients transported through the root system of the plant from the soil go to the branches, leaves (needles) and cones. Thus, it determines a significant amount of ash obtained after burning these parts of the tree.

Figure 6. Ash content in a given wood waste
6.3 Calorific value of the heat of combustion

After the tests, it was found that there was a large relationship between the species of wood and the calorific value, heat of combustion, humidity and ash content and hydrogen content in the tested samples (table 1). Coniferous species and deciduous species are separate groups that are characterized by different compositions of mineral substances in wood, contents of resins, and essential oils. The results are also influenced by the characteristics of a given species, soft and light wood will be less caloric than hard, medium hard wood.

| Table 1. Comparison of parameters of selected wood waste |
|--------------------------------------------------------|
| **Unit** | **Sawdust obtained from** | **Spruce cones** |
| | birch | beech | poplar | aspen | aspen | spruce cones |
| Moisture content in the sample surface dry | % | 14.53 | 30.55 | 22.88 | 16.26 | 22.55 | 15.60 |
| Moisture content in a fresh sample | % | 44.27 | 57.83 | 46.19 | 31.12 | 63.24 | 52.36 |
| The calorific value samples surface dry | MJ/kg | 16.3746 | 16.8284 | 14.582 | 15.6580 | 16.0412 | 17.5744 |
| The calorific value fresh sample | MJ/kg | 9.8217 | 9.2552 | 9.4305 | 12.4445 | 7.798 | 8.8511 |
| Heat of combustion | MJ/kg | 17.7544 | 18.4088 | 16.0668 | 17.0592 | 18.5221 | 18.9094 |
| Ash content | % | 0.39 | 0.40 | 0.36 | 0.42 | 0.35 | 5.32 |
| Hydrogen content | % | 4.66 | 3.78 | 4.21 | 4.56 | 4.22 | 4.33 |

7. Conclusions

The research conducted related to the calorific value of forest waste allowed us to make the following conclusions:

The moisture content of the wood determines the calorific value. The moisture content of wood depends on the predisposition of wood for water intake, age of the tree (growth phase), substrate and external factors. Trees cut in winter show the lowest humidity. The freshly cut tree provides much less energy because it loses heat to evaporate the water. Therefore, wood for combustion requires prior drying, and proper storage and storage. It was found that the higher the water content in the wood waste, the lower the calorific value. In addition, high humidity affects the mold and bruising of wood.

The highest calorific value was obtained after firing spruce sawdust, the smallest one - fir sawdust. The most calorific wood according to the species was beech (deciduous) and spruce (coniferous) while the least calorific - aspen poplar. Due to the high degree of resination, spruce wood causes sparks during smoking, which is why it is suitable for burning only in closed furnaces. Wood is easy to ignite and is prone to splitting. That is why it works great as wood for a kindling. Spruce is ideal for heating logs, because it is 30% cheaper than hardwood; Spruce wood dries much faster and, moreover, it is much easier to process. Therefore, beech is often used for combustion. It is one of the hardest and best wood types for burning. It burns evenly and for a long time, but it needs a lot of time to dry completely.

As for the ash content, it depends on the amount of mineral substances contained in the wood. It was found that the highest ash content would be obtained after the burning of leaves, branches and cones.

This ash can be used as a fertilizer. It improves the physicochemical properties in the soil. Has alkaline reaction and rich elemental composition. It increases the amount of yields obtained and is used for de-acidification of soils. It is an excellent alternative to mineral fertilizers…
References

[1] P. Sawicka-Chudy, E. Rybak-Wilusz, M. Cholewa, “Thermal efficiency of a solar power system in a collective residential structure based on performance tests”, *Journal Of Renewable And Sustainable Energy*, t.8, z.5, s.1-12, 2016.

[2] K. Pietrucha-Urbaniak, “Assessing the Costs of Losses Incurred as a Result of Failure”, *Eds.: Zamojski W., Mazurkiewicz J. & Sugier J. in: Advances in Intelligent Systems and Computing*, 470, 355–362, 2016.

[3] B. Tchorzewska-Cieślak, K. Pietrucha-Urbaniak, D. Szpak “Safety problems of small water supply systems”, *Journal of KONBiN*, 1(37)/2016, pp. 51-72, 2016.

[4] K. Nowak, M. Bukowska, D. Proszak-Miąsik, S. Rabczak, “Emission of Air Pollutants in the Hot Water Production”, *IOP Conf Ser-Mat Sci.*, 245., 2017.

[5] S. Rabczak, D. Proszak-Miasik, “Effect of the Type of Heat Sources on Carbon Dioxide Emissions”, *Journal of Ecological Engineering*, vol.17(5):186-91, 2016.

[6] W. M. Lewandowski, M. Ryms, „Biofuels. Pro-ecological renewable energy sources”, *WNT*, Warszawa, 2013,

[7] T. Juliszewski, „Biomass heating”, *PWRiL*, Poznań, 2009.

[8] W. Kokociński, „Anatomy of wood”, *Prodruk*, Poznań, 2005.

[9] PN-ISO 1928:2002, Paliwa Stałe – oznaczenie ciepła spalania metodą spalania w bombie kalorymetrycznej i oznaczenie wartości opałowej.

[10] Encyklopedia – lasypolskie, Otwarta Encyklopedia Leśna, 2017 [Online] Available at: <https://www.encyklopedia.lasypolskie.pl>.