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COMPARATIVE STUDY OF SPRUCE AND BEECH PELLETS IN TERMS OF PHYSICAL, MECHANICAL, AND ENERGY PROPERTIES

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Abstract:
This paper aims to highlight the importance of physical, mechanical, and energy properties of pellets from the two species of wood, spruce and beech. A comparative analysis was performed between the two categories of pellets. In the paper, bulk density and effective density of pellets were analyzed, with slightly higher values for spruce. In terms of calorific value, the values obtained were 0.3% higher for spruce than for beech. Calorific density evaluation observed that the spruce pellets had an energy density 7.8% higher than that of beech pellets. Referring to ash content it was observed that the ash content of spruce pellets is lower than for beech pellets, with a more than double decrease. As a general conclusion the values of the pellets obtained from spruce are better than those obtained from beech.

Key words: *beech; spruce; density; pellets.*

INTRODUCTION

Biomass is natural plant components, obtained as a result of the photosynthesis process. For growth and development, plants absorb a part of the solar energy, water and nutrients in the soil, which it then transforms into biomass. From the point of view of the relationship with the natural environment, the biomass is a neutral fuel, as the amount of CO_2 absorbed during growth is equal to the amount resulted from its burning or degradation. As a means of storing solar energy in chemical form, biomass is one of the most popular energy resources on Earth. Today, fuels obtained from biomass can be used for various purposes, from heating of rooms to producing electricity and fuels for vehicles. Biomass is diverse and, at a global level, the following general features can be observed (Aebiom 2013):

- Total mass (including moisture content) over 2000 billion tons;
- Total mass of terrestrial plants 1800 billion tons;
- Total mass of forests 1600 billion tons;
- Amount of energy amassed in the terrestrial biomass 25000 $*10^{18}$ J;
- Annual growth of biomass 400000 million tons;
- Speed of energy storage by the terrestrial biomass 3000 $* 10^{18}$ J/year (95 TWt);
- Total annual consumption of energy types 400 $* 10^{18}$ J/an (22TWt);
- Use of biomass energy 55$*10^{18}$ J/an (1.7 TWt).

Distinguishable advantages of biomass exploitation:

- its use is consistent with the environmental standards imposed by the European Union;
- use, at a higher level of production, of the residues and wood waste resulted from wood exploitation and processing technologies;
- the existence of a simple alternative for producing heat in homes or in industry.

Pellets are solid fuels with a low moisture content, obtained from small-size biomass (dust, wood dust, sawdust, wood shavings and fine wood chips), compacted in cylindrical shapes with a diameter between 6-10mm and length between 10-30mm. Lignin and temperatures over 100ºC to activate it in the wood dust, have the role of maintaining the pellets compact and, thus, they do not contain other adhesives and/or additives (Garcia 2004). The transport of pellets is cost-effective as these are fuel obtained by compression at a ratio of approximately 1-4. Also, due to uniform dimensions and special supply kits, pellets allow the use of complex automated storage, supply and non-intervention systems for approximately 1-2 days (Oberbenger 2004). Obtaining pellets from production residues and waste creates the opportunity for the recovery and introduction of waste in the economic circuit. If the waste is not properly collected, massive environmental pollution can occur caused by its inevitable decomposition in the environment, while an amount of CO_2 equal to that of combustion will be found in nature. The properties of lignocellulosic pellets can be grouped in dimensional, physical, chemical, and mechanical properties. The testing of pellets is made according to specific standardised methodologies, namely density according to EN ISO 17828:2015

EN. The limiting technical characteristics of pellets, for non-industrial use, according to the European standard EN ISO 17828:2015 are the following:
- diameter: 4-10 mm;
- length: less than 50 mm;
- bulk density: 650 kg/m^3;
- effective density: more than 1120 kg/m^3;
- moisture content: less than 8%;
- ash content: less than 1.5%
- caloric value: 16.9-19.5 MJ/kg;
- nitrogen content < 0.3 % (for class A_1), < 0.5 % (for class A_2), < 1.0 % (for class B);
- sulphur content < 0.03 % (for classes A_1 and A_2) and< 0.04 % (for class B);
- chlorine content < 0.02 % (for classes A_1 and A_2) and< 0.03 % (for class B);
- determining the ash content at temperatures > 1200 °C for class A_1 and > 1100 °C for classes A_2 and B.

OBJECTIVE

The main objective of this paper is to carry out a comparative study of the physical, mechanical, and energetic properties of spruce and beech pellets for their efficient use in combustion. Effective and bulk density will be analysed from the physical properties, from the mechanical properties shear strength will be analysed, and from the energy properties heating value, energy density, and ash content.

MATERIALS AND METHODS

Two types of pellets, spruce and beech, taken from the market, have been analysed for their physical, mechanical, and energy properties (obtained from waste sawdust). The density of the pellets was determined for the two types, bulk and effective, for each pellet. For determining the bulk density of pellets (EN ISO 17828:2015) we used a taper container with the following dimensions (Fig.1): a 45.31mm larger radius of the truncated cone, a 23.435mm smaller radius, and 99.06mm height. Taking into consideration the volume of the truncated cone and the mass *m* of the contents of the container (the mass of the container with pellets from which the mass of the empty container has been subtracted), the following equation was used (Eq. 1):

$$\rho = \frac{3 \cdot m}{h(R^2 + r^2 + Rr)} \quad [g/cm^3] \qquad (1)$$

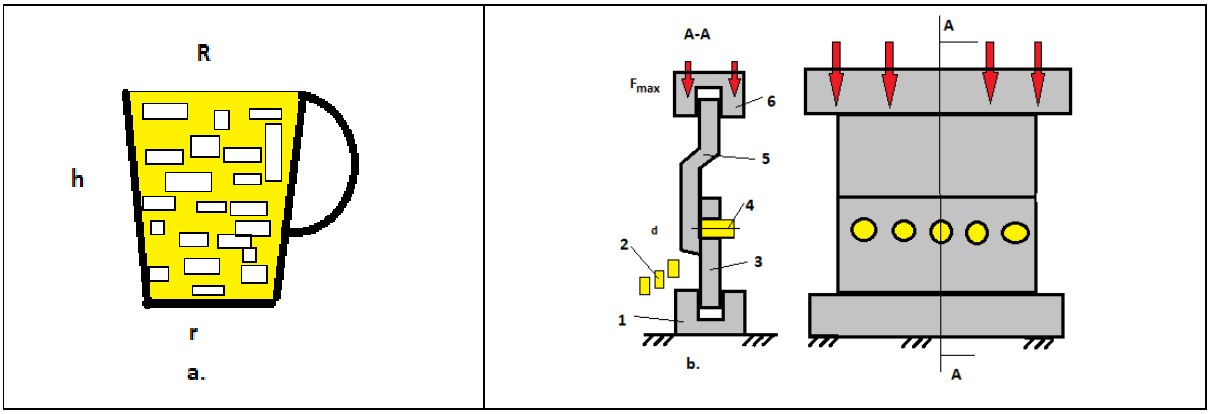

Fig. 1.
a. Vessel for determining the bulk density of the pellets; b- Determination of the shear strength of pellets; 1- fixed lower support; 2- fragments of sheared pellets; 3- lower arm; 4- pellets; 5- upper arm; 6- upper arm subjected to compressive force.

One 15kg plastic sack bag of pellets has been analysed for each type of pellet, respectively one bag of spruce pellets and one bag of beech pellets. The main properties analysed were: bulk and effective density, shear strength, caloric value, energy density, and ash content.
For determining the effective density of the pellets, 50 pieces of pellets were randomly selected, the ends were straightened by grinding in order to obtain a surface of the ends directly perpendicular to their length and taking into account that each pellet represents a right circular cylinder, the following formula was used (Eq 2):

$$\rho_{ef} = \frac{4 \cdot m}{\pi \cdot d^2 \cdot l} \quad [g/cm^3] \tag{2}$$

where:
ρ_{ef} - effective density of pellets (g/cm^3);
m - mass of pellets (g);
d - diameter of pellets (cm);
l - length of pellets (cm).

The shear strength of the pellets is a mechanical property that indicates the compaction and internal adhesion of the pellets (Bridgwater 2012). The shearing cross section test in the pellets has been achieved by developing a device (formed from two metal pieces, with correspond form and edges) suitable for this test and the amplification of the effect has been achieved by simultaneous shearing of 5 pellets. The operating speed was 4 mm/min. For determining the shear strength, it was taken into consideration that the shearing area was determined by the transverse area of the five pellets inserted in the shearing device and the following equation was used (Eq 3):

$$\tau_s = \frac{4 \cdot F_{max}}{5 \cdot \pi \cdot d^2} \quad [N/mm^2] \tag{3}$$

where:
F_{max} is the maximum breaking or shearing force, in N;
d- diameter of pellets, in mm;

The caloric value was determined by means of a calorimeter with explosive combustion, using samples from pellets with a mass of 0,6-0,8 g and a pressure of oxygen in the calorimeter bomb of 30 bars (Grîu 2014) (Fig.1). The calculation reaction used by the computer software (Grîu and Lunguleasa 2014) was the following (Eq 4):

$$CV = \frac{C \cdot (t_f - t_i)}{m} - q_s \quad [kJ/kg] \tag{4}$$

where:
CV - caloric value, in kJ/kg
C - calorimetric constant determined through the calibration of the device with benzoic acid, expressed in kJ/°C;
t_f- final temperature registered by the thermocouple of the calorimeter, in °C;
t_i- initial temperature registered by the thermocouple of the calorimeter, in °C;
m- mass of the pellet sample, in g;
q_s- amount of heat released by the copper nickel thread and cotton twine, in kJ/kg.

From the image of the computer software for the calorimeter (Fig 2) the following can be observed: the calorimeter type XRY-1C, work method (Bunte or Regnard-Phunder), type of testing (determination or calibration), start - stop, mass of sample, temperature, the three periods of testing (fore, main, and after period), diagram of temperature increase and phase of testing (Fore, Main, After etc.).

For determining the ash content of the pellets, the general standardised method for determination was used (ASTM D2866-11:2012, EN ISO 18122:2015). According to this method, the ground and dried material to 0% moisture content is calcined at a temperature of 650 °C in a laboratory oven, for at least 3 hours.

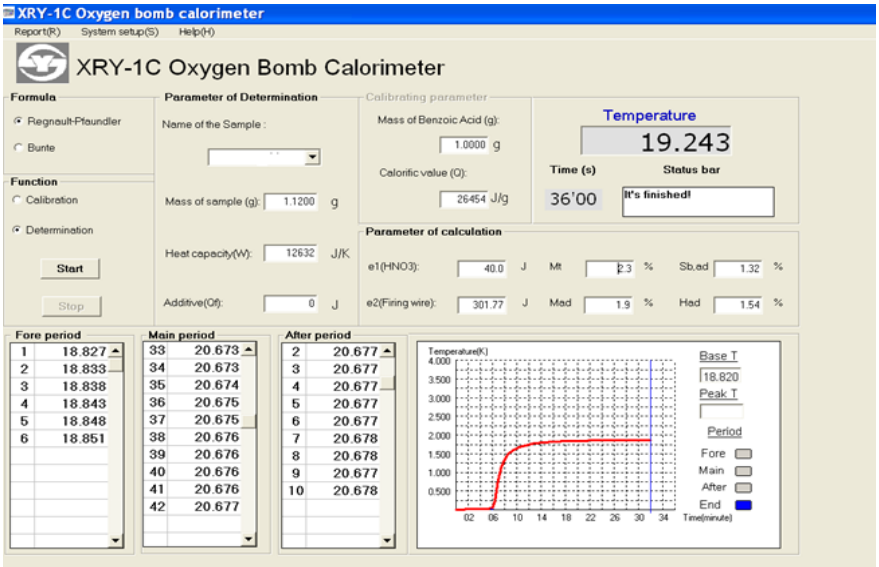

Fig. 2.
Image of computer software for the calorimeter.

The advanced combustion operation called calcination was performed on a metal crucible that can withstand high temperatures, and the weighing was realized on an analytical balance with a precision of 3 decimal places. When determining the ash content, the sample had to be completely dry and the mass of the empty and clean crucible was also taken into consideration. The equation for determining the calcined ash content was the following (Eq 5)

$$A_c = \frac{m_f - m_c}{m_i - m_c} \cdot 100 \quad [\%] \qquad (5)$$

where:
A_c- ash content, g;
m_f- final mass of crucible with calcined sample, in g;
m_i- initial mass of crucible with sample subject to testing, in g;
m_c- mass of empty crucible, in g.

As pellets have different densities and caloric values, it has been found that the caloric density is a measure that better characterises the energy offered by the pellets. The equation for the calorific density of the pellets depends both on the calorific power and on density and is as follows (Eq 6):

$$CD = CV \cdot \rho [MJ/m^3] \qquad (6)$$

where:
CV- low calorific power, in MJ/kg;
p- density of pellets, in kg/m^3.

The results obtained were statistically processed, thus obtaining the limiting maximum and minimum values, the central value, and standard mean deviation. All these statistical values have been obtained when the acceptance probability was at least 95%.

RESULTS AND DISCUSSION

The mean value of the effective density for spruce pellets was 1.22 g/cm^3, 1.18 g/cm^3, respectively, for beech pellets, and the mean value of the bulk density for spruce pellets was 0.693 g/cm^3, 0.709 g/cm^3, respectively, for beech pellets (Fig 3).

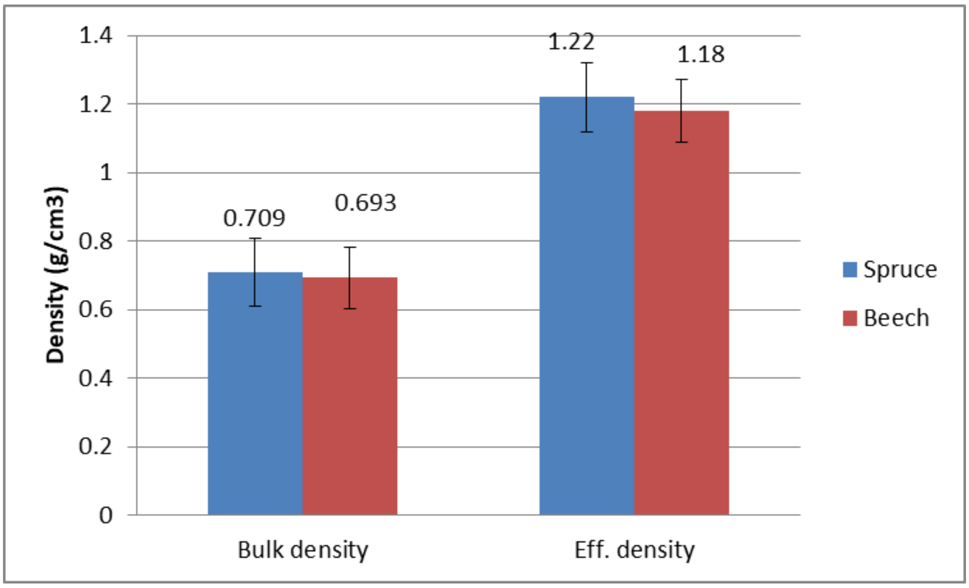

Fig. 3.
Density of spruce and beech pellets.

It may be observed that both types of pellets exceed the minimum acceptable value of 1.12 g/cm^3 stipulated by the European Standard EN 14961-2, and the difference between the two types of spruce and beech pellets was statistically insignificant at the 95% level (which means that the wood species do not influence the density, but the type of pelletizing unit).

In respect of the shear strength, the mean values of the two types of pellets are very close, respectively 3.92 N/mm^2 for spruce and 4.02 N/mm^2 for beech but statisticaly signicant at a confidence level of 95%. These values are in concordance with that of other researchs (Czachor et al. 2016) with value of 4-5 N/mm^2 for a medium density of 1.1 g/cm^3. This slight difference may be due to slight difference in the effective densities of pellets. However, only a slight increase of shear strength with effective density was observed for both species (Fig 4). The values of shear strength both for spruce and beech pellets are above the limit value found in prior studies of 1.5 N/mm^2 (Griu 2014).

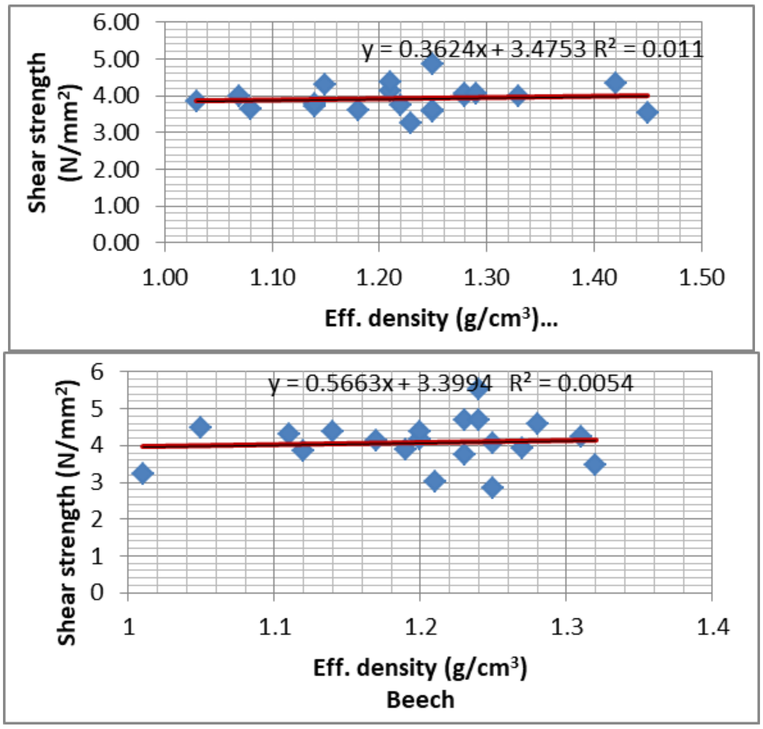

Fig. 4.
The influence of the density on the shear strength of pellets.

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These increases can be observed on the linear trend equation of values in Fig 4, respectively (Eq 7) with angle of increasing (obtained from tg α=0.362, or tg α=0.566, respectivelly):

$$\text{Spruce: } y=0.362x+3.475,\ \alpha_1=19.9^0$$
$$\text{Beech: } y=0.566x+3.399,\ \alpha_2=29.6^0 \quad (7)$$

Knowing that the coefficient of x in Eq 7 represents the tangent of the angle that the straight line makes with Ox axis, the angle can be determined and the angles obtained are 19.9^0 and 29.6^0, greater for spruce pellets by 48%, compared to beech pellets.

The caloric value expressed by the calorimeter was given as Net Calorific Value (NCV) Gross calorific value (GCV), the upper value for spruce pellets was 19184±98 kJ/kg, and for beech pellets 19113±102 kJ/kg (medium values of 8 values), as it can be observed in Fig 5.

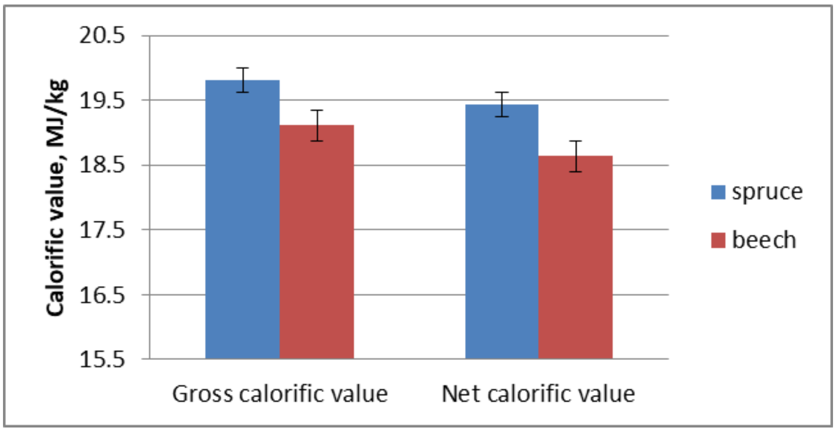

Fig. 5.
Values for caloric power for the two types of pellets.

It is observed that the calorific power of the spruce is slightly higher than that of the beech, a fact which has also been noted by other authors before (Griu and Lunguleasa 2014) and can be explained by the content of wood resin in resinous species. Even though the resin content in spruce is low, the calorific power of the resin of 34.6 MJ/kg makes it possible to have a calorific power superior to the deciduous trees species. Similar values of calorific value were found in the centralized Wood Fuels Handbook (Aebiom 2013), with a value of 18.8 MJ/kg for spruce and 18.4 MJ/kg for beech.

Taking into consideration the calorific power of the pellets and their effective density, a calorific density of 23.72 MJ/kg was obtained for spruce pellets, and 22.01 MJ/kg for beech. Calorific density helps in determining the calorific power on unit of volume and it can be observed that the spruce pellets had an energy density 7.8% higher than that of beech pellets.

The ash content of pellets indicates the amount of ash which has to be removed daily from the combustion installation furnace. It can be clearly observed (Fig 6) that the ash content in the case of beech pellets is higher than for spruce pellets, with a more than double increase.

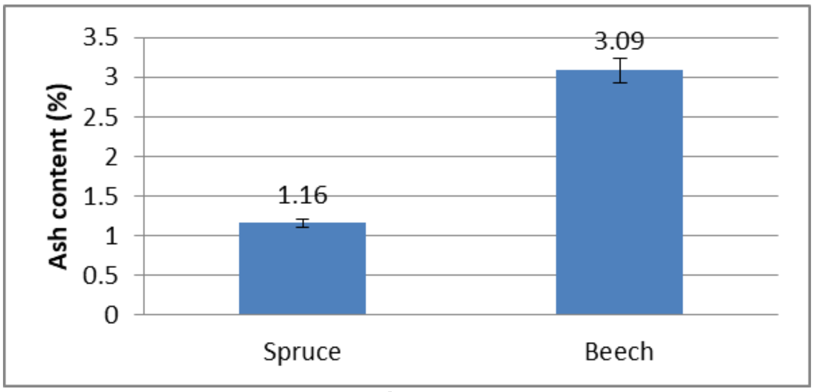

Fig. 6.
Ash content for spruce and beech pellets.

CONCLUSIONS

The beech and spruce pellets analysed in this paper are made of renewable wood biomass (waste sawdust from spruce and beech), due to its plant origin, obtained through photosynthesis, and secondly due to the fact that it represents wood residue obtained continually in processing wood and that would pollute the environment. The properties analysed indicate that these two types of pellets, regardless of the species obtained from, meet the minimum conditions stipulated by European standards. If we compare these two types of pellets, it can be observed that the density of spruce pellets is higher by 3.3% than beech pellets, the shear strength by 2.5%, calorific power by 1.8%, and the ash content by over 2.6 times better. Even if the values of increases have low differences the pellets obtained from spruce resin are better than those obtained from beech specie.

REFERENCES

Aebiom (2013) (European Biomass Association), Wood Fuels Handbook, Available from:http://www.aebiom.org/IMG/pdf/wood_fuels_handbook_btc_en.pdf.Accessed: 2013, July, 8.

ASTM D2866-11 (2012) Standard Test Method for Total Ash Content of Activated Carbon, ASTM International, 100 Barr Harbour Drive, PO Box C700, West Conshohocken, PA 19428-2959. United States.

ASTM D3865-12. (2000) Standard Test Method for Gross Calorific Value of Coal and Coke. American Society for Testing and Materials.

Bridgwater AV (2012) Review of Fast Pyrolysis of Biomass and Product Upgrading, Biomass bioenerg; 38:68-94.

Boutin JP, Gervasoni G, Help R, Seyboth K, Lamers P, Ratton M et al. (2007) Alternative Energy Sources in Transition Countries. The Case of Bio-energy in Ukraine. Environ Eng Manag J, 6(1):3-11.

Czachor G, Bohdziewicz J, Krzysztof Kawa K (2016) Shear strength of the selected types of pellets, Agricultural Engineering, 20(3):35-42. DOI: 10.1515/agriceng-2016-0042

Demirbas A. (2001) Biomass Resource Facilities and Biomass Conversion Processing for Fuels andChemicals. Energ Convers Manag, 42(11):1357-78.

Demirbas A, Demirbas AS (2004) Briquetting Properties of Biomass Waste Materials. Energ Source Part A, 26(1):83-91.

Eurostat, Forestry in the EU and the World.(2011) A Statistical Portrait.edition. Available from: http://epp.eurostat.ec.europa.eu/cache/ity_offpub/ks-31-11-137/en/ks-31-11-137-en.pdf.

European Commission (EC) Energy for the Future: Renewable Sources of Energy.(2007) White Paper for a Community Strategy and Action Plan, COM (97)599 final (26/11/1997). Available from: http://ec.europa.eu/energy/library/599fi_en.pdf.

DIN 51900-1. Determining the Gross Calorific Value of Solid and Liquid Fuels Using the Bomb Calorimeter and Calculation of Net Calorific Value. Part 1: General Information 2000. German National Standard. Organization for Standardization.

Garcia AM, Barcia BMJ, Diaz DMA, Hernandez JA (2004) Preparation of Active Carbon from a Comercial Holm-Oak Charcoal: Study of Micro-and Meso-porosity. Wood Sci Technol, 37(5):385-94.

Gavrilescu D (2008) Energy from Biomass in Pulp and Paper Mills. Environ Eng Manag J ,7(5):537-46.
Gavrilescu M (2008) Biomass Power for Energy and Sustainable Development. Environ Eng Manag J2008, 7(5):617-40.

Griu T (2014) Evaluarea şi mărirea puterii calorice a biomasei lemnoase, Doctoral thesis, Transilvania University of Brasov.

Griu T, Lunguleasa A (2014) Utilizarea biomasei drept combustibil solid (The use of biomass as solid combustible. Recent Journal, vol.15, March, Nr. 1(41):12-18):

Jehlickova B, Morris R (2007) Effectiveness of Policy Instruments for Supporting the Use of Waste Wood as a Renewable Energy Resource in the Czech Republic, Energ Policy, 35(1):577-85.

Junginger M, Bolkesjo T, Bradley D, Dolzan P, Faaij A, Heinimö J et al. (2008) Developments in International Bioenergy Trade. Biomass Bioenerg 2008; 32(8):717-29.

ISO 1928:2009. New York (1981).Solid Mineral Fuels. Determining the Gross Calorific Power by Calorimeter Bomb and Calculus of Net Calorific Power. 2009. International Standardization Institute.

Hansen MAT, Jørgensen H, Laursen KH, Schjoerring JK, Felby C (2013) Structural and Chemical Analysis of Process Residue from Biochemical Conversion of Wheat Straw (*Triticum aestivum* L.) to ethanol. Biomass Bioenerg, 56:572-81.

Kaliyan N, Morey RV (2009) Factors Affecting Strength and Durability of Densified Biomass Products. Biomass Bioenerg 2009; 33(3):337-59.

Kers J, Kulu P, Aruniit A, Laurmaa V, Križan P, Šooš L et al. (2013) Determination of Physical, Mechanical and Burning Characteristics of Polymeric Waste Material Briquettes. Estonian Journal of Engineering, 19(3):307–16. On line: http://www.kirj.ee/18098/?tpl=1061&c_tpl=1064.

Lunguleasa A, Budau G, Cosereanu C (2010) Density and Compression Strength of Beech and Spruce Briquettes. ProLigno 2010; 6(3):61-66. On line: http://www.proligno.ro/en/articles/2010/3/paper7.htm.

Lunguleasa A (2011) Compaction Coefficient of Wooden Briquettes Used as Renewable Fuel, Environ Eng Manag J, 10(9):1263-68.

Lunguleasa A, Budău G (2010) Two Features of the Ecological Wooden Briquettes. Recentonline.ro, 11(1):33-6. On line: http://www.recentonline.ro/030/Lunguleasa_R30.pdf.

Lunguleasa A (2010) The Compressive Strength of Wooden Briquettes Used as Renewable Fuel, Environ Eng Manag J, 9(7):977-82.

Obernberger I, Thek G (2004) Physical Characterisation and Chemical Composition of Densified Biomass Fuels with Regard to their Combustion Behaviour. Biomass Bioenerg, 27(6):653–69.

Toscano G, Riva G, Duca D, Foppa Pedretti E, Corinaldesi F, Rossini G (2013) Analysis of the Characteristics of the Residues of the Wine Production Chain Finalized to their Industrial and Energy Recovery, Biomass Bioenerg, 55:260-7.